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# Performance Evaluation of E-Bicycle through Simulation and Experimental Analysis

**Mrs. Priyanka Chawhan[1], Prof. A. V. Harkut[2], Prof. P. R. Jawale[3]**

PG Scholar, Department of Electrical (Electronics & Power) Engineering, PLIT&MS, Buldana[1]

Assistant Professor, Department of Electrical (Electronics & Power) Engineering, PLIT&MS, Buldana[2,3]

**Abstract**: *Electric mobility contributing to greater extent to balance the energy and power demands, energy storage units as well as environment safety for current automobile sector. 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 need to give on proper battery connections 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. The present work focused on comparison of different batteries used in electric vehicle, various Lithium-ion parameters of electric vehicle i.e., Comparative analysis of both series and parallel connection of batteries through its charge and discharge circuit connection, various electrical connections for battery and its effects on performance parameters. This analysis will be carried out with Experimental and simulation study by analyzing the behavior of it on battery performance characteristics such as state of charge, voltage and current variation as per load cycle.*

**Keywords**: E-mobility, Types of Batteries, Series and Parallel Connections, State of Charge, etc.

## I. INTRODUCTION

Due to the single battery cell's restricted voltage and capacity, series and parallel connections are required in actual operation to achieve higher voltage and capacity and match the equipment's actual power consumption. When Lithium batteries are connected in series, the capacity of the batteries remains the same while the internal resistance increases. When Lithium batteries are connected in series at a constant voltage, the capacity, internal resistance, and power supply duration are all increased. As needed, a single 2000mAh battery can be combined into a battery pack with a capacity of 2*(N) Ah (N: number of single batteries).

Robert Anderson invented the electric vehicle in the early nineteenth century, between 1832 and 1839. He also invented the world's first primitive electric carriage. A. L. Ryker created an electric tricycle in 1895, while William Morrison built a six-passenger wagon the following year.

In the 1920s, the electric vehicle's popularity and production declined. The following factors contributed to the drop in output: improved road systems, lower gasoline prices due to the discovery of Texas crude oil, the invention of the electric starter, and the mass manufacture of internal combustion engine automobiles. Instead of a gasoline cylinder, the Electric Vehicle has an electric motor that is powered by rechargeable batteries. There are several types of batteries that can be used to power an electric car. However, these batteries might add to the vehicle's weight. From the outside, all vehicles have the same design, whether they are electric or not. An electric bike can also be described as a noiseless vehicle that does not pollute the environment. Electric bikes are categorised based on the amount of power their electric motor can produce and the control system, which determines when and how the motor's power is delivered.

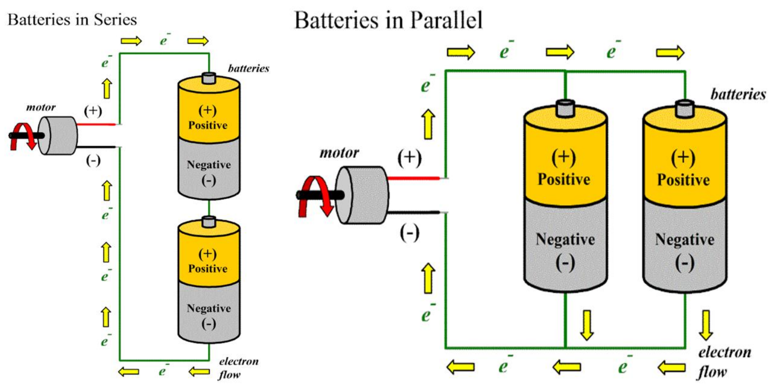


**Figure 1:** Battery in series and parallel connection

**Charging and Discharging on Battery:**
Lithium batteries are now commonly charged in series, owing to their simple construction, low cost, and ease of implementation. However, while charging lithium batteries in series, the battery cell with the smallest capacity will be fully charged first, and the other battery cell will not be fully charged at this moment due to differences in capacity, internal impedance, ageing characteristics, and self-discharge performance. If you keep charging in series, you risk overcharging the fully charged battery cell. Overcharging a lithium battery may degrade its performance and may potentially result in an explosion and injury.
Lithium batteries are coupled with a Battery Management System to avoid cell overcharging (BMS). Overcharge prevention is included into the Battery Management System for each and every lithium battery cell, among other features. If the voltage of a single lithium battery cell reaches the overcharge protection voltage while charging in series, the battery management system will cut off the entire series charging circuit and stop charging to prevent the single lithium battery cell from being overcharged, preventing other lithium batteries from being fully charged.
Each lithium-ion battery requires an equalising charge when charging in parallel; otherwise, the performance and life of the entire lithium-ion battery pack will be compromised. Constant shunt resistance equalising charge, on-off shunt resistance equalising charge, average battery voltage equalising charge, switch capacitor equalising charge, step-down converter equalising charge, inductance equalising charge, and other charging equalisation methods are common. Several issues must be addressed when charging lithium batteries in parallel:

1. Lithium batteries with and without PCM cannot be charged in parallel. Batteries without PCM can easily be damaged by overcharging.
2. Batteries charged in parallel normally need the removal of the battery's built-in PCM and the use of a unified battery PCM.
3. If a parallel charging battery does not include a PCM, the charging voltage must be limited to 4.2V, and a 5V charger cannot be utilised.
4. There will be a charging protection chip for lithium battery charging protection after lithium-ion batteries are connected in parallel. Prior to battery production, lithium battery manufacturers carefully analysed the changing properties of lithium batteries in parallel. Because of the importance of the current design and battery selection, users must carefully follow the directions for charging parallel lithium batteries, step by step, to avoid any damage from wrong charging.

## II. LITERATURE SURVEY

**Hampus Ekblad, Ase Svensson et.al.** Have worked on “Bicycle planning – A literature review”. Knowledge about bicycle planning, policies, and other factors that influence bicycle use in daily transportation has been obtained through the literature review. The appeal of the bicycle should be viewed in connection to the car, according to the literature review. It will be difficult to persuade people to ride a bike instead of driving a car if motorised modes of transportation are more appealing (e.g., parking regulations, pricing, and level of service). It became evident that there are significant disparities in how biking and bicycle planning research is undertaken. The findings indicate that bicycle infrastructure is critical. This means that if proper infrastructure is built, people are more likely to ride bicycles.

**Gicky Jose Malppan, Tom Sunny, and others collaborated** on "A Review on Design Developments in Bicycle," which focused on a better knowledge of diverse bicycle design developments. The various empirical methods of transmitting human power from the pedal to the rotation of the wheels are explored, with the key benefits and drawbacks of each approach noted. A new mechanism should be created that is environmentally friendly and energy efficient. This study paper reviews current research on several ways for transmitting human force from the pedal to the rotation of the wheels, as well as the primary benefits and drawbacks of these transmission methods as documented in the literature. It covers how the energy efficiency of the bicycle is calculated considering the case of a chain driven safety bicycle.

**"Generation of Electrical Energy by Dynamo**," developed by Akshay N. Chakole, Vishal A. Dhotre, and others, generates electricity at a low level by pedalling a bicycle. Using a dynamo or an alternator, power generated by pedalling can be transferred from mechanical to electrical energy. The dynamo's rotating energy can be used to power a number of small powered gadgets. You can utilise a dynamo or an alternator. Laptops, cell phones, and other electronic devices may all be charged using this energy. Many Indian villages also use bicycles as their primary source of transportation. The majority of these settlements are without electricity. Using a dynamo or an alternator, power generated by pedalling can be transferred from mechanical to electrical energy.

**Table 1:** Summary of literature

| Sr No | Title of Paper | Publication on Details | Conclusion | Future Scope |
|---|---|---|---|---|
| 1 | Hampus Ekblad, Ase Svensson et.al. | 2016 | literature of how different parameters are associated with bicycle planning | Evolution in implemented factors for Bicycle design |
| 2 | Gicky Jose Malppan, 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 Megalingam, et.al. | 2012 | Generation of power with the help of bicycle paddling | Alternate resource for nonrenewable source of energy |
| 5 | Chien-Cheng Lin, Song-Jeng et.al. | 2017 | Development And optimization of frames of bicycles | Points to decrease the self-weight of vehicle and implement in transportation |
| 6 | Rupesh H. Patil, Mrunalini E. Raut, et.al., | 2019 | Development in fabrication for E Bicycle | Implementation in bicycle using electric as well as solar energy |
| 7 | TinaNielsenSadieMaeet. al. | 2020 | Recreation conflict focused on emerging E-Bike technology | Restrictions, limits and regulation for sustainability of E- Bike trials |
| 8 | Hardik Keshan, Jesse Thornburg 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, B Varga, et.al. | 2017 | Comparison of various batteries for E-Bicycle | Comparison of Lithium-ion and Lead- Acid batteries, studying its advantages for future use |
| 10 | S Manish Yadav, Ajey Kumar et.al. | 2018 | Importance of human powers and alternative energy source is investigated | Replacement to non-renewable energy resources |

## III. SIMULATION OF SERIES AND PARALLEL COMBINATION OF LITHIUM-ION BATTERIES FOR LOGHT WEIGHT

Over the last few years, sales of plug-in (hybrid) electric cars (EVs) have exploded. So has renewable electricity generation. Electric vehicles have large batteries to store electrical energy. In most situations nowadays, this is a Lithium-Ion Battery (LIB) [1]. Renewable energy output has extremely high variations, necessitating such storage. Smart grids, which are also on the rise, provide the opportunity to merge those two technologies through the use of vehicle-to-grid (V2G) applications. V2G proposes to use the battery of electric vehicles as an additional storage device, giving energy back to the grid during heavy load periods and charging during low load periods.

This helps to flatten the grid's demand curve and promises to become even more fascinating as the percentage of electric vehicles and renewable energy grows [2], [3]. Because private vehicles, including EVs, have a high percentage of stoppage time [4], they might theoretically be used for V2G. However, in addition to the lower range when the battery is depleted to support the grid, the fundamental disadvantage of V2G application is the increased ageing of the LIB due to additional charge transfer [5]. As a result, owners must first be persuaded to accept the usage of their vehicle for V2G reasons. Financial incentives are a viable alternative. Owners could make money by giving regulated energy while also lowering the cost of their vehicle.

As a result, in order to establish appealing business models, it is vital to understand the additional costs associated with V2G usage. Because real-world data is rare, simulating battery behaviour with and without V2G use can help define the impact on the system. Another stumbling block is the scarcity of directional charging stations. Because there are no technical issues with the implementation, it is anticipated that these will be provided when V2G becomes economically viable. The electro-thermal model based on equivalent circuit modelling is briefly introduced in this work. Second, the ageing model used for ageing due to cycling and ageing due to storage is discussed; third, five scenarios for EV usage with and without V2G applications are developed; and finally, five scenarios for EV use with and without V2G applications are derived. fourth, the models are parameterized using data from two distinct commercial large-scale automobile cells, and the cost of whole battery systems is estimated. Fifth, the findings are presented and debated, followed by a summary and forecast. [10]

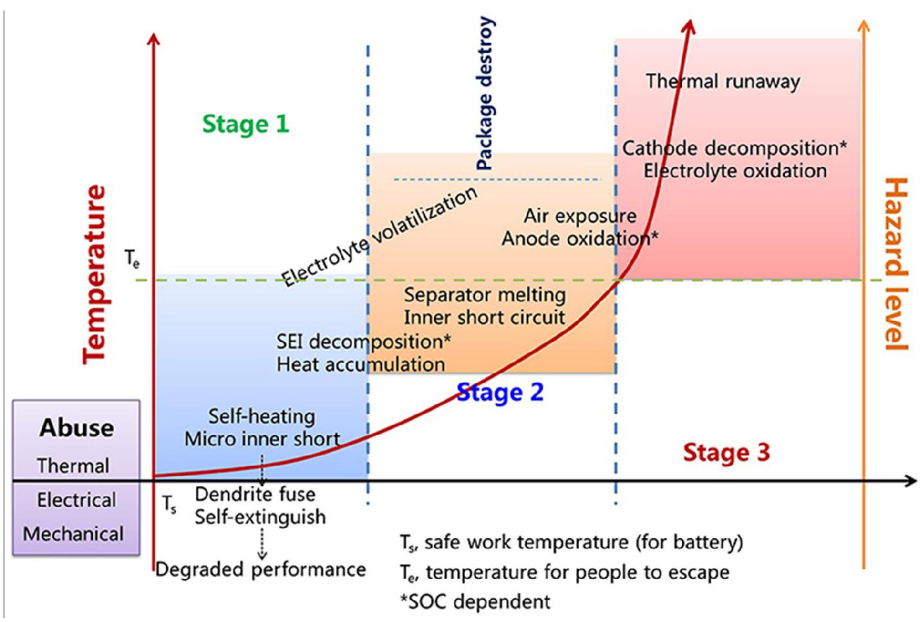


**Figure 2:** Safty of lithium ion battery

## IV. TO STUDY ACTIVE AND PASSIVE BALANCING OF LITHIUM-ION BATTERIES CELL TO MAKE ITS BATTERY PACK

Balancing is used to increase the amount of energy transported to or from the cell during the charging or discharging operation. When the cell is neither charged nor discharged, the idle balancing mode kicks in. The balancer's balancing algorithms are either voltage or charge based, and they can be utilised in both active and passive balancing systems. Because of its low cost and ease of installation, the passive balancing system is often employed in EV applications. The balance resistor causes excessive heat dissipation, a long balancing time, and low efficiency. To decrease power loss and handle thermal concerns, the balancing current must be kept low. Instead of the balancing resistor, the MOSFET (metal–oxide–semiconductor field effect transistor) switch was used as a variable resistor to control the power dissipation optimally.

To fight excessive power loss, a robust thermal management system must be incorporated in the passive scheme to restrict any accidental rise in temperature that leads to pack degradation. Traditional passive systems are being phased out in favour of evaluation and comparative study of cell balancing methods for lithium-ion batteries used in electric vehicles. The three forms of active balancing methods are capacitor, inductor, and transformer-based. The capacitor-based technique is inexpensive to build, but it balances slowly. A transformer-based scheme has a fast-balancing speed and a high cost due to the presence of a transformer. With a trade-off between balancing speed and implementation cost, the inductor method provides higher performance.

A next-to-next inductor balancing topology consists of (N-1) inductors that transfer energy between nearby cells, increasing the battery discharge period, although it is challenging to build due to the increased number of components. The number of switches is reduced by using a single switch per cell with unidirectional balancing, although there are drawbacks such as voltage stress on the centre-cell switch. Fixing independent equalisers in distinct levels as a remedy to the charge equalizer's slow balancing time. Any-cell-to-any-cell bidirectional inductor-based topology was introduced to improve equalisation current and efficiency. The existence of a large number of switches, however, results in a high cost and size.

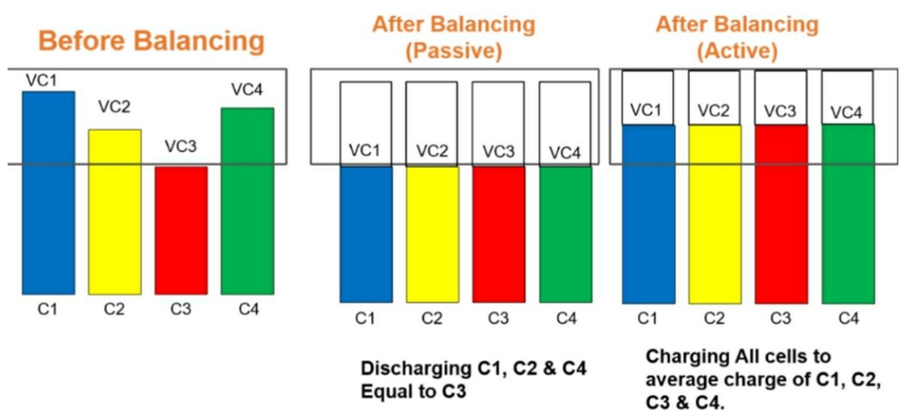


**Figure 3:** Active and passive balancing of lithium-ion battery

## V. RESULT AND DISCUSSION

**To perform Experimental Analysis of modes of thermal cooling for lithium-ion Battery Pack with Liquid and Air Types.**

For best performance and calendar life, Li-ion batteries should be operated between 25°C and 40°C. The liquid cooling system is more effective at removing heat from the cell and providing the battery with an optimal operating condition. Electrically imbalanced cells can be avoided, and the cell's cycle life, as well as the battery's safety, can be increased. When four batteries are connected to form a battery pack, the distance between them may be determined, and a suitable diameter metal pipe can be added through which suitable cooling fluid can be passed to offer an effective cooling solution for the battery pack, reducing thermal concerns.

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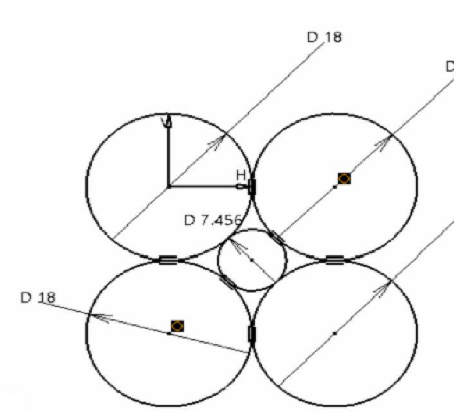
**Modes of battery pack cooling**

1. Air cooled
2. Liquid cooled
3. Fin cooling method
4. Phase change material (PCM) cooled

Here we have taken 18650 battery cells to form a battery pack.

Considering above the diameter of hollow copper wire is taken as 7 mm



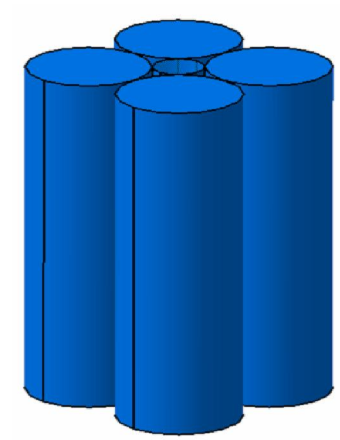



**Table 2**: Comparison of different cooling method

| Sr. No. | Parameters | Air cooling | Liquid Cooling | Fin cooling | Phase change material |
|---|---|---|---|---|---|
| 1. | Medium | Air (Atmospheric air) | Liquid (Water, ethylene, propylene glycol) | Metals (Copper, Aluminium) | Semi solid (Al-foam) |
| 2. | Cooling Capacity | Medium | High | Very low | Very low |
| 3. | weight | Light | Medium | Heavy | Heavy |
| 4. | Cost | Low | Medium | High | Medium |
| 5. | Size | Large | Compact | Very compact | Large |
| 6. | Complexity | Simple | Complex | Medium | Medium |
| 7. | Life | Medium | Medium | Long | Less |
| 8. | Leakage &safety | More but less risk | Less than air but more risk | No & no risk | More fin but more risk |
| 9. | Efficiency | Medium | More | Less | Less |
| 10. | Temperature distribution | Uneven | Uneven | Medium even | Even |
| 11. | Energy consumption | High (fan) | High (motor) | None | None |
| 12. | Maintenance | Medium | Medium | Less | High |

**Battery Pack Calculation**

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)

$$\text{time(t)} = \frac{\text{Efficiency} \times \text{Battery voltage} \times \text{Battery capacity}}{\text{Total required power}} = \frac{0.8 \times 11.1 \times 20}{100} = 1.776 \cong 2\text{Hours}$$

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.

**Charging Circuit of Battery**

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

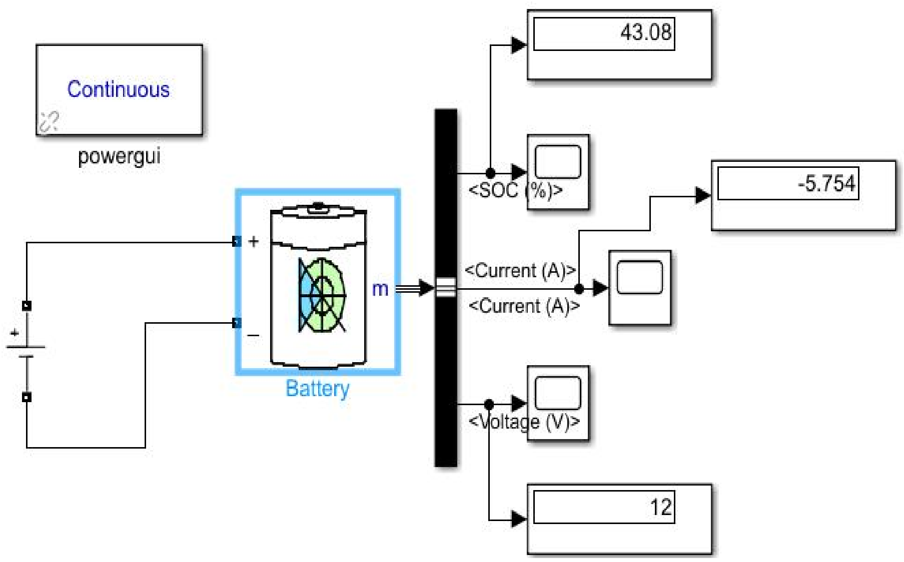



**Figure 4:** Charging Circuit for Lithium-ion Battery in MATLAB / Simulink

**Structural And Experimental Analysis if light Weight Electric Vehicle Using Simulated Circuit in Matlab\Simulink**

In order to design and test the supervisory control algorithm, the electric vehicle was modelled in MATLAB/Simulink environment. Additionally, the feasibility for converting the existing electric vehicle into a series PHEV was studied using simulations with Matlab/Simulink. Simulating the control strategy in Simulink facilitates the final hardware implementation, since the hardware for the Supervisory Control Module (SCM) used in the electric vehicle can be programmed directly from a Simulink model. For vehicle simulation, a forward-looking model was developed where the model responds to the driver input commands to develop and deliver torque to the wheels [3].

The SCM uses the driver input commands to control the different sub-system components and collects feedback data from the sub-system components. The vehicle model uses the 23-command torque information from sub-system components to calculate the traction force for the vehicle, and it models the effect of different forces acting on the vehicle. The vehicle velocity calculated from the vehicle model was given as a feedback signal to the driver model. The simulation block diagram of the Simulink model showing the interactions among the driver, the SCM, the subsystems, and the vehicle model is shown in the figure.

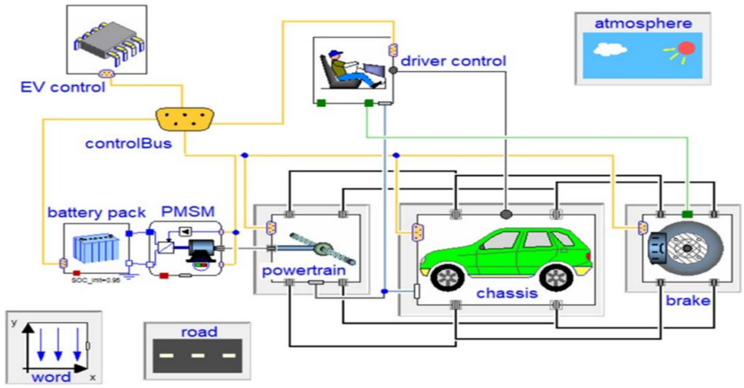



**Figure 5:** simulation of Electric vehicle

## VI. CONCLUSION

1. The Design calculations and Analysis results of Bicycle Frame for 150Kg load was verified with catiav5 software and found to be satisfactory within limit for load effects and stresses incurred.
2. 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.
3. The Simulink analysis shows different graphical results such as State of Charge (SOC), Voltage, Current, Velocity, and Displacement using Lithium-Ion Battery as an energy source for running the bicycle which indicates approximately 59.97 state of charge of battery which was initially charged 100 %, velocity of bicycle for 1000 seconds is 3.063 km/hr. and distance covered is 20.11 km which is near to the target value of the proposed project.
4. 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.
5. Battery connections is most crucial point in battery pack design for efficient use as per the need of applications. Some of it need only series/parallel or combination of both. Proper Battery management system and battery pack making steps need to follow to overcome drawbacks of thermal runaway, battery overcharging etc.
6. Simulation results shows tremendous increase in battery state of charge in parallel connection but with reduce current capacity. Whereas in series connection significance increase in voltage capacity but with reduced current. Therefore, battery connection plays and vital role in efficient structural and thermal investigation of battery pack system.

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