Design and Fabrication of a Solar-powered Electric Bike

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Abstract

Electric bikes have experienced significant growth due to several factors, including price reductions and increased climate and environmental awareness. This trend presents a promising solution for replacing fossil fuels, with batteries emerging as a new power source. However, limitations such as limited mileage, extended charging times, and the scarcity of charging stations persist. Renewable solar energy also significantly reduces the carbon footprint of urban transportation. The research objective is to enhance the driving range of electric vehicles using solar power. This project aims to design a market-ready solar-powered electric bike using flexible solar panels and a foldable, adjustable solar panel mount for on-the-go charging. This design enables the bike to charge for free when parked in the sun, reducing dependence on traditional charging stations, waiting time reduction and lowering operational costs. Calculations, analyses, and various tests are conducted based on technical specifications, energy consumption requirements, and vehicle movement using the proposed method.

Keywords: Electric bike, Solar-powered mobility, Sustainable transportation, Renewable energy

I. INTRODUCTION

Electric scooters (e-scooters) are becoming increasingly popular as a means of urban mobility, providing a convenient, efficient, and eco-friendly solution for short-distance travel in congested city environments. Their compact size, ease of use, and low operational costs make them an attractive alternative to traditional gasoline-powered vehicles. In a study by Yuvaraj *et al.*, (2024a), the Electric Vehicle Charging Stations Market predicts that the EV market will be worth USD 974 billion by 2027. This growth is driven by a strong annual increase from 2020 to 2027, influenced by global industries and government actions. As urban populations grow and traffic congestion worsens, the demand for e-scooters is expected to continue rising, driven by both consumer preference and supportive government policies aimed at reducing carbon emissions and promoting sustainable transportation options. (Parker *et al.*, 2021) showcase over the past decade, there has been a significant increase in the demand for electric vehicles (EVs) due to their ability to reduce carbon dioxide(CO_2) emissions significantly, and (Zhou *et al.*, 2021) review their lower operating costs compared to traditional internal combustion engine (ICE) vehicles.

Despite their growing popularity, e-scooters face several significant limitations that hinder their widespread adoption. One of the primary challenges is their reliance on charging stations. The limited range of e-scooters often necessitates frequent recharging, which can be inconvenient for users, particularly in areas where charging infrastructure is sparse. Additionally, the time required to charge an e-scooter battery can be substantial, leading to extended waiting periods at charging stations. This not only diminishes the convenience of using e-scooters but also increases the overall cost and time associated with their use.

To address these challenges and enhance the practicality of e-scooters, integrating solar panels into their design offers a promising solution. By equipping e-scooters with flexible, foldable solar panels, it becomes possible to harness solar energy for on-the-go charging. This innovation can significantly reduce the dependence on traditional charging stations, decrease waiting times, and lower the cost of operation. Furthermore, utilizing renewable solar energy aligns with broader environmental goals by reducing the carbon footprint of urban transportation.

Our project aims to develop a solar-powered e-scooter that leverages flexible solar panels for efficient, cost-effective, and eco-friendly urban mobility. By addressing the current limitations of e-scooters and introducing a sustainable charging solution, we hope to contribute to the advancement of green transportation and the realization of a more sustainable urban future.

II.LITERATURE REVIEW

A. Existing EV Charging Systems

The current electric vehicle (EV) charging systems have several limitations that can hinder the widespread use and convenience of electric scooters (e-scooters). These systems include public charging stations, battery swapping stations, and grid charging at home, each with its own challenges.

B. Public Charging Stations

Public charging stations are commonly used for recharging e-scooters, but their limited availability can be a major inconvenience. In many cities, there aren't enough charging stations to meet the growing demand, leading to long wait times and network congestion. The increasing global use of EVs presents new challenges for distribution system (DS) infrastructure and operators. Potential issues include higher power demands, changes in bus voltages, power loss, stability concerns, harmonic distortion, voltage mismatches, and power efficiency. These factors significantly impact the DS. Experts particularly emphasise the shortage of EV charging infrastructure as a major concern. According to Yuvaraj *et al.*, (2024) the growing popularity of EVs has created a need for more reliable charging stations capable of quickly recharging EV batteries.

Users often have to wait for a charging slot, wasting valuable time and disrupting their schedules. These issues can include unreliable charging stations, delays caused by waiting in line, and concerns about security and management. To address these problems, Erol-Kantarci, Sarker and Mouftah, 2012 showcase it is essential to have proper systems in place to reduce EVRA (Electric Vehicle Range Anxiety) and waiting times at stations. Additionally, the fees at public charging stations can be high, reducing the economic benefits of owning an e-scooter. These factors make public charging stations less efficient and appealing as a reliable charging solution.

C. Battery Swapping Stations (BSS)

Battery swapping stations allow users to exchange their depleted batteries for fully charged ones. Mahoor *et al.*, 2017 the early 19th century backs the history of swapping when interchangeable battery services were first suggested to overcome the limited range of electric cars, trucks etc. The exchange process initially relied on manual labor. According to Better Place y China Southern Grid firman acuerdo estratégico que se concentra en el modelo de intercambio de baterías, 2011. Better Place was the first company to commercially deploy a battery swapping service for electric cars. The main benefit of the swapping model is speed, with the process taking less than five minutes, similar to refueling at a gas station. Additionally, users can stay in their vehicles without handling cords. However, there are complexities and challenges, as shown in Figure 01.

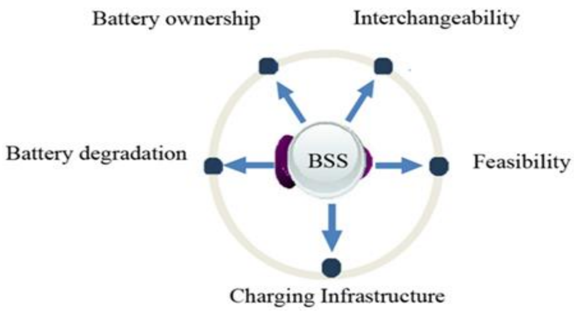


Figure 09: Complexities and challenges of BSS (Ahmad, Alam, *et al.*, 2020)

Challenges of BSS

i. *Interchangeability*

The success of battery swapping depends on the availability of interchangeable battery packs from different manufacturers. This requires manufacturers to agree on standardization, which may limit innovation and product uniqueness. Different power segments could lead to supply and compatibility issues with vehicles.

ii. *Feasibility*

Gao *et al.*, 2017 showcase current battery designs pose significant challenges for battery swapping technology. The batteries need to be robust and easy to remove and reinstall. Yang *et al.*, 2014 review in India, only a few vehicles, like the Hero Maxi, currently offer such designs, allowing easy swapping of discharged batteries with charged ones.

iii. *Infrastructure*

The infrastructure for battery swapping is more complex and expensive than charging stations. Ahmad, Alam and Asaad, 2017 showcase that swapping stations need to keep enough charged battery packs to meet demand, requiring two battery packs per car. The economic feasibility of a nationwide battery swapping system remains uncertain compared to a car charging system

iv. *Battery Degradation*

Sarker, Dvorkin and Ortega-Vazquez, 2016 review battery performance degrades over time, making new battery packs more desirable for customers. This preference for new batteries will reduce the operating cycle of each pack, as older batteries offer less energy storage and lower mileage for EVs.

v. *Battery Ownership*

Cheah and Heywood, showcase if vehicle owners do not own the battery packs, EVs become cheaper as they don't need to buy the batteries. However, they must pay additional lease fees and service charges for swapping stations. This could deter frequent use of swapping stations, especially when charging options are available.

However, this system faces several logistical challenges. Firstly, there are not enough swapping stations, making it hard for users to find convenient locations. Secondly, different e-scooter manufacturers use batteries with various voltages, sizes, and capacities, making standardization difficult. Swapping stations need to keep extra batteries in stock for exchanges, and the returned batteries must be recharged before they can be used again, leading to delays and potential shortages of fully charged batteries. Ahmad *et al.*, 2020 Showcase, despite the rapid development of conductive and wireless (inductive) charging, battery swapping systems have not yet been deployed as a commercially viable option. These issues reduce the efficiency and practicality of battery-swapping stations.

D. *Grid Charging at Home*

Charging e-scooters at home via the grid is convenient but also has drawbacks. Home charging relies on grid electricity, which may not always come from renewable sources, reducing the environmental benefits. The cost of electricity can be high, especially with tiered tariffs that increase rates as more units are used, making home charging expensive for frequent users. Additionally, home charging can take several hours to fully charge a battery, which can be inconvenient for daily commuters.

Researchers have thoroughly investigated these challenges, focusing on how EVs affect electricity generation capacity, transformer ageing, and power quality within the distribution system (DS). Charging EVs during peak demand could increase peak load requirements, necessitating more power generation. Additionally, the higher demand for EV charging can strain substation and service transformers, reducing their lifespans.Dubey and Santoso, 2015 Showcase integrating EV charging stations (EVCS) may also cause power quality issues such as voltage fluctuations, power distribution imbalances, and disturbances in voltage and current waveforms.

N. *Actions Taken to Minimize Challenges in Charging Systems*

The limitations of electric vehicles (EVs) have driven various innovations and strategies to improve charging systems. However, despite technological advancements, these solutions often fall short of providing a sustainable, long-term answer to the challenges faced by EV users.

E. *Faster Charging Technologies*

One approach to addressing the limitations of EVs is the development of faster charging technologies. While these technologies can reduce charging times, they also introduce several technical and operational issues. Fast charging can lead to battery degradation, reducing the overall lifespan of the battery. This occurs because high charging rates generate more heat and stress on the battery cells, accelerating wear and reducing capacity over time.

Additionally, fast charging can cause significant problems for the electrical grid. Issues such as load profile distortion, voltage deviation, frequency imbalance, harmonic injection, and overloading of distribution system components can arise. These problems can lead to excess power loss and grid instability, making the widespread implementation of fast charging infrastructure challenging. Steen and Tuan, 2017 review that the lack of efficient fast-charging stations increases the strain on power demand, affecting the overall stability of the electrical grid. Implementing fast charging ports at home is particularly difficult due to the high power requirements and potential impacts on household electrical systems. Furthermore, the increased fees associated with fast charging at public stations can negate the cost savings of operating a low-cost EV.

F. *Increased Battery Capacity*

The first EV applications adopted a rechargeable battery invented by Gaston Planté in 1859 which was the lead-acid battery. One of the first was created in 1899 by Waldemar Jungner as the nickel-cadmium battery; they advanced the storage capacity but had the problem of a suppressed voltage or memory effect as the battery aged. Research continued throughout the early and latter half of the 20th century, but it wasn't until 1985 that the first lithium-ion (Li-ion) batteries were created. Tarascon and Armand, 2001 created a ragone plot of several of the battery technologies used in EVs.

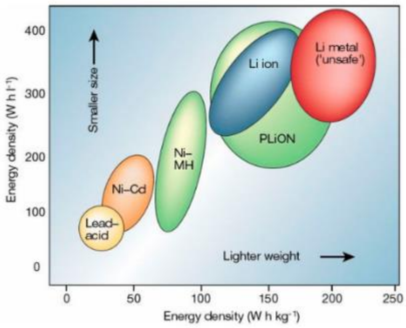


Figure 02: Ragone plot of several of the battery technologies used in EVs(Tarascon and Armand, 2001)

This is a detail of the batteries depicted in Figure 02; each battery has its merits and demerits. Advancements and new technology in Li-ion batteries have placed the battery as the market favourite for small portable electronic gadgets including EVs. Keshan, Thornburg and Ustun, 2016 Showcase that this is mainly due to their specific energy (Wh/kg), long cycle life, and high efficiency. Despite these benefits, they also have downsides, such as high costs and the need for complex safety and monitoring systems.

Another strategy to maximize the range is to increase the number of batteries in EVs to extend their range. However, this solution presents its own set of challenges. Adding more batteries increases the weight of the vehicle, negatively impacting its handling and control. The added weight can make the scooter harder to maneuver and reduce its efficiency.

The cost of additional batteries is another significant issue. Batteries are one of the most expensive components of an EV, and increasing their number significantly raises the overall cost of the vehicle. Moreover, batteries have a limited lifespan and need to be replaced after a few years, leading to high replacement costs. This recurring expense can be a deterrent for potential EV users.

G. Increasing the Number of Charging Stations

Expanding the number of charging stations is another commonly proposed solution. However, this approach also has limitations. The infrastructure cost of building and maintaining a large network of charging stations is substantial. The increasing prevalence of new energy vehicles has consequently generated a heightened demand for accessible electric vehicle charging stations (EVCSs).

Mukherjee and Gupta, 2015 showcase that during the transition to EVs, the general public encounters two major challenges: the relatively high upfront costs of EVs and the inadequate availability of EVCSs . Even if the number of charging stations is increased, the fundamental issue of charging time remains. Unlike refueling a gasoline vehicle, which takes only a few minutes, charging an EV can take hours. If a large number of commuters need to charge their EVs, long wait times at charging stations can become a significant problem. This scenario can be likened to the current situation at gas stations but with much longer waiting periods.

H. Potential Benefits and Impact of Solar-Powered Electric Bikes

Solar-powered electric bikes offer several potential benefits and can address existing gaps in current transportation solutions. Here’s how they can make a significant impact:

I. Reduce Waiting Time at Charging Stations

One of the primary advantages of solar-powered electric bikes is their ability to charge on-the-go. By integrating solar panels into the design, bikes can recharge while parked or even while in use, reducing the need to wait at charging stations. This feature not only enhances user convenience but also improves overall efficiency in urban mobility.

J. Lower Charging Costs

Solar-powered charging significantly reduces operational costs compared to traditional methods. Charging from public stations often incurs high fees, while home grid connections can lead to increased costs with higher electricity usage. In contrast, solar energy is renewable and essentially free once the initial investment in solar panels is made. This reduces dependency on expensive charging infrastructure and helps to stabilize long-term operational costs.

K. Environmental Impact

The environmental benefits of solar-powered electric scooters are substantial. The transportation sector contributes significantly to carbon emissions, contributing to climate change and air pollution. Adnan *et al.*, 2018 have indicated that by 2030, EVs could potentially contribute to a noteworthy 28% reduction in CO2 emissions. By utilizing solar panels, e-scooters can operate using clean, renewable energy, effectively reducing their carbon footprint. Unlike electricity sourced from fossil fuels, solar energy is a green energy source that minimizes greenhouse gas emissions and environmental degradation associated with traditional power generation methods.

Shrivastava, Alam and Asghar, 2019 showcase that a VIPV (Vehicle-Integrated Photovoltaics) charging system reduces the strain on the electricity grid and decreases CO2 emissions by 0.92 kg per 100 km driven compared to a PV-grid charging station.

L. Overview of Existing Vehicle Integrated Photovoltaic (VIPV) Initiatives

Solar-powered electric vehicles (EVs) represent a niche yet promising area of innovation within the transportation sector. These vehicles integrate solar panels directly into their design to harness solar energy for propulsion or auxiliary functions. Centeno Brito *et al.*, 2021 had the first demonstration of using PV for electric engines in commercial passenger vehicles was made, following earlier models like Audi's solar roofs. In 2010, Toyota introduced the Solar-Prius, a plug-in hybrid with a 180 W PV module on the roof, which is useful for battery charging during long parking periods but not much while driving. Even more recently, many automobile manufacturers have been announcing vehicle concepts where solar contributes to its motion (Tesla (Tesla, 2019), Hyundai (Hyundai, 2019); Lightyear (Lightyear, 2021), Fisker Karma (Fisker, 2020), Hanergy (Hanergy Thin Film Power Group Limited, 2019), Sono Motors (Sono Motors GmbH, 2020), and Stella Lux (Eindhoven University of Technology. “Stella Lux” Solar Team Eindhoven, 2019).

Kutter *et al.*, 2021 showcases the potential of solar yield and range extension VIPV installed only on the roof of the electric vehicle covers a significant part of the energy consumption of commercial vehicles within all investigated scenarios. Considering an optimized system efficiency, the following annual solar ranges can be obtained in Stockholm and Seville. The value in % states the VIPV coverage of the estimated annual energy demand of the vehicle:

i. A - Parcel Delivery Vans: 6637 to 11450 km/year, solar energy coverage 35 to 60%
ii. B – Rural Delivery Trucks: 3084 to 5272 km/year, solar energy coverage 9 to 15%
iii. C – Long Haul Truck 4828 to 8173 km/year, solar energy coverage 5 to 9%
iv. D – Trailer (only harvesting while driving) 763 to 1424 km/year, solar energy coverage 0.9 to 1.6%
v. E – Trailer with battery/grid feed-in 4791 to 8134 km/year, solar energy coverage 5 to 9%

Shrivastava, Alam and Asghar, 2019 showcase the VIPV system is compared with solar carport and rooftop charging stations, showing the VIPV system as a cost-effective solution. Thus, it reduces the burden on the electricity generation system. VIPV charging system reduces the CO2 emission by 0.92 kg to 100 km drive of PEV as compared to PV-grid charging station. Using VIPV charging system the driving range improves to 9 km.

By 2030, Vehicle Integrated Photovoltaics (VIPV) are expected to significantly contribute to the annual mileage of electric vehicles. Projections suggest that VIPV systems could cover up to 9,739 kilometers per year, accounting for approximately 24% of the total distance driven. During optimal conditions, such as in peak sunlight months, VIPV could achieve daily distances of up to 47 kilometers. However, this potential is somewhat diminished by shading losses; with a 30% shading loss, the annual coverage drops to about 3,711 kilometers. The benefits of VIPV are anticipated to increase notably due to technological advancements. From 2022 to 2030, improvements in VIPV technology are expected to enhance efficiency by approximately 34%. These advancements could involve better solar panel materials, improved integration techniques, and more efficient energy conversion systems.

The environmental benefits of VIPV are also significant. Karoui *et al.*, 2023 showcase life cycle assessments indicate that over a 20-year lifespan, VIPV systems could reduce the carbon footprint by up to 28 tons of CO2-equivalent. This reduction is achieved through decreased reliance on conventional energy sources and lower overall vehicle emissions

III.METHODOLOGY

1) Introduction

This section describes the methodological process used in the development of the electric bike's chassis and the integration of its solar power systems. The process starts with concept generation and moves through several stages, such as fabrication, electrical system integration, chassis design, and integration of the solar power system. In order to guarantee the seamless integration of mechanical and electrical components and maximize the overall performance of the bike, the entire methodology is divided into sequential steps. Before hardware implementation, simulation software was used to verify the system's functionality and design.

The process involved in designing and implementing the bike chassis and solar integration is broken down into steps in the flowchart:

2) Concept Generation:

The process begins with generating ideas for the overall bike design, taking into account structural, mechanical, and electrical requirements.

A. Design Chassis Models:

Different chassis models are designed based on the concept generated to ensure that the vehicle meets the structural integrity and weight requirements.

B. Analyze the Chassis:

Once designed, the chassis models are analyzed for mechanical stresses, load distribution, and other critical parameters to ensure safety and efficiency.

C. Fabricate Chassis Models & Design Body Panels:

After analysis, the selected chassis models are fabricated, and the body panels are designed for aesthetic appeal and aerodynamic efficiency.

D. Electrical System Design and Integration:

The electrical systems, including wiring, control units, and power management systems, are designed and integrated into the bike's structure.

E. Assemble Parts:

Once the chassis and electrical systems are ready, the components are assembled to form the basic structure of the vehicle.

F. Calibrating System:

The electrical and mechanical systems are calibrated to ensure smooth operation and safety.

G. Integrating Solar Panels into the Overall Design:

Solar panels are incorporated into structure design for energy harvesting.

H. Integrating Solar Charging System:

The solar charging system, responsible for converting solar energy into electrical power, is integrated with the vehicle’s power management system.

I. Performance Testing:

The final vehicle is tested under real-world conditions to evaluate its performance, efficiency, and reliability

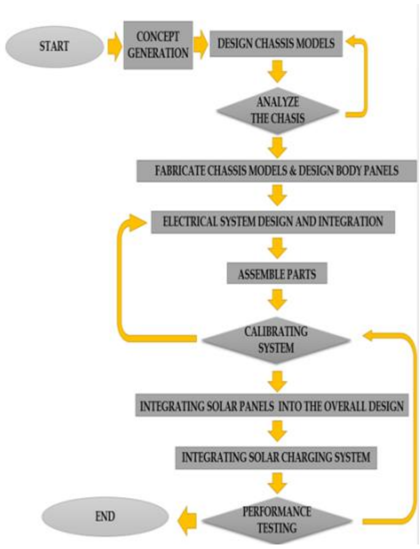


Figure 03: Methodology flowchart

The initial step in vehicle performance modeling is to formulate an equation for the electric force. This force, transmitted to the ground through the drive wheels. When modeling vehicle energy consumption, several resistances must be considered, including rolling, aerodynamic, climbing resistances. These factors are crucial in determining the motor size needed to provide sufficient torque for the vehicle

J. *Calculations*

Motor selection

Mass of e-bike including riders,
Passenger weight = 70kg * 2
= 140kg
Weight of bike = 60kg
Total Weight (m) = 200 kg;

Maximum velocity bike should reach [when slope is 2.5° (Shivhare *et al.*, 2021)],
v = 30 km/hr
= 8.33 m/s;

Wheel diameter, d = 10 inches
= 254 mm;

Drag coefficient d = 0.50;
(Considering approximate value for two-wheelers(Shivhare *et al.*, 2021))
Frontal area, Af = 0.45 m^2;
(As per the CAD);

Coefficient of rolling resistance,
Crr = 0.004;
(Considering for bike tyres on Asphalt road(Shivhare *et al.*, 2021))

Acceleration due to gravity,
g = 9.81m/s^2

Air density at 30°C,
ρ = 1.1644kg/m^3

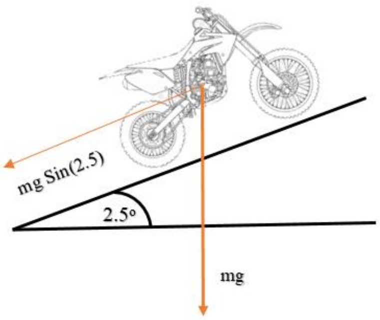


Figure 04: Force diagram

$F_{ROLLING}$ = Crr × mg
= 0.004 × 200kg × 9.81m/s^2
= 7.848 N

$F_{AERODYNAMIC}$ =1/2 × Cd × P ×Af × V_2
= 0.5× 0.5 ×1.1644 × 0.45 × 8.332
= 9.0896 N

$F_{GRADIENT}$ = mg Sin (2.5)
= 200 × 9.81 × Sin (2.5)
= 85.5812 N

F_{TOTAL} = 85.5812 + 9.0896 + 7.848
= 102.519 N

POWER = FTOTAL × V
= 102.519 N × 8.33 m/s
=0.854 Kw

Therefore, after calculation it can be concluded that a 1kW motor would be sufficient for the proposed e-bike. As per the market availability, a motor of 48V, 1kW rating is selected. According to Contò and Bianchi, 2022 its increased power density and dependability, the BLDC motor is smaller in size. Furthermore, brushed DC motors need more frequent maintenance, are heavier, and make more noise.

K. *Material selection*

Motor

Although many types of motors can be used in the bike, the type recommended and used is called the BLDC, standing for a brushless DC hub motor. BLDC hub motors are always characterized by low noise and as such provide the required power and regulation for a proper ride. How the motor is incorporated in the hub also helps in simplifying the bike structure and cutting down its weight. There are four power transmission systems

Chain drive
Gear hub motors
Crank drive motors
Direct drive motors.

According to Arango, Godoy and Lopez, 2018 the mid-drive develops more power than the hub-drive configuration, this because mid-drive motor operates in the optimal rpm ranges a condition that differs from the hub-drive motor. But for this project hub motor is selected because of its easy fabrication and it will reduce the complexity of the project.

Battery

For the battery, Lithium-ion technology was chosen because of its high energy density, low volume and mass, and longer cycle than the other types of batteries. Lithium-ion batteries offer a good power to weight ratio acting as a power source and charge which is vital for the bike's performance and mileage. This decision allows the bike to store and output the needed amount of energy to support extended use.

Batteries currently in use in electric bikes include 12V to 72V. The preferred 48V 50Ah battery was selected because it is readily available, reasonably priced, and requires no thick wires to the motor due to the increased voltage, which causes the motor to draw less current.

Motor controller

The controller plays an important part in controlling the efficiency and performance of the electric bike. Following a review of several controller types, a choice was made based on elements like programmability, responsiveness, and compatibility with the chosen lithium-ion battery and BLDC hub motor. The primary goal of this project is to use solar energy to charge the battery. We can accomplish this by optimizing the battery's performance by adjusting additional parameters. Because of its higher efficiency and smoothness, we employ a sine wave controller. In the end, the selected controller ensures the best possible operation of the electric bike by offering the required balance of performance, dependability, and ease of integration.

Solar panels

Compared to rigid solar panels, flexible solar panels are more design-flexible. Due to their flexibility, they can easily interphase with the form of the bike thus complementing the structural design of the bike. It also assures that for the panels to have a vantage point in attracting sunlight they are made in a way that it can be unfolded whenever needed or folded back when no longer required. Flexible panels commonly have a lower efficiency level compared to the rigid type; however, their adaptability makes up for this. The panels can in fact be placed on various parts of the bike so that it is charging from the rays of the sun all day. This charging capability cuts down the reliance on the normal charging stations, increases the range of the bike and improves the bike's performance. Also, there is enhanced control and efficiency by the use of flexible panels as they are light in weight.

IV.RESULTS

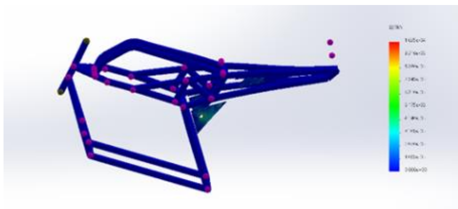
D. Proposed design

The design of the e-bike was created using SolidWorks software. The design prioritizes easy control and stability incorporating a low center of gravity to enhance balance and a smooth ride. And also focuses on ergonomics and aesthetics. This design ensure that the e-bike provides a comfortable and user-friendly ride for commuters. The design is sleek and modern appealing to a wide range of users. It ensures low plastic involvement to the body panels as it is easy to fabricate and minimizes the fabrication cost.

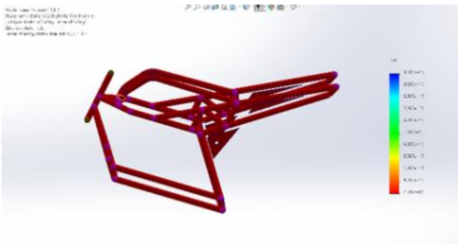
The current design will be further enhanced with the addition of a solar panel mounting system, which will be seamlessly integrated into the e-bike. This integration will allow for on-the-go solar charging, reducing reliance on traditional charging infrastructure and aligning with our sustainability goals.

Figure 05: Final design without body panels and solar structure

Stress, strain analysis, displacement analysis and Factor of safety analysis for loading conditions are performed and incorporated into our project to analyze the strenuous of the bike design. Analyzed the loading conditions and visualized how they affect the components through the application of SolidWorks by applying on the bike 250kg of weight. This evaluation is critical to guarantee that the bike's planned usage comes with no dangerous consequences and to find out the stress factors.



(a)



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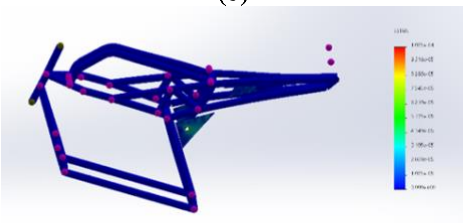
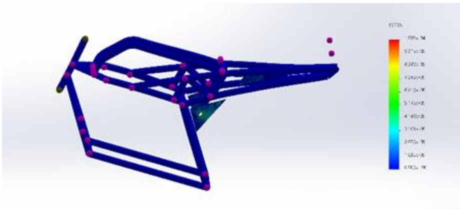


(c)



(d)

Figure 06: Finite Element Analysis results,
(a) Displacement analysis, (b) Factor of Safety analysis, (c) Stress analysis, (d) Strain analysis
(b)

V. CONCLUSION AND FUTURE WORKS

The development of a solar-powered electric bike presents a promising solution to the limitations of traditional e-bikes, such as limited range and dependence on charging stations. By integrating flexible solar panels, the bike can charge on the go, reducing operational costs and environmental impact. Future works include: complete the construction and assembly of the bike, ensuring all components are securely integrated; develop a robust structure to firmly attach the solar panels to the bike, optimizing sunlight capture; and conduct extensive testing under various conditions to ensure reliability and performance. Further, enhance the integration of solar technology to improve energy efficiency.

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