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Design and Development of a Solar Electric Delivery Pod

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ABSTRACT- Use of autonomous solar electric vehicles for road delivery purposes in India remains highly unexplored area. The aim of these research paper is to cover major design aspects and develop a prototype solar electric delivery vehicle with autonomous drive for city logistic purposes. The vehicle design is constructed using the locally available raw materials and is aerodynamically tested. CAD modelling on SolidWorks'20 has been used to build a virtual physical model of the vehicle and aerodynamic testing is performed. MATLAB Simulink has been used to develop a mathematical simulation model with various subsystems like battery, motor, vehicle dynamics and PV charging module. Vehicle has been tested for 2 major drive cycles and results are plotted. The vehicle operates with a wheel hub BLDC motor by rechargeable Li-ion battery pack charged with the help of PV panel.

General Terms: Vehicle Development, Mathematical Modelling, Computer Aided Design, Solar Energy.
Keywords: Solar Vehicle, Electric Vehicle, Urban Freight, Industry 4.0, Autonomous vehicles, E-commerce.

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1. INTRODUCTION

Exploring newer alternatives to conventional fossil-based energy is the prime focus of present generation amongst which solar energy seems to be the most promising one [13]. India is putting major emphasis into the subject since 1980s with setting up of the Ministry of New and Renewable Energy (MNRE) working to derive cleaner energy for the country. Last 2 decades witnessed a major boom in the development of renewable alternatives to fuels and with a net solar potential of 750GW laid out by MNRE by 2022 the country hopes to increase the share of solar energy to 175 GW with support from active government policies and solar parks [3].

The Indian transport sector uses around 94 million tons of oil equivalent which is 18% of total energy consumed by the country [10]. Along with that in the past decade, explosive growth of e commerce has generated massive amount of deliveries in urban areas with numbers growing at a rapid rate. The need for fast home parcel is putting a lot of pressure on the urban logistics network [5]. Implementation of EVs in local city logistics mainly in last mile deliveries seems like a viable option for freight transport industry [4]. European projects like BESTUFS 2006; SUGAR 2011, and BESTFACT working on developing best inventory for urban freight incorporate electric assistance in cargo cycles, delivery consolidation centers and using electric vans for last mile delivery. Such inventories are reflecting the growth of electric deliveries in modern cities [8]. On-Road Autonomous Delivery Robots (RADRs) equipped with sensors and navigation systems delivering groceries and parcels is the future [15]. The major barriers for EVs in real-life urban freight transport are manly their extensively high cost, charging duration, limited payload and range which are critical to the logistics companies. Though the national and many state governments are deriving out policies to provide incentives on purchase and use of EVs [6]. With NEMMP, FAME I and FAME II (by Department of Heavy Industry) the government of India is encouraging widespread adoption of EVs in major cities, further by GST slashing, exemption from permits requirements, road tax incentives and by building charging stations the government is working on developing a sustainable EV ecosystem in the country [10].

Immense amount of literature related to studies on EVs, autonomous drives, Solar energy is available but there is a lack of studies on compiling PV technology with electric autonomous drives and using it for urban logistics [2]. Developing a commercial solar electric vehicle presently seems unfeasible due to efficiency barrier of PV modules and Li-ion batteries along with cost constraints [16-17]. Also a major barrier is that solar energy is extremely variable over places and time [13]. We need a sustainable solution to these barriers to ensure growth and development in the sector along with least effect on the environment.

2. SYSTEM MODEL

2.1 Surveys and Reference Studies

Mamta L Prajapati et al studied and analyzed the success with focus on innovative developments of solar electric vehicles like cars, e-rickshaws, buses and in India as a large scale alternative for future [1]. Mohammad Waseem et al reviewed the solar mass scale integration of PV technology with 3 wheeled and 4 wheeled solar-electric drives, PV compatibility with robotics and self-driving modules and challenges in their adoption [2]. Muhammad Irfan et al analysed major features of solar based power like consumption, life, operational and maintenance cost, emissions and conditional requirements to derive out the potential for solar power in 4 major Indian cities [3]. S. Iwan et al. performed studied the electro mobility potential for city logistics and last mile deliveries using Nissan eNV200 in Szczecin, Poland [4]. R.A. de Mello Bandeira et al. performed similar study on using electric tricycles and LDVs as delivery vehicles covering economic environmental and social aspects to it [5]. S.M. Mirhedayatian, S. Yan created a frame network combining optimization techniques and economic analysis for delivery companies on response to EV support policies like taxes and subsidies by performing numerical experimentation and sensitivity analysis [6]. Muhammad Hosnee Mobarak et al modelled a solar electric vehicle and analysed the solar capture of 150 drivers on response to panel tilting and shading to calculate energy consumption, grid improvements, driver response, environmental and economic advantages of SEVs [7]. Christophe Rizet et al. analysed the effects of constraints of vehicle range, payload and emissions on transferring urban freight from ICEVs to EVs in France [8]. Tharsis Teoh et al reviewed the 4 opportunity charging (OC) strategies—during breaks and shift changes, during loading activity, during unloading activity, or while driving on highways using a parametric model to study effects on costs and emissions [9]. V.S. Patyal et al. analysed and modelled 13 major barriers to adoption and future prospects of EVs for different major states like Delhi, Karnataka, Tamil Nadu, UP, MP etc. in India to recognize pertinent barriers and insights into the EV economy [10]. Ashish Kumar and Lal Bahadur Prasad reviewed the issues and challenges to the mass adoption of Electric Vehicles with emphasis on policy recommendations, government schemes and ecosystem development [11]. Bambang Sri Kaloko et al. laid a foundation to the development of a solar electric vehicle using mathematical modelling of various vehicle dynamics and behaviors on MATLAB Simulink [12]. J. Ashok et al. developed a solar based electric vehicle with low eight and aerodynamic features for Indian roads. With solar different solar irradiation for different latitudes, optimized tilt angles were derived and an auto rickshaw was developed with appropriate weight, range and power [13]. Zahari Taha et al. constructed a solar car using reused and recycled parts after WSC off the shelf which was low in cost and at par in performance [14]. Jennings, Figliozzi studied the cost savings per dollar of using road autonomous delivery robots by comparing 3 major RADR developing technologies with conventional vehicle data and how it varied over size and time [15]. Paterson et al. designed and developed a record braking solar electric vehicle with arrange of 800km and speed over 130kmh [16].

2.2 Research Gap and Objectivity of Study

There was a lack of literature on development of solar based autonomous freight vehicles for Indian ecosystem. The rise of Industry 4.0 and smart manufacturing in India has paved the way for self-driven cars to be a reality in India. A major area of immediate impact is last mile freight and delivery logistics. Given the rise of E-commerce in India it is imperative to focus on cleaner ways of delivery and innovation. Major firms like Amazon (Amazon's Scout) are working to develop road autonomous delivery vehicles and bringing such models into their business line. Theoretical testing and research has supported the idea of replacing fossil based freight with electric self-driven systems. To take this one step further, integrating sustainable energy source for power like PV module seems highly appropriate. Recent large scale investment into the green energy sector and with government schemes like FAME I, FAME II and NEMMP India is moving towards electrification of its vehicle fleet at an astonishing rate. To aid such a revolutionary transformation it first needs to convert all its logistics to electric. The objective of this project was to design and develop such an electric vehicle to be used for logistics and delivery purposes mainly to be used on Indian roads. The vehicle would be autonomously driven and be powered by an onboard PV module making it one of a kind autonomous solar electric delivery pod. Based on findings and research conducted all over the world, we derived a combined methodology of preparing a mathematical model of all the vehicle subsystems on MATLAB Simulink and perform simulation testing on it. A CAD model was also developed for testing purposes and to work on design and ergonomics. As the vehicle was supposed to operate on Indian roads designed the vehicle for a top speed of around 60-80 kmph and a range of 60-80 km. The payload capacity was kept 25 kg. Commercially available parts with detailed specification sheets available were to be used and vehicle was supposed to be economical in manufacturing and operation.

3. COMPONENTS AND SPECIFICATIONS

The concept vehicle design consisted of (i) a chassis, (ii) a body, (iii) a traction motor with controller, (iv) a Li-Ion battery pack with a battery management system, (v) tires and (vi) a PV module with controller. The commercially available components used for the design and their major specifications used for designing purposes are listed in *Table 1 and Table 2* respectively. The complete design including all measurements and limitations were based on the specifications of these components so that the design is as close to the real world as possible. Subsystems have been developed individually. The vehicle subsystems have further been briefly described:

Table 1: Commercial components used in vehicle

Vehicle Components	Commercial model used
BLDC in-hub motor	Tech Imperial 48V 2000W Hub Motor [21]
Cells used in Battery Pack	LG - Lithium Ion INR 21700 M50 18.20WH [17]
PV Panel	Luminous 330W 24V Polycrystalline Solar Panel, LUM 24330. [20]
Rear wheel	Ceat Zoom XL 80/100-17 46P Tubeless Bike Tyre, Rear [18]
Front Wheels	TVS Tyres Jaya 4.00-8 Tube-Type Auto Tyre [19]
Chassis Material	Carbon fibre - Hexcel AS4C (3000 filaments)
Body Material	Plastic - PP copolymer

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3.1 Chassis and Body

The Chassis is the skeletal frame of the vehicle consisting of tires and suspension systems over which the vehicle body and accessories are attached. In the designed vehicle we used a carbon fibre chassis with a polypropylene copolymer vehicle body. The carbon fibre chassis was used because of its excellent weight to power characteristics and the copolymer plastic body for its low weight and durability. The chassis and body were mainly designed for low weight and optimal aerodynamic characteristics and were designed on Solidworks'20 using 3D sketching. The Body was based on teardrop design with equation: y = .25/.2*100*(.2969*sqr(x/75)-.126*(x/75)-.3516*(x/75) ^2+.2843*(x/75)^3-.1015*(x/75)^4) with x from 0 to 75. Similarly, iso pipes were used for chassis with 21.3 mm diameter and 2.3 mm thickness. The vehicle has been kept as spacious as possible so as to accommodate whatever it needs to deliver.

3.2 Wheels

The vehicle had a three wheeled configuration with 1 rear driven 17-inch diameter and 85 mm section width wheel and 2 front wheels with 8-inch rim diameter and 4-inch section width. Tubeless tires were used for the design with low rolling resistance and low weight. Both wheels had aspect ratio 1 and were attached to the vehicle chassis. CAD and mathematical model of wheels were designed with set specifications. The rear wheel had the BLDC hub motor.

3.3 Traction Motor

The traction motor is the part that replaces the engine in a conventional automobile to propel the electric vehicle. They derive electrical power from the battery pack and convert electricity to mechanical rotation at the wheels. They may be placed at the front or back according to design and connected to the wheels via driveline or some designs use a hub motor which is directly attached to the wheel. EV applications don't use conventional motors instead more efficient motors like BLDC, PMSM or SRM motors are put to use. In our design we used an in-hub BLDC motor which is attached to the rear wheel of our vehicle. The BLDC motor comes with a controller and works on direct current via phased pulses generation by the controller. BLDC motors are very efficient (our motor was 82% efficient), provide great power to weight ratio and they are very cost effective. A hub motor is used as it occupies lesser space (which is the purpose of a delivery vehicle), weighs less, is cheaper and provides excellent traction without any driveline losses. So for our design we used a 48V 2000W hub BLDC motor. The CAD design and Mathematical Simulink model were built as per specifications of the Tech Imperial motor.

Table 2: Vehicle Component Specification

Specification	Value
Chassis	
Weight	2.3 kg
Body	
Weight	5.1 kg
BLDC Motor	
Operating Voltage	48 V
Rated Power	2000 W
Rated Torque	12.5 Nm
Weight	17.2 kg
Rated Current	47 A
Rated RPM	2850
Li-Ion Battery Pack	
Nominal voltage of each cell	3.63 V
Cell capacity	18.2 Wh
Weight of each cell	68 g
Cells in battery pack	14S 14P
Battery pack voltage	51 V
Battery pack current	13.6 A
Battery pack capacity	3.55 kWh
Weight of battery pack	13.32 kg
Rear Wheel	
Weight	4 kg
Rim diameter	17 inch
Section width	80 mm
Aspect ratio	1
Front Wheel	
Weight	2 kg
Rim diameter	8 inch
Section width	4 inch
Aspect ratio	1
PV Panel	
Weight	22.5 kg
Rated module voltage	24 V
Peak power	330 W
Open circuit voltage	45.53 V
Short circuit current	9.2 A
No. of cells	72

3.4 Battery Pack

The battery pack is the most important and usually the most expensive part of an Electric Vehicle. It is analogous to the fuel tank of a conventional automobile. EV battery packs consist of modules connected in series. These modules themselves consist of cells connected in parallel. The standard cells used for EV battery packs are Li-Ion cells. They have significantly higher specific power and energy density than the lead acid or metal hydride cells also they can be discharged to deeper levels. Our design uses a Li-Ion cell which is collected into modules and packed into a battery pack with a configuration of 14S 14P to give a net battery pack voltage 51 V and capacity 3.5kWh. The battery pack is operated by a battery management system which monitors the state of health and state of charge of the pack to make sure pack operates on optimum level and safely. The Mathematical Simulink model and CAD model had been built and the pack was placed it the front of vehicle for better weight distribution.

3.5 PV Module

Photovoltaic panels convert heat energy from solar radiation to electricity. This generated emf is further boosted by a module and is used to charge the battery which turns the motor and

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propels the vehicle. The design uses a 72 cell PV panel with rated voltage 24V. The design vehicle has to operate in India, where there is abundance of solar irradiance in most places especially during summer months. The module design consisted pulse width modulation and a boost converter using a IGBT gate to charge the battery pack via a solar charging module. The specification sheet of Luminous LM 24330 was used to build the CAD model and Simulink model of the PV panel and it was placed over the top of the vehicle.

4. MODELING AND SIMULATION

4.1 CAD Modeling and Testing

All the components used in the pod design were recreated using Solidworks'20. The specifications were taken from the available data and were in accordance with the objectives of the project i.e. to maximize the range and payload capacity while reducing the weight and cost of the pod. We performed extensive research to find best off the shelf available products made from optimal material. Once all parts were designed and their material properties configured, they were assembled into the chassis and the copolymer body was added. The vehicle was 0.63 m wide ,1.62 m in length (without panel) and 0.74 m in height. The complete vehicle assembly was aerodynamically tested using flow simulation module of SW'20. The aerodynamic pressure drag at 60km/h (assumed as top speed) was around 33N. The calculated frontal area was around 0.41m^2 and the drag coefficient (Cd) was 0.46. The CAD models and flow simulation have been presented in *figure 1-12*.

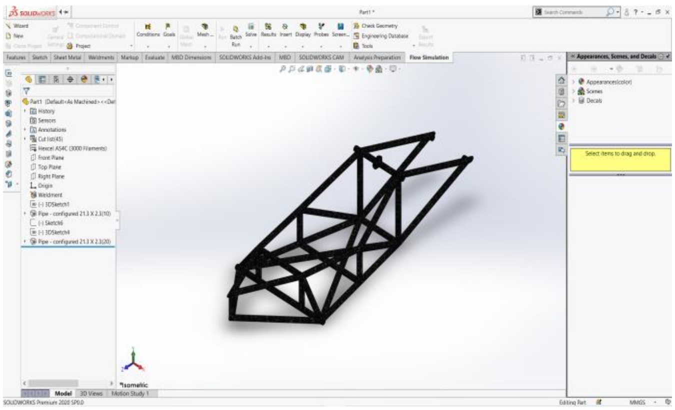

Figure 1: Chassis

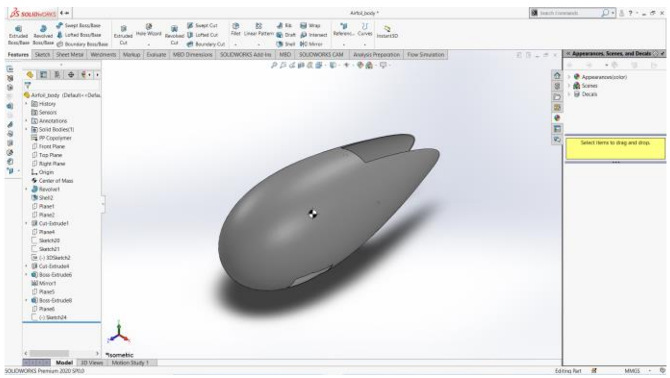

Figure 2: Body

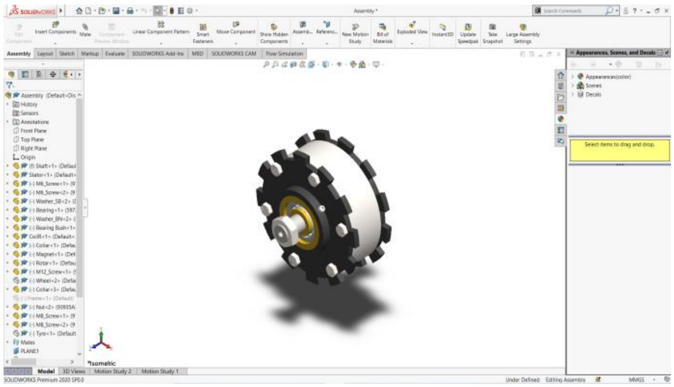

Figure 3: BLDC hub motor

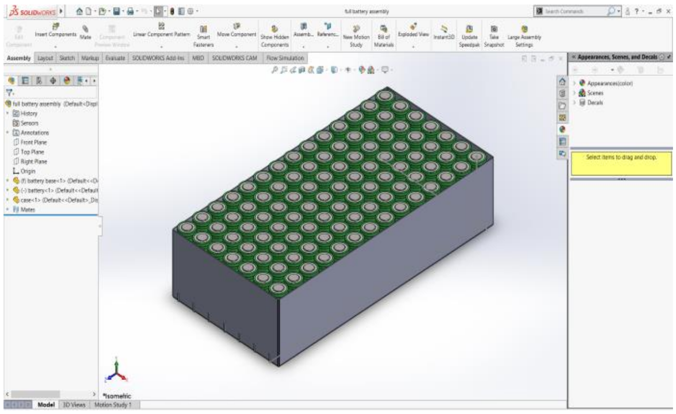

Figure 4: Battery pack

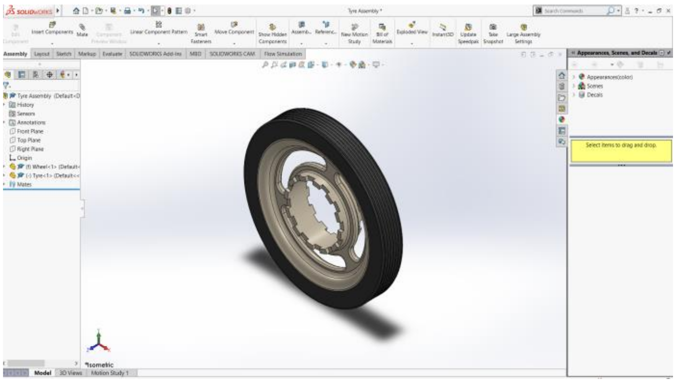

Figure 5: Rear wheel

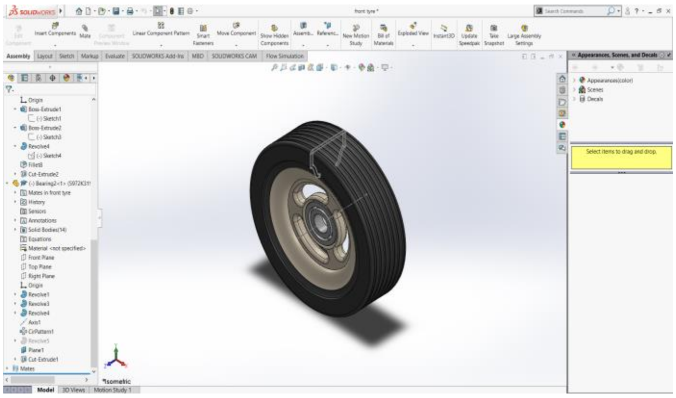

Figure 6: Front wheel

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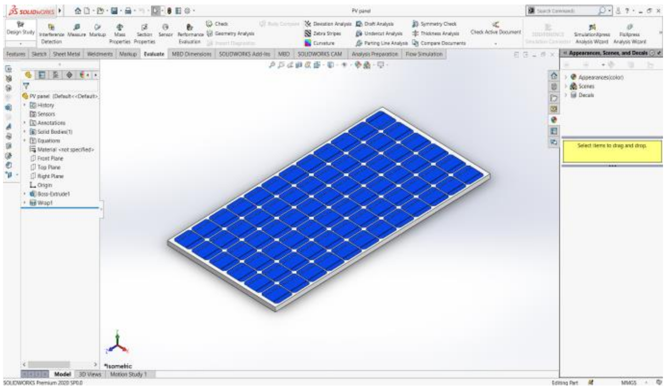

Figure 7: PV panel

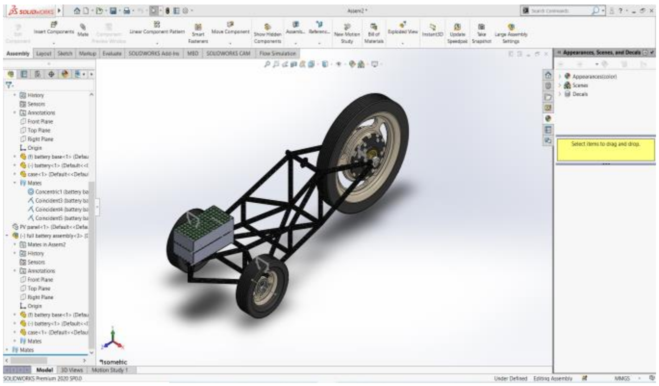

Figure 8: Chassis assembly

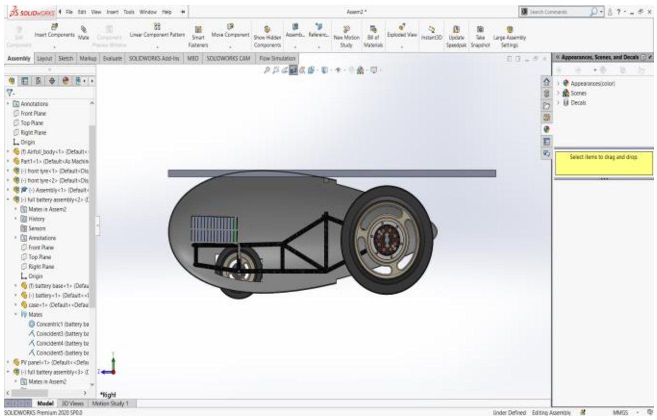

Figure 9: Vehicle Assembly

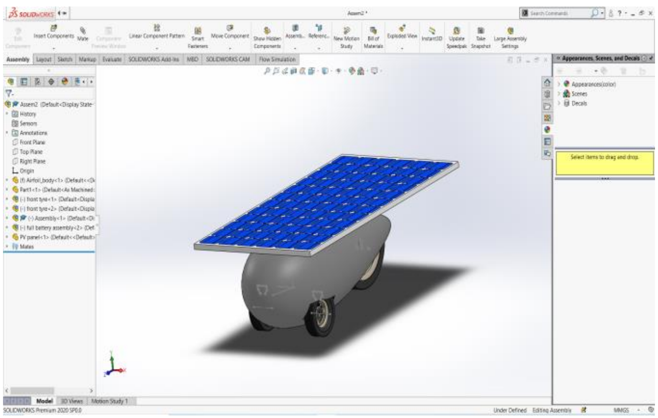

Figure 10: Complete vehicle

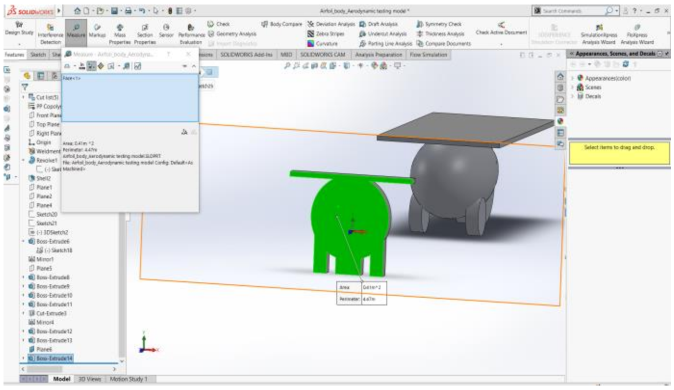

Figure 11: Frontal area calculation

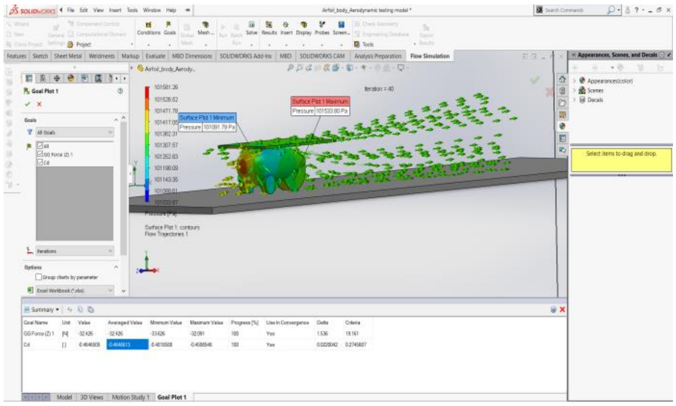

Figure 12: Air flow simulation

4.2 Mathematical Modeling

To perform various tests on the vehicle and check its operability it was imperative to mathematically model the different vehicle components and create a complete mathematical model of the project vehicle. We designed the equations-based subsystems on MATLAB Simulink using Simulink library and Simscape tools (for PV module). Major equation-based subsystems were designed and compiled to test the model for certified drive cycles. We tested the model for 2 drive cycles (WLTC_class1_1022 and FTP75) both having different characteristics to evaluate vehicle performance in different conditions. The complete Simulink model has been presented in *figure 13* and the subsystems discussed briefly:

4.2.1 Drive Cycle Source

This provides the drive cycle input as velocity-time plot. In or project we test 2 drive cycles. (*i*) WLTC_class1_1022 cycle which is 1022 seconds 8103-meter-long cycle. It has a top speed of 17.9 m/s and frequent braking and accelerating maneuvers. It is suitable for inner city movement and heavy traffic conditions which is common on Indian roads. (*ii*) FTP75 cycle which is a 2474 second cycle 17667-meter cycle. It has a top speed of 25.3 m/s and is suitable representation of intense driving conditions with frequent acceleration and braking. Thus, both the drive cycles combined should provide an ideal indicator of project vehicle performance and represent majority of real-life cases. These drive cycles are fed to the leader vehicle and our project pod should follow this leader autonomously effectively.

4.2.2 Control Module

This module consists of a leader vehicle, a mode selection module and a driver module. The leader gets the drive cycle input from the source module and initial speed and position input from the user to calculate position and speed. The mode selection module takes input leader reference position and relative speed to shift between 3 modes (*i*) free drive mode, (*ii*) vehicle following mode and (*iii*) emergency braking mode. During free drive mode when relative distance is greater than 50 m module commands free acceleration, when relative distance is less than 10 m module commands emergency braking. When relative position is between 10 m to 40 m module switches to a vehicle following mode which is based on a controller and provides acceleration and braking commands on basis of reference leader's speeds and position and calculates our project vehicle's reference speed which it should maintain. The driver module inputs this reference speed and used a PID controller to output acceleration and braking command to motor and brake modules.

4.2.3 Torque and Brake Distribution Module

This module receives acceleration and braking commands, present vehicle speed and motor rpm. It compares available motor's rated (& maximum) power which is 2000W and rated (& maximum) torque from the motor which is 12.5 N and calculates the net torque to be produced by the motor now. It also calculates and distributes regenerative and friction braking. The friction brake inputs act as input to the driveline module whereas the regenerative acts on the motor. The net motor torque is calculated by this difference and is fed to the Motor Energy and losses module and the driveline module.

4.2.4 Motor Energy and Losses Module

This module inputs net motor torque, motor speed (in rpm) to calculate motor losses including power and energy losses, motor input energy and motor power. It is based on basic motor equations with values of constants taken from specification sheet of the motor. It mainly takes into account all the losses (copper and iron) and derives the net power input from the battery module.

4.2.5 Battery Module

This module consists of the power storage system. It inputs net motor power requirements and accordingly supplies mathematically calculated voltage and battery current across its terminals. It takes into account the accessory loads, the open circuit voltage, the battery energy capacity, the discharge current and calculates the state of charge of the battery, energy and power at the terminals of battery during the drive cycle. It also accounts for the battery power and energy losses during battery operation. For the project vehicle the rated voltage is 51V, while the rated current is 13.6 A. The energy capacity of the battery pack is 3.54 kWh.

4.2.6 Driveline Module

This module signifies the driveline of the vehicle. It inputs motor torque, friction brake command and present vehicle speed to calculate the driveline torque with driveline energy and power losses and eventually the net vehicle tractive force acting on the vehicle which is used for vehicle dynamics calculations. It takes into account the spin losses in the driveline and also calculates the motor speed (in rpm) which is required.

4.2.7 Vehicle Dynamics Module

This module represents the base vehicle propulsion equations and vehicle dynamics. It inputs the net tractive force and calculates all the resistive forces including aerodynamic drag, gradient force, rolling resistance acting on the vehicle to derive final vehicle speed, tractive power, braking power and position.

4.2.8 Solar Panel (PV) Module

This module consists of PV panels, a boost converter and the battery pack. The PV panels used have rated voltage 24V and OCV 45.53 V. There is a source input of solar irradiance and temperature over time. A boost converter with IGBT gate is provided with pulse width modulation of 10000Hz.The Li-ion battery pack is similar to the battery module and it gets charged over the cycle.

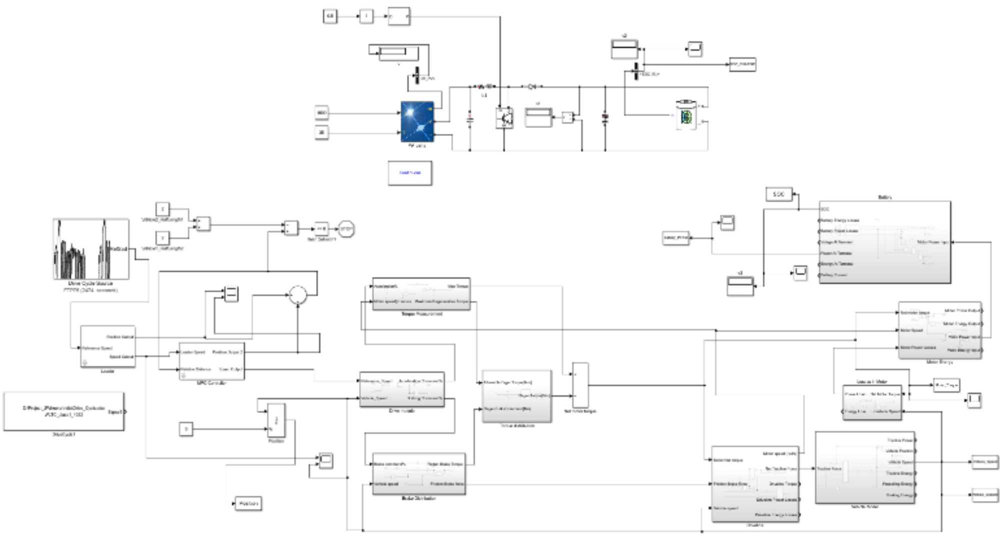

Figure 13: MATLAB Simulink Model

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4.3 Simulation Testing

The testing of the vehicle model was performed in 3 stages each for a different cycles and graphs were plotted for performance evaluation. For the first and the second stage the leader vehicle started 40 m ahead of the project vehicle with an initial velocity of 10m/s while the project vehicle started with an initial velocity of 5m/s. The initial battery SOC for 1st & 2nd stage was 95%. During the first stage the leader vehicle was subjected to the WLTC_class1_1022 Cycle. The simulation ran for 1022 seconds and the project vehicle's performed optimally for the whole cycle. During the second stage the leader vehicle was subjected to the FTP75 cycle. The simulation ran for 2474 seconds and the project vehicle's performed efficient for most of the cycle except for the top speed peaks where the vehicle was unable to cross the motor speed barrier. During the third stage with initial battery SOC at 50%, the PV module was subjected to constant solar irradiance of 1000W/m^2 and temperature 35ºC for 300 seconds. The module worked efficiently and the battery was charged. 5 major performance graphs of the vehicle were plotted over time for the WLTC_class1_1022 Cycle and the FTP75 cycle tests and compared. These were velocity plot, displacement plot, state of charge plot, battery power plot and motor torque plot. State of charge plot for the PV module test was derived.

4.3.1 Plot 1: Velocity Time Graphs

As shown in *figure 14-15*, velocity plots clearly show the vehicle completes both the cycles efficiently. During WLTC cycle the vehicle attains a top speed of 17.9 m/s at around 770 seconds mark which is equivalent to the cycle. While for FTP75 cycle the vehicle attains a max speed of around 21.5m/s where as the top speed requirement for the cycle was 25.3m/s at the 241 seconds and 2211 seconds barriers. Other than this the project vehicle is able to follow the velocity profile of both the cycles while accelerating and braking. The majority time the velocity of vehicle is 8-12 m/s for WLTC cycle and average speed is higher during the second half while it is 10-15 m/s for FTP75 cycle and it seems constant throughout except for the stop at 1367 second till 1989 seconds.

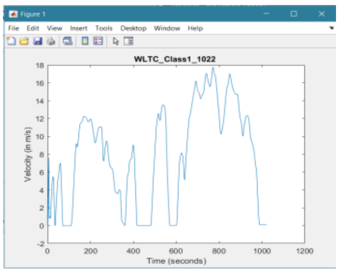

Figure 14: Velocity (WLTC 1022 Cycle)

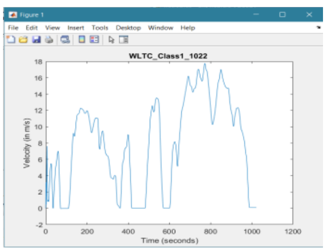

Figure 15: Velocity (FTP75 Cycle)

4.3.2 Plot 2: Displacement Time Graphs

As shown in *figure 16-17* the vehicle completes the journey of both the cycles efficiently. The vehicle covers 8103 m following the WLTC cycle while it covers 17667 m following the FTP75 cycle. The slopes are analogous to vehicle speeds during these drive cycles. The vehicle constantly moves during the WLTC cycle while it stops at the 12km mark for about 10 minutes during the FTP75 cycle.

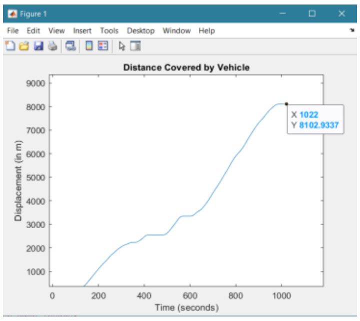

Figure 16: Displacement (WLTC 1022 Cycle)

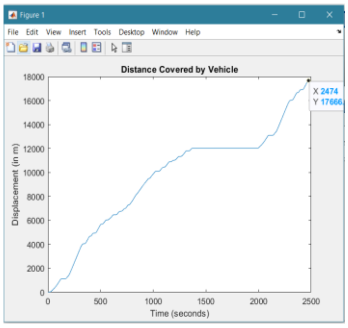

Figure 17: Displacement (FTP75 Cycle)

4.3.3 State of Charge-Time Graphs

As shown in *Figure 18-19* the battery pack of the vehicle discharges during both the cycles. The WLTC cycle is shorter and there are lesser instances of braking and acceleration so battery discharges from 95% to 82.06% during the 1022 second cycle. The slope is relatively steeper after the 600 second mark due to higher speeds in the 2nd half of the cycle. The FTP75 cycle is relatively larger although the vehicle stops for a significant time after 1367 seconds for 622 seconds. The battery discharges from 95% to 62.6% during the 2474 second cycle. The slope is abruptly steep after the 2000 second mark after which vehicle attains higher speeds.

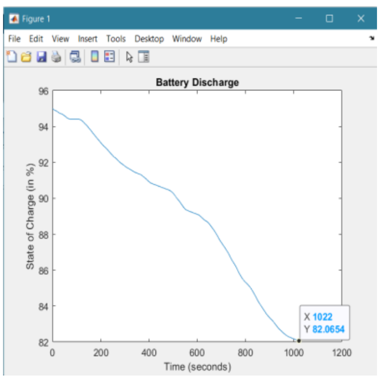

Figure 18: Battery SOC (WLTC 1022 Cycle)

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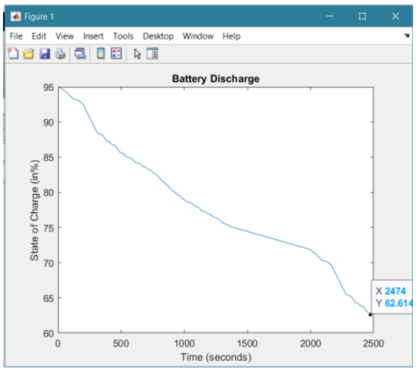

Figure 19: Battery SOC (FTP75 Cycle)

4.3.4 Plot 4: Battery Power and Time graphs

As shown in *Figure 20-21* the battery power follows a similar trend like the velocity profile. Same motor and battery pack have been subjected to both the cycles. During the WLTC cycle the power derived from the battery was mostly in the region 1800 – 2200 W and since the rated motor power is 2000 W it works efficiently. The power demand peaks at higher speeds to around 3000W but it is not for longer duration and can be sustained. During the FTP75 cycle the power derived from the battery is mostly in 2000 – 2300 W region which again proves that a 2000W rated power motor works efficiently for this cycle. The peak power demands more than 3700W although cannot be sustained due to limitations of motor. Overall the performance of the vehicle motor and battery pack is optimal.

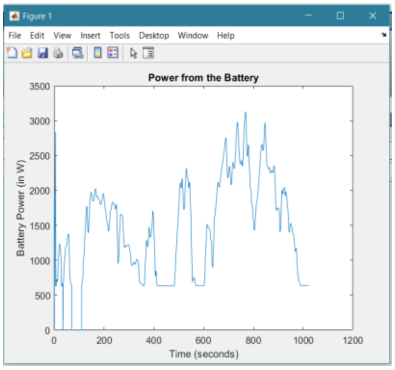

Figure 20: Battery Power (WLTC 1022 Cycle)

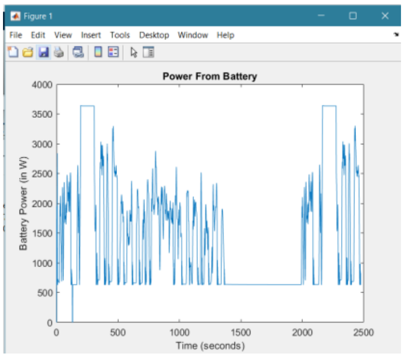

Figure 21: Battery Power (FTP75 Cycle)

4.3.5 Plot 5: Motor Torque and Time Graph

As shown in *Figure 22-23* the motor torque varies differently for both cycles. During the WLTC cycle the net motor torque mostly lies in the 8-11 Nm region. The motor works efficiently as the rated torque value is 12.5 Nm. There are less spikes in this cycle and the motor delivers the required torque without a load. During the FTP75 cycle however the required torque mostly lies in the 9-12 Nm region which is close to the rated value. There are spikes requiring larger torque of about 18-19Nm. This mainly due to intense acceleration and deceleration during the FTP75 cycle which is not the case of WLTC cycle. Overall the motor works close to its rated value and so performs optimally.

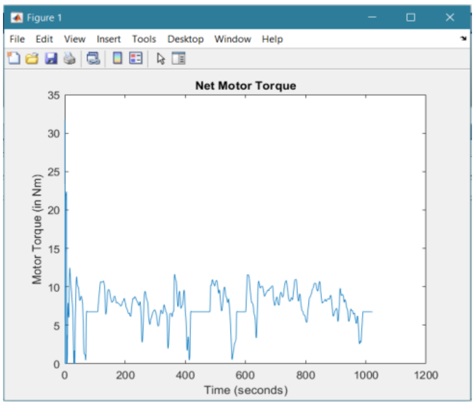

Figure 22: Motor Torque (WLTC 1022 Cycle)

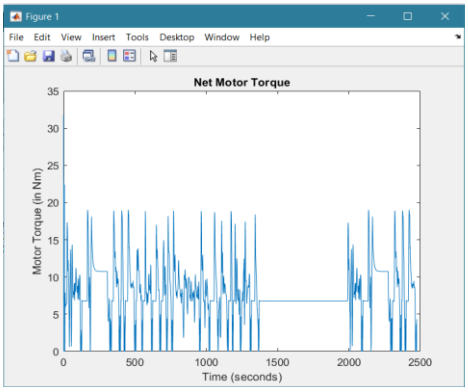

Figure 23: Motor Torque (FTP75 Cycle)

4.3.6 Plot 6: State of Charge and Time Graph

As shown in *Figure 24* during the third stage testing the PV module was put under solar irradiance 1000W/m^2 and temperature 35^o for 300 seconds. The battery pack charged from 50% to 50.54%.

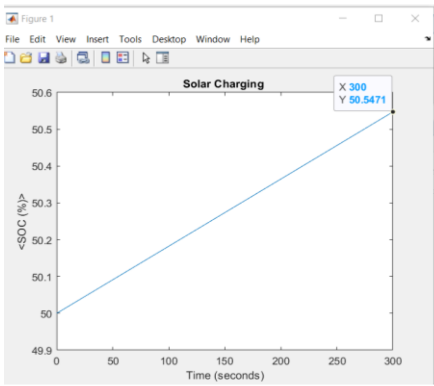

Figure 24: Solar Charging over 300 seconds

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The net vehicle weight was around 80 kg so it was able to carry a load of 20kg effectively. The vehicle travels around 8km dropping 13% battery so the vehicle has a range of about 60-70 km on such extreme cycles. The vehicle ran smoothly with the PID driver model running efficiently. The attached solar panel was 1.96m^2 and it charged the battery from 50% to 50.54% in 300 seconds i.e. 5 minutes making it a viable source to charge the battery in areas with extreme sunny days. Major battery losses, driveline losses, motor losses were incorporated in the simulation making the vehicle fit for real world applications. The vehicle was inspired by vehicles designed for World Solar Challenge and used modern innovative subsystems like Li-ion cells, carbon fiber chassis, PV modules, regenerative braking etc.

5. CONCLUSION AND FUTURE SCOPE

Autonomous vehicles continue to be a distant reality. Although recent advances in AI and neural networks can turn this into a reality. Similarly, climate change is the biggest world issue and it's a global agreement that we need better energy alternatives and stop burning fossils. Solar energy is the cleanest and one of the most sought after sustainable alternatives to oil. India is presently going through an electric revolution in the automotive sector. Major reforms, incentives, schemes, startups and laws are forming up a new ecosystem for development of Indian automotive sector. Along with this the due to the rise of e-commerce, last mile freight deliveries have seen a massive explosion. The main objective of this particular project is to combine these all developments to provide a novel futuristic solution. The idea behind developing this model is to solve multiple problems together optimally. The approach of the project uses latest technologies like computer aided designing, mathematical modelling and simulation testing. The objectives of the project were based on providing one solution to four problems together. These problems were putting autonomous vehicles under safe conditions, using a renewable source for transforming mobility, providing the last mile deliver sector a sustainable alternative amid rising fuel prices and being a part of India's E-mobility revolution The project vehicle performed optimally and fulfilled all its objectives. Such solar electric vehicles have potential to replace small delivery vehicles for last mile deliveries. This project vehicle pod has been thoroughly tested for different cycles and has proven efficient in simulation testing. The vehicle has been constructed using off the shelf parts and it fulfilled the major objectives of the study like range, charging and speed criteria satisfactorily the vehicle is simple, lightweight and easy maintenance. It can be easily dismantled and parts like PV module and battery be used for other purposes. The vehicle is created using a mathematical model so different parts may be tested for the same model. Such model can be used to check the effectiveness of such vehicles on different drive cycles. The further steps include making the vehicle structurally stronger and performing major safety tests like impact fatigue and torsional tests. The present vehicle deals with only longitudinal dynamics so adding lateral motion and reforming the self-driving module is also due.

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