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Design, Testing, And Validation Of An Electric Vehicle Using Simulation Software's

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Abstract: An electric vehicle (EV) will be designed using CATIA software, and its performance will be optimized through simulation using IPG Car-maker. The goal is to develop a high-performance electric vehicle especially for racetrack environments. Finding the ideal balance between structural integrity, power-train efficiency, and aerodynamics is the main goal of the design process. Following the original design, Car-maker simulations are used to test and confirm the performance of the vehicle under various racing circumstances virtually. These simulations aid in the fine-tuning of elements like handling, energy consumption, and vehicle dynamics to guarantee that the EV satisfies demanding performance requirements appropriate for professional racing.

Index Terms - CATIA , IPG Car-Maker, MATLAB

I. Introduction

This project focuses on optimizing the performance of an Electric Vehicle (EV) on a race track using simulation software like IPG Car-Maker. Design the car model in CATIA. The goal is to enhance key aspects of the EV's performance, such as speed, energy efficiency, and handling by leveraging advanced simulation tools to fine-tune vehicle parameters and driving strategies like MATLAB.

With the rapid adoption of electric vehicles in both consumer and competitive motor-sports, optimizing EV performance has become crucial. Unlike traditional internal combustion engines, EV's face unique challenges, such as managing battery life, ensuring efficient energy use, and maintaining performance across varying track conditions. It is very costly and time consuming process. Simulation tools like IPG Car-Maker allow engineers to model these challenges accurately and test so of track.

The purpose of this project is to use simulation to explore and implement optimizations in the EV's power train , aerodynamics, and driving strategies. By creating a detailed vehicle model and running simulations under different conditions, the project aims to identify the most effective ways to improve overall race performance.

This project is significant because it addresses critical challenges in EV racing, such as energy management and vehicle dynamics. The insights gained will not only enhance the competitiveness of EV's in motor sports but also contribute to broader advancements in electric vehicle technology.

II. Literature Review

1 Omer Can Tolun, Onder Tutsoy "3D Modeling And Justification Of An Electrical Vehicle With Multibody Modeling Softwares" Conference: 5Th International Conference On Life And Engineering Sciences At: Alanya, Turkey Icoles 2022

The electric vehicle (EV) energetic model discussed in this paper was created using the multibody modeling software MapleSim and MATLAB/Simulink. The main components of the vehicle model were systematically gathered and arranged to form the EV. This EV model comprises a DC servo motor, a controller, a battery, and a mechanical component. To simulate the constructed EV, four distinct driving cycles were used: the Federal Test Procedure (FTP75), the Highway Fuel Economy Test (HWFET), the Artemis Rural Road (ARR), and the LA92/UCDS (Unified Cycle Driving Schedule). The Root Mean Square Error (RMSE) data obtained from each driving cycle, along with data derived from well-established physical principles, were used to validate the simulated position and speed states of the EV models.

2 .Demin Nalic Hexuan Li1 , Arno Eichberger Christoph Wellershaus , Aleksa Pandurevic , And Branko Rogic "Stress Testing Method For Scenario-Based Testing Of Automated Driving Systems" VOLUME 8, 2020

This paper explores traditional testing methods for automated driving systems (ADS) at SAE levels 1 and 2, which concentrate on specific scenarios and maneuvers. However, for ADS at SAE level 3 and higher, the variety of scenarios is limitless, making virtual testing essential. One major challenge is developing a realistic virtual environment that accurately replicates vehicles, objects, traffic, and environmental factors to yield reliable test data. In this study, a co-simulation method was used, combining the traffic flow simulation software PTV Vissim with the vehicle simulation software IPG CarMaker to assess ADS in detailed traffic situations. Besides, a new stress testing method (STM) was introduced to generate safety-critical scenarios (SCS) by altering traffic participants, thus enhancing the frequency of SCS based on accident data collected from Austrian motorways.

3 Mohammed Rabhi1 , Imre Zsombók "Simulation Based Validation of Range Prediction of Electric Vehicles" Periodica Polytechnica Transportation Engineering, 50(2), pp. 136–141, 2022

This paper analyzes the increasing support for electric vehicles (EVs) as a way to combat rising urban pollution and the depletion of oil resources. However, the global adoption of EVs faces challenges, including low energy density, high costs, and a shorter range when compared to traditional vehicles. Often, automakers give misleading range estimates that overlook various factors such as driving conditions, temperature, or the usage of auxiliary equipment. For EV owners, it is critical to have accurate information regarding their vehicle's remaining range and energy consumption to ensure a comfortable and stress-free journey, even with the restrictions on driving range.

Papers [1] use only CATIA for structural and ergonomic design.

Papers [2] focus on MATLAB for motor simulation and vehicle dynamics.

Papers [3] rely solely on IPG Car-Maker for performance validation.

This paper combines CATIA, MATLAB, and IPG Car-Maker to create a comprehensive approach to EV development. By leveraging the strengths of these three software tools, the design, analysis, and simulation processes are integrated to enhance EV performance holistically. This method bridges the gap in existing literature by addressing multiple aspects of EV design and validation in a unified framework.

III. Problem Statement

The problem in the today's world is testing and validation Electrical vehicles is the very time consuming and costly process. In this process material wastage and safety concerns is the issue. The goal of the our project is testing and validation of the Electrical Vehicle using software's. For Enhancing the Reliability,Durability and efficiency of the Vehicle.

Customize the EV's setup to match specific race track characteristics, such as curves, slopes, and surface conditions, to maximize performance. Run multiple simulations under different scenarios, including varying track conditions, to identify the optimal configurations for the EV. Analyze simulation data to inform adjustments and refinements to the vehicle model. Promote the use of electric vehicles in competitive racing by demonstrating that E Vs can achieve high performance while being energy-efficient and sustainable.

EV's involve complex systems like electric motors, battery management systems (BMS), inverters , and regenerative braking systems. Testing these systems individually and as part of the whole vehicle cab be resource intensive and time-consuming.

IV. Methodology

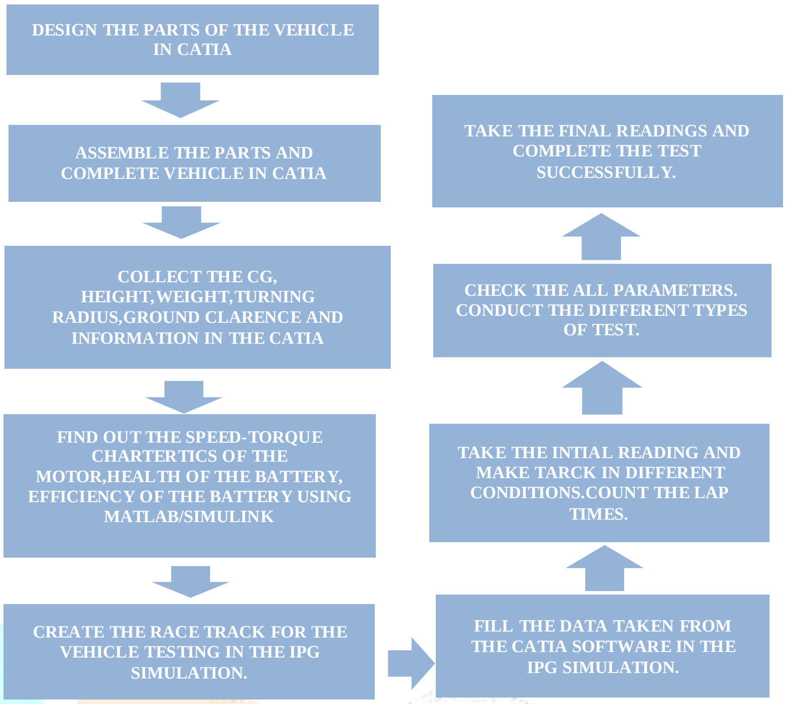

Fig.1 : Methodology

1. Design the Parts of the Vehicle in CATIA
Conceptualization: Start by sketching initial designs for key components such as the chassis, body, wheels, suspension, battery housing, and motor mounts. Focus on achieving a balance between aesthetics and functionality.
Part Modeling: Utilize CATIA to create precise 3D models of each component. Consider factors like weight distribution, aerodynamics, and manufacturability during the design process.
Material Selection: Select materials based on requirements such as strength, weight, cost, and thermal properties. Ensure choices align with the performance goals of a race-ready EV.

2. Assemble the Parts and Complete the Vehicle in CATIA
Assembly Modeling: Import individual part models into a single assembly file in CATIA and arrange them according to the design blueprint.
Constraints and Joints: Apply appropriate constraints, such as fixed joints for structural parts and rotational constraints for moving parts like wheels and axles, to ensure realistic movement and functionality.
Final Design Review: Conduct a comprehensive review to check for potential interferences, misalignment's, or weak points. Validate structural integrity and aerodynamic coherence.

3. Collect Key Parameters Using CATIA
Center of Gravity (CG): Use CATIA's analysis tools to calculate the vehicle’s center of gravity, which is critical for maintaining stability during high-speed maneuvers.
Dimension Analysis: Measure parameters such as vehicle height, weight, turning radius, and ground clearance.
Documentation: Compile the collected data into a detailed report for use in subsequent simulation and analysis phases.

4. Analyze Speed-Torque Characteristics Using MATLAB/Simulink
Model Development: Create a MATLAB/Simulink model of the electric motor to evaluate its speed-torque characteristics. Include motor specifications such as voltage, current, and load capacity.
Data Analysis: Study the simulation results to identify optimal operating points for motor efficiency and performance. Use graphical plots to illustrate the relationship between speed and torque.

5. Design the Race Track and Testing Scenarios in IPG Car-Maker
Track Design: Build a virtual racetrack in IPG Car-Maker that includes various features like straight paths, curves, inclines, and uneven surfaces to replicate real-world racing conditions.

Scenario Setup: Define diverse testing scenarios such as wet surfaces, sharp turns, and sudden braking to challenge the vehicle's handling and stability

6. Conduct Initial Tests and Collect Baseline Data
Initial Testing: Run the EV model on the virtual track to record baseline performance data, including acceleration, braking distance, and lap times.
Parameter Validation: Compare test results with design expectations to confirm the accuracy of collected parameters and identify any deviations.

7. Verify Parameters and Conduct Various Tests
Parameter Verification: Reassess performance metrics such as handling, stability, and energy efficiency to ensure alignment with design goals.
Types of Tests:
Dynamic Testing: Evaluate vehicle responsiveness and cornering capabilities under different scenarios.
Durability Testing: Simulate extended use to assess component reliability.
Efficiency Testing: Measure energy consumption across varying speeds and driving conditions.

8. Integrate CATIA Data Into IPG Car-Maker for Simulation
Data Integration: Input vehicle parameters from CATIA, such as dimensions, weight distribution, and aerodynamic properties, into the IPG Car-Maker simulation software.
Simulation Execution: Run simulations with the integrated data to observe how the vehicle performs in the virtual testing environment. Analyze the results for insights into potential improvements.

V. CATIA

Suspension Analysis :
In a racing car, suspension geometry plays a crucial role in ensuring stability, handling, and performance. Below are some key parameters essential for designing and analyzing a suspension system:

1. Scrub Radius
The scrub radius is the distance between the center of the tire's contact patch and the point where the steering axis intersects the ground. It is a critical parameter that directly affects the steering characteristics, stability, and feedback of the vehicle.

Types of Scrub Radius:

Positive Scrub Radius:
Occurs when the steering axis intersection point is closer to the vehicle's centerline than the tire contact patch center. It enhances steering feel but can increase torque steer.

Negative Scrub Radius:
Occurs when the tire contact patch center is closer to the vehicle's centerline. It improves stability under braking, especially in vehicles with ABS.

2. Camber Change Rate (CCR)
The Camber Change Rate refers to the rate at which the camber angle of the wheels changes as the suspension compresses or rebounds during motion.

Importance:

1. Maintains optimal tire contact with the road surface, improving grip and handling.
2. Helps in counteracting the body roll during cornering, enhancing vehicle stability.

Positive and Negative Camber:

Positive Camber: The top of the tire tilts outward from the center of the vehicle.
Negative Camber: The top of the tire tilts inward toward the center of the vehicle. Negative camber is commonly used in performance and racing cars to improve cornering grip.

Application in Double Wishbone Suspension:

In this project, a double wishbone suspension is designed to ensure precise camber control. This design is ideal for maintaining grip and tire contact during high-speed maneuvers and varying road conditions.

Formula for Camber Change Rate:
CCR= KPI / Wheel Travel

Where:

KPI (Kingpin Inclination): The angle formed between the vertical axis and the steering axis.
Wheel Travel: The vertical displacement of the wheel during suspension compression or rebound.

3. Front View swing Arm :

A front swing arm refers to part of vehicle suspension system. These component connects wheel hub to the chassis of the vehicle, allowing the vehicle to move vertically in response to uneven surfaces while maintaining control and stability.
Swing arms are often found in double wishbone suspension setup.
The swing are appears as horizontal are slightly inclined structure attached at one end to the chassis and at other end to the steering knuckle and wheel hub.
It movement is guided by ball joints at it works in conjunction with shock absorbs to absorb road impacts.

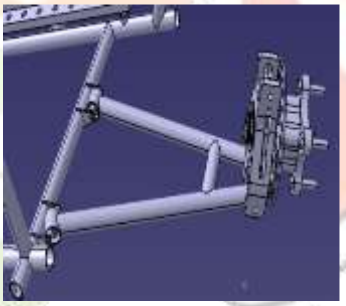

Fig 2 : Front View swing Arm

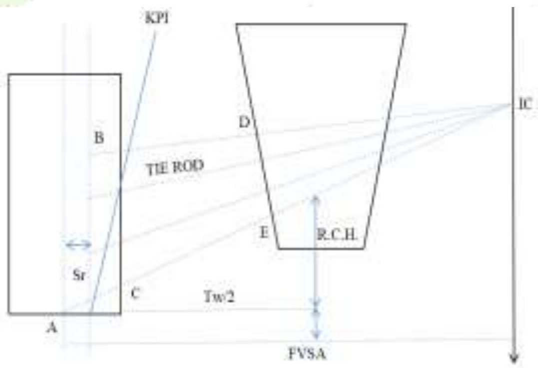

Fig 3 : Suspension Analysis

Axis passing through bottom point of contact path ‘A’ and the roll centre intersects at point Instent centre (IC)

Where :

BD = Upper control arm length
CE = Lower control arm length
TW = Track Width
SR = Scrub Radius
KPI = King pin point

- **Calculation Of Suspension Analysis**

CCR = KPI/Wheel travel
=11.73 /10
=1.173

CCR = Tan-1 (1/FVSA length)
1.173 = Tan-1 (1/FVSA length)
FVSA = 48.83 in

King pin = 11.730
Wheel Travel = 10 in

Factor Of Safety = Ultimate strength/ Working Stress
= 600.35 / 517.25
= 1.16

- **Centre Of Gravity**

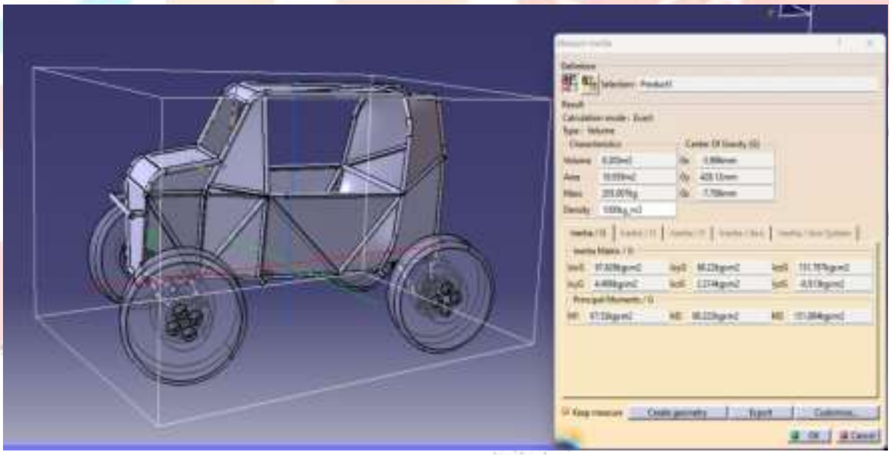

Fig 4: Centre Of Gravity

Battery Placement : Batteries, being the heaviest component, are typically placed on the floor of the vehicle to lower the CoG.
Chassis and Suspension Design : The chassis and suspension are designed to support a low CoG while maintaining adequate ground clearance.
Motor and Drivetrain : Lightweight and compact motors can be placed to balance the CoG longitudinally and laterally.

By carefully managing the CoG, EV designers can create vehicles that are safer, more efficient, and enjoyable to drive. It is a cornerstone of modern EV design philosophy.

- **Parts Of Vehicle**

1. A Arm Wishbone

1. Independent Wheel Movement: The A-arm suspension allows each wheel to move independently, providing improved handling and comfort, particularly when driving on rough or uneven surfaces.
2. A-Arm Structure: The unique A-shape of the suspension arms provides a robust and lightweight design, which is essential for supporting vehicle loads while minimizing overall weight. This is particularly beneficial for improving the efficiency of electric vehicles (EVs).

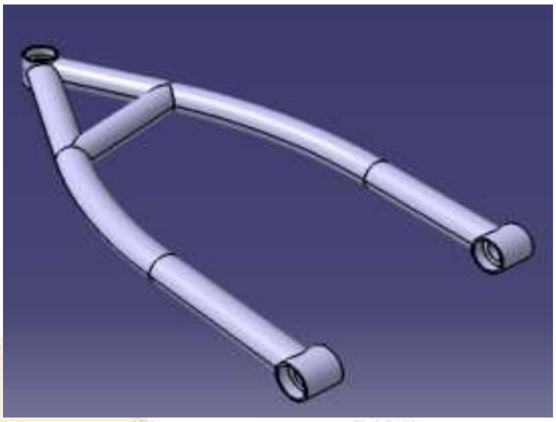

Fig 5 : A Arm Wishbone

2. H Arm Wishbone

The H-arm wishbone suspension is a variation of the double-wishbone system that includes an additional horizontal link, forming an "H" shape. This design enhances the rigidity of the suspension while still allowing for the flexibility needed to ensure smooth wheel movement.

Importance of H-Arm Wishbone Suspension in Electric Vehicles (EVs)

1.Enhanced Stability: The H-arm design minimizes lateral movement, providing better stability, especially during high-speed cornering or when navigating uneven surfaces.

2.Increased Durability: Given the heavier weight of EVs due to their battery packs, the H-arm suspension offers extra strength to support this weight, ensuring the vehicle performs efficiently without compromising on suspension integrity.

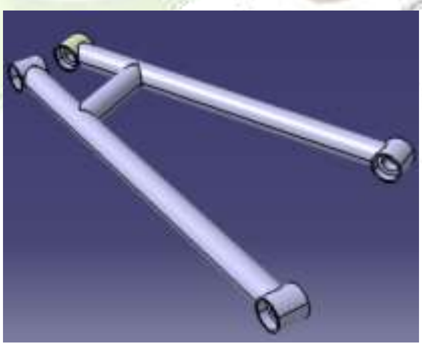

Fig 6: H Arm Wishbone

3. Ball Joint

1.Pivot Point: The ball joint serves as a pivot, allowing the wheel to move in multiple directions. It facilitates both vertical movement (suspension travel) and lateral movement (steering) to accommodate road irregularities and steering inputs.
2. Load Support: It supports the vehicle's weight while ensuring that the wheel remains correctly aligned throughout motion, which is essential for safe and stable driving.
3.Improved Maneuverability: The ball joint enhances the vehicle's steering precision and stability, especially when cornering or driving over uneven surfaces, contributing to better overall handling.

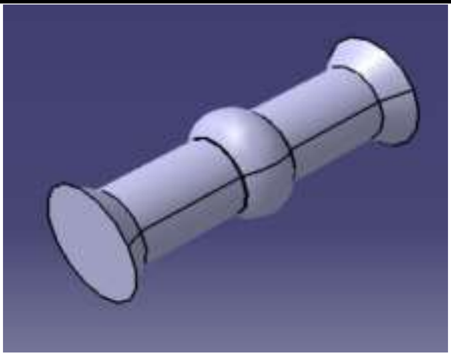

Fig 7: Ball Joint

4. Bracket

1. Battery Pack Mounting
Brackets play a crucial role in securing the battery pack to the vehicle's chassis. They ensure the battery remains stable during dynamic driving conditions, such as acceleration, braking, and cornering. The design of these brackets helps absorb vibrations and impacts, protecting the battery from damage.
2. Motor and Drivetrain Support
Brackets are essential for holding the electric motor, transmission, and other drivetrain components securely. They help align these parts for efficient power transfer, contributing to overall vehicle performance.
3. Cooling System Mounting
Cooling systems, including radiators, heat exchangers, and fans, are mounted using brackets. These systems are vital for keeping the motor and battery within optimal operating temperatures, preventing overheating and maintaining efficiency.
4. Electronic Component Housing
Various control modules, inverters, and chargers within the EV are secured by brackets. These components are insulated and kept in place to prevent damage and ensure reliable operation.

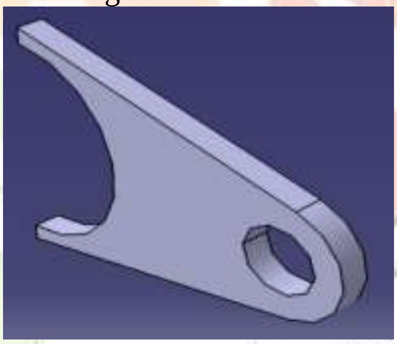

Fig 7: Bracket

5. Suspension

1. Battery Weight Management
EVs feature heavy, low-mounted battery packs that require suspension systems capable of supporting the added mass without compromising the vehicle's ride quality. To handle this extra weight, reinforced components or adaptive suspensions are often employed.
2. Instant Torque Handling
Electric motors provide instant torque, which can result in abrupt weight transfer. The suspension system is carefully tuned to minimize wheel spin and maintain traction, enhancing stability during acceleration.
3. Enhanced Ride Comfort
With EVs being quieter than traditional vehicles, the ride comfort becomes more noticeable. To improve the passenger experience, advanced suspension systems, such as multi-link or air suspension, are used to ensure a smoother ride.
4. Regenerative Braking Dynamics
During regenerative braking, the suspension must accommodate shifts in weight, maintaining vehicle stability and preventing issues such as nosediving. This ensures smoother and safer braking performance.
5. Energy Efficiency
Optimized suspension systems help reduce rolling resistance and ensure even tire wear, contributing to improved energy efficiency and a greater driving range for the vehicle
.

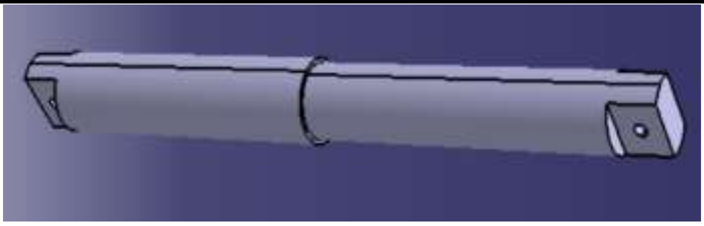

Fig 8: Suspension

6. **Hub**

1. Location

Hub motors are mounted directly inside the wheel hub, and can be located in the front, rear, or all wheels, depending on the design (in-wheel motors).

2. Direct Drive

These motors operate by driving the wheel directly, eliminating the need for traditional drivetrain components such as axles and gearboxes. This simplification enhances the overall efficiency and reduces mechanical complexity.

3. Compact Design

With their compact structure, hub motors save valuable space within the vehicle, streamlining the mechanical design and making them ideal for space-constrained EV configurations.

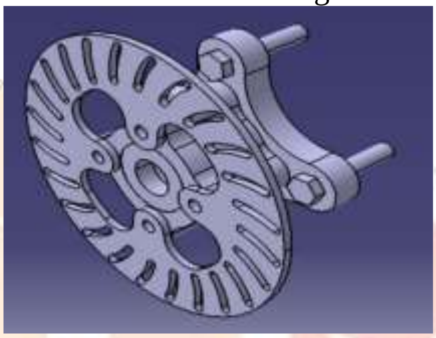

Fig 9 : Hub

7. **Knuckle**

1. Wheel Hub Connection

The knuckle securely holds the wheel hub and bearings, allowing the wheels to rotate smoothly.

2. Steering Control

It serves as the connection point for the steering components, such as the tie rods, enabling the wheels to turn as the driver steers.

3. Suspension Integration

The knuckle links the suspension system components (such as control arms, struts, or shocks) to the wheel, allowing for vertical movement that helps absorb road shocks and improve ride comfort.

4. Brake Mounting

The knuckle also provides the mounting point for the brake caliper or drum, ensuring efficient braking action when the system is engaged.

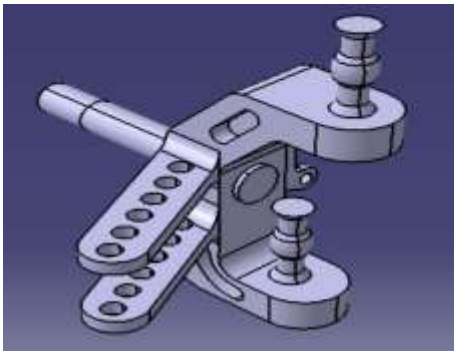

Fig 7 : Knuckle

8. **Rack And Pinion**

1. Efficient Steering

The rack and pinion system offers precise control of wheel alignment with minimal play or backlash, providing smooth and responsive steering, ideal for EVs.

2. Compact Design

This steering mechanism is compact and can be easily integrated into the vehicle's architecture, making it ideal for space optimization in electric vehicles.

3. Low Maintenance

With fewer components compared to other steering systems (like recirculating ball mechanisms), the rack and pinion requires less maintenance, offering enhanced durability over time.

Fig 7 : Rack & Pinion

- **Chassis Of Vehicle**

The chassis serves as the main structural framework of a vehicle, providing essential support for components such as the body, engine, and wheels. It ensures the stability and safety of the vehicle during operation. Utilizing advanced software like CATIA (Computer-Aided Three-Dimensional Interactive Application) during the design process allows for precise modeling and optimization, ensuring that the chassis meets the required performance and safety standards efficiently.

Line Diagram Of Vehicle :

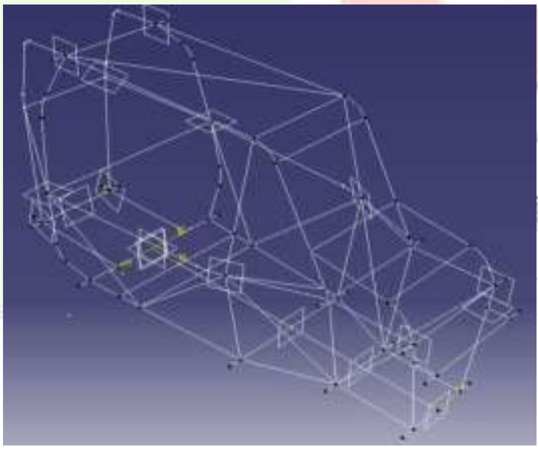

Fig 8 : Line Diagram Of Vehicle

Tubular Roll-cage of Vehicle

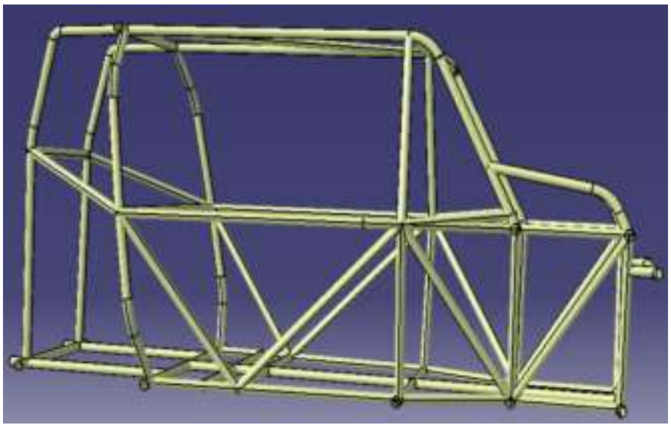

Fig 9 : Tubular Roll-cage of Vehicle

Tubular Roll-cage of Vehicle With Material:

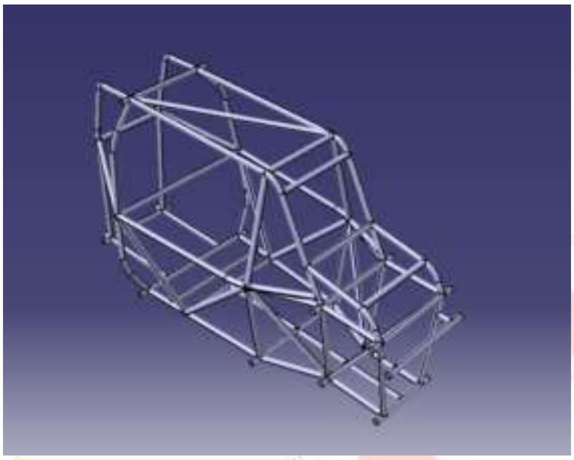

Fig 10: Tubular Roll-cage of Vehicle With Material

Roll-cage with Material :

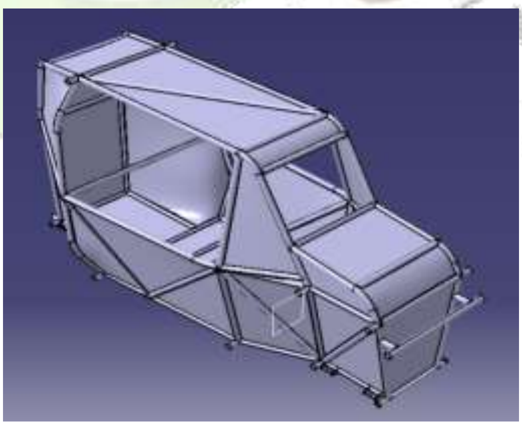

Fig 10: Roll-cage with Material

VI. MATLAB

The speed-torque characteristics of a motor define the relationship between its rotational speed (RPM) and the torque it produces (Nm). These characteristics are crucial for evaluating motor performance and are particularly important in applications like electric vehicles (EVs) and industrial automation. Understanding the speed-torque relationship helps in optimizing motor efficiency, selecting the right motor for specific tasks, and achieving the desired performance under varying load conditions.

Three-Phase Inverter:

A three-phase inverter is essential for controlling the speed-torque characteristics of a PMSM. In systems like MATLAB Simulink, the inverter works with advanced control strategies such as Field-Oriented Control (FOC) or Direct Torque Control (DTC). These strategies adjust the motor's performance, regulating speed, torque, and efficiency, thereby allowing the motor to operate optimally across different operating conditions.

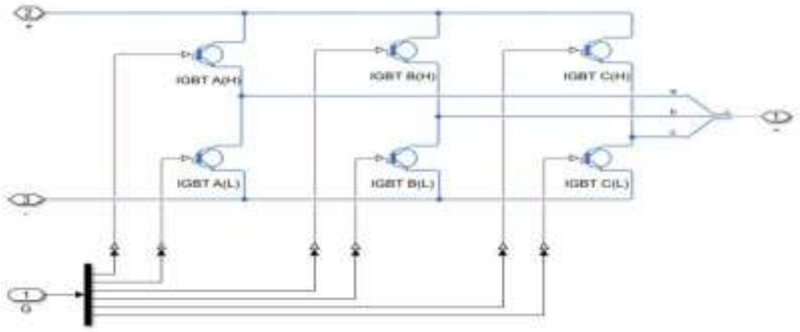

Fig 11 : Three Phase Inverter

Signals :

In the simulation of speed-torque characteristics for a Permanent Magnet Synchronous Motor (PMSM) using MATLAB/Simulink, various key signals are utilized to assess the motor's performance. These signals provide essential data to understand how the motor behaves under different conditions, including speed, torque, current, voltage, and flux. By analyzing these signals, engineers can optimize motor control strategies, identify performance limitations, and ensure efficient operation in real-world applications.

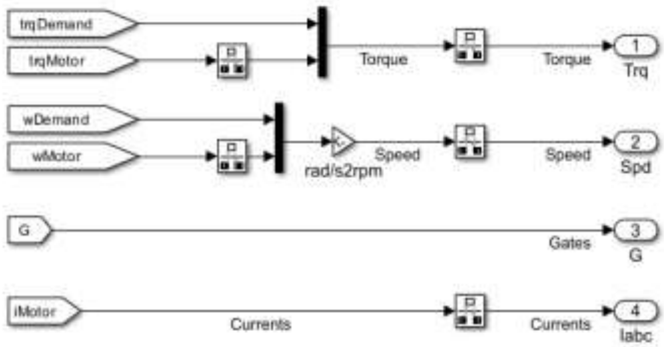

Fig 12 : Signals

Encoder

An encoder is an essential component in electric motor systems, providing real-time feedback on the rotor's position and speed. This feedback is vital for ensuring accurate motor control, particularly when employing advanced control methods such as Field-Oriented Control (FOC) or vector control. By continuously monitoring the rotor's movement, the encoder helps adjust the motor's performance, enabling precise synchronization and efficient operation.

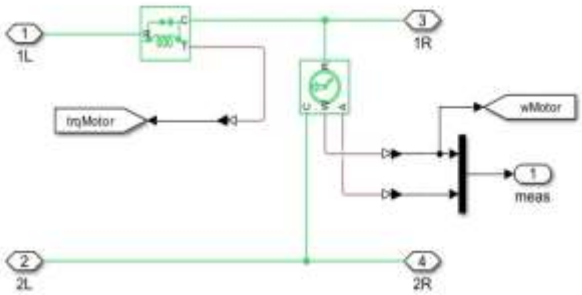

Fig 13: Encoder

Speed Torque Characteristics (MATLAB)

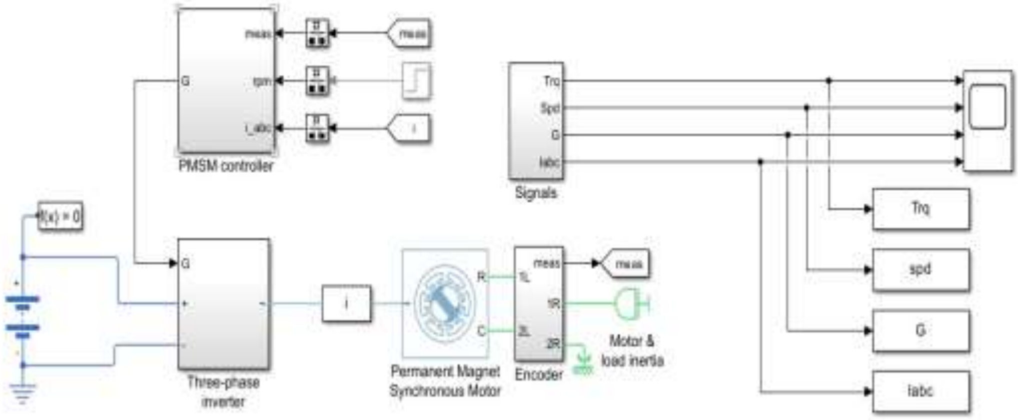

Fig 14: Speed Torque Characteristics

VII. IPG Car-Maker

Fig 15: Data Set

In vehicle kinematics, suspension parameters play a crucial role in determining the vehicle's behavior. The translation along the x, y, and z axes (tx, ty, tz) influences key dimensions such as wheelbase and track width. The rotational parameters around the x, y, and z axes (rx, ry, rz) affect critical angles like camber, caster, and toe. Additionally, deflection parameters represent the variation in lengths, which can alter the suspension's behavior under different loads and driving conditions. These factors collectively define the vehicle's dynamic performance and handling characteristics.

Weight of the vehicle

Sr No.	Parts Of the Vehicle	Weight
1.	Roll cage	30
2.	Hub,Knuckle	6
3.	Motor,Gearbox, Mounting	30
4.	Battery	38
5.	Wishbone	7
6.	Wheels	32
7.	Steering	6
8.	Drive Shaft	4
9.	seat	3.5
10.	Fasteners	7
11.	Controller	3
12.	Pivot and ball joint	2
13.	suspensions	12
14.	Break assembly	15
15.	safety kit	8
16.	Total	230

Fig 16: Weight Of the Weight

VIII. Results

1. CATIA Simulation Results

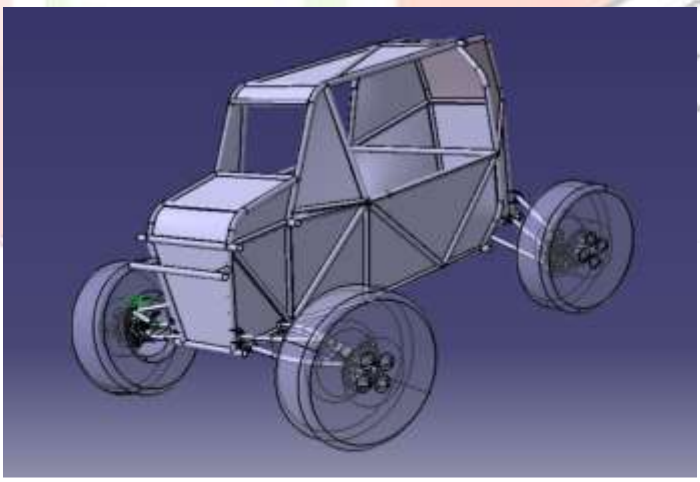

Fig 17: Designed Electric Vehicle

2. **MATLAB Simulink Result**

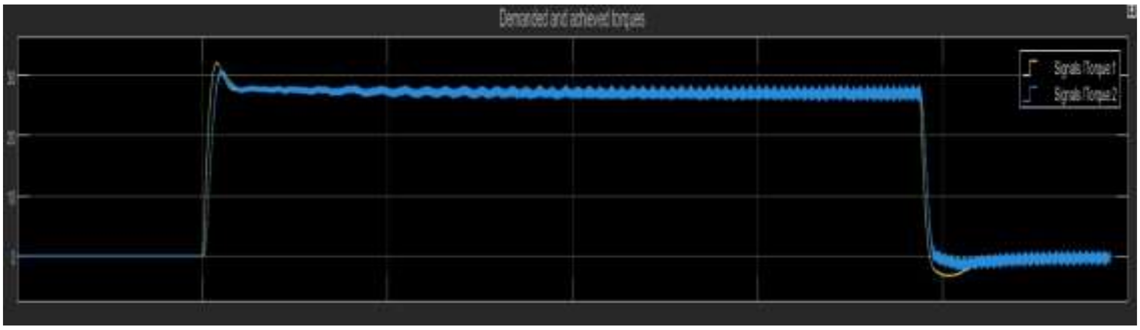

Fig 18: Torque Characteristics

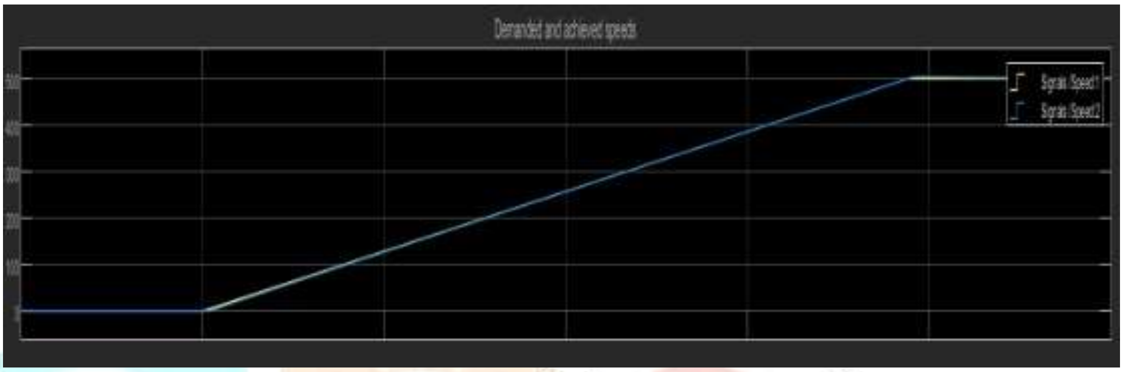

Fig 19: Speed Characteristics

Constant Torque Region: At low speeds, the motor can maintain a constant torque, primarily determined by the stator current. In this region, the motor operates below its rated or base speed, and the available voltage is limited. Torque increases directly with the stator current, meaning the more current supplied, the more torque the motor generates.

Constant Power Region: As the motor's speed increases, the back electromotive force (back EMF), which is generated by the motor itself, rises. This increase in back EMF reduces the motor's ability to generate torque. To maintain constant power output, the torque must decrease as speed increases. In this region, while power remains constant, the reduction in torque occurs as speed continues to rise.

3. IPG Result :

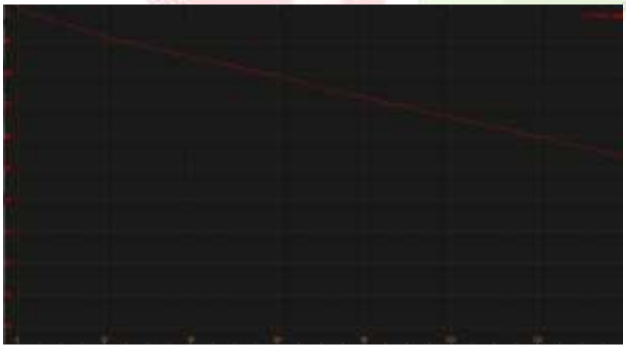

Fig 20: SOC Characteristics

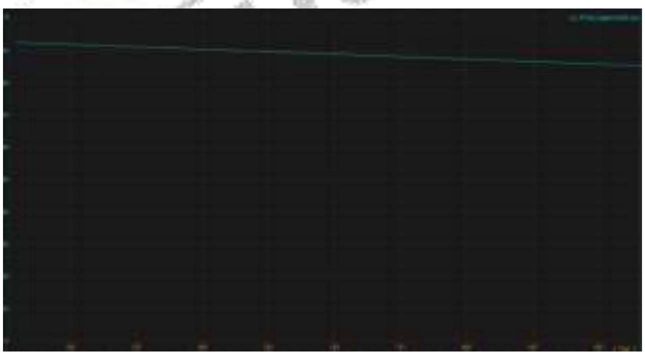

Fig 21: SOH

Characteristics

Fig 21: Temperature Characteristics

IX. Conclusion

This project successfully designed and optimized an electric vehicle (EV) using CATIA for the design phase and IPG CarMaker for simulation. MATLAB was utilized to analyze the EV's speed-torque characteristics, which played a key role in refining the vehicle's overall performance. Key conclusions drawn from the project include:

1.Design Optimization: Through iterative design adjustments in CATIA, the vehicle's aerodynamics and structural integrity were improved, resulting in reduced drag and enhanced overall efficiency.

2.Simulation Results: Using IPG CarMaker, the vehicle's performance was evaluated under race track conditions. Key performance metrics such as acceleration, energy consumption, and handling were examined, leading to optimized suspension and drivetrain configurations that balance high-speed performance with safety.

3.Speed-Torque Characteristics: The analysis conducted with MATLAB allowed for precise tuning of the motor and transmission system, ensuring efficient torque delivery across various speeds while maintaining energy efficiency and meeting performance targets.

In summary, this project effectively combined design, simulation, and performance analysis to create a well-rounded electric vehicle model. It lays a solid foundation for further research and development in the field of electric mobility. The approaches used in this project have the potential for application in real-world automotive development, advancing the future of sustainable vehicle design.

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