Grenze International Journal of Engineering and Technology, June Issue

Design and Development of a Hybrid Electric Vehicle with Dual Drive System

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***Abstract*— This study focuses on the design and construction of a hybrid electric vehicle (HEV) having a dual drive system. Such a system incorporates the benefits of both internal combustion engines and electric propulsion. The underlying objective of such a system is to improve fuel economy and reduce emissions while enhancing the overall performance of the vehicle. In such a system, the two sources of propulsion (an internal combustion engine and electric hub motors) are connected in parallel. The internal combustion engine is connected to the vehicle's wheels mechanically, while the hub motors are powered by a lithium-ion battery. Central to the system is a vehicle control unit (VCU), which regulates both sources of power. The VCU is designed to determine the most efficient method of propulsion in order to reduce energy expenditures on the vehicle. The combined use of a battery management system, engine controller, and motor controller creates the seamless transition between power modes, as well as enhanced reliability and reduced energy expenditures. This dual drive configuration enables the vehicle to operate in electric mode for low-speed urban driving, while allowing the vehicle to switch to, or combine, engine power for driving at higher speeds and for longer distances. The project promotes cleaner transportation through hybrid vehicle design to sustain mobility.**

***Keywords*— Hybrid Electric Vehicle (HEV), Electric Vehicles (EV), Internal Combustion Engine (ICE), Fuel Cell Vehicles (FCV), vehicle control unit (VCU).**

I. INTRODUCTION

This section provides a brief overview of the design and development of a hybrid electric vehicle with a dual drive system, combined with different concepts necessary to understand the core of the project, a literature survey along with its results, and finally specifying the goals of the proposed system [1]. The negative effects of fossil fuel consumption and greenhouse gas emissions, especially climate change and air pollution, have resulted in a global shift to cleaner and sustainable modes of transport. In this regard, electric and hybrid vehicles have the potential to be more environmentally friendly compared to vehicles with internal combustion engines (ICEs). Battery electric vehicles (BEVs) have no emissions at the tailpipe. However, the global adoption of BEVs is stalled due to limited driving ranges, lengthy charging times and technological difficulties, charge and discharge of batteries and the lack/poor charging infrastructure in many emerging economies, including India. As a compromise solution, hybrid electric vehicles (HEVs) are the most appropriate option to fulfill the prevailing demands of performance, eco-friendliness and operational flexibility [2].

Grenze ID: 01.GIJET.12.2.4_25

Transportation systems are very important to the entire world today. Most of them use of vehicles that have internal combustion engine (ICE). Using the ICE have caused and continuously cause serious problems, such as air pollution, global warming, and the rapid depletion of the Earth's petroleum resources. Electric vehicles (EV), hybrid electric vehicles (HEV), and fuel cell vehicles (FCV) are the three typical vehicles that are proposed to replace conventional vehicles with ICE. The performance of EV and fuel cell vehicle is far behind the requirement. Thus advanced vehicle technology research has been turned to focus on HEVs. A hybrid vehicle is a vehicle that stores energy on board in two or more forms. In a typical hybrid electric vehicle one form is gasoline with an engine as a fuel converter. The other is a bidirectional electrical storage device. By use of energy storage, there are several different ways that hybrid electric vehicles reduce fuel consumption; recover energy during braking, downsizing of the engine, operating engine more efficiency, and shutting the engine off when it is not moving [3]. This literature involves the design and development of a hybrid electric vehicle that employs a dual power train architecture. The front wheel is driven by a hub motor, which operates using energy stored in a battery pack. The rear wheel is powered by a belt-driven internal combustion (IC) engine, forming a hybrid configuration. The belt-driven mechanism simplifies the transmission system and reduces mechanical losses compared to traditional gear-based systems. This configuration allows the vehicle to operate in electric mode, engine mode, or a hybrid mode, depending on driving conditions, energy requirements, and system availability.

The vehicle optimally manages its power sources through a manual or automatic selector that switches between electric and engine propulsion. For instance, during typical driving operations within a city environment, the hub motor allows the vehicle to run quietly and without emitting any exhaust. If the State of Charge (SOC) of the battery falls below a preset level, the Internal Combustion (IC) engine is started. The alternator, which is connected to the rear wheel through a belt, electrically powers the vehicle and charges the battery simultaneously. On the other hand, if the IC engine has insufficient fuel, the vehicle operates in electric mode to ensure functionality. This intelligent system optimally manages the vehicle's energy in the most effective and reliable manner, even under the most uncertain conditions.

In addition, the IC engine and hub motor can operate simultaneously, or in a combined mode, to provide higher levels of torque and/or power to the vehicle for operations like climbing hills or when rapid acceleration is required, or when the vehicle is heavily loaded. This combined mode facilitates hybrid synergy that ultimately offers enhanced vehicle performance. The engine is further supplemented by its alternator to provide the required charging of the battery to the vehicle, while simultaneously assisting the vehicle in reducing its dependency on external battery charging by optimally capturing regenerative braking energy.

The hybrid architecture of the vehicle offers the additional benefit of significantly reducing the vehicle's carbon dioxide (CO2) and nitrogen oxides (NOx) emissions. Due to the Hub motor's application in the urban areas, especially in the frequent stop and go traffic conditions, the vehicle's noise levels and emissions are reduced to almost zero, since the Internal Combustion (IC) engine is idle and consuming fuel.

This configuration is both economical and modular. It makes use of readily available parts such as hub motors, small IC engines, and belt-pulley sets. Given the modular design, the system's ability to cross different terrains, and the independence of a charging source, it is particularly applicable to semi-urban and rural areas where both electric and fuel supplies are erratic. This is shown in the example of hybrid electric vehicles (HEV) [5] in Figure-1.The vehicle optimally manages its power sources through a manual or automatic selector that switches between electric and engine propulsion. For instance, during typical driving operations within a city environment, the hub motor allows the vehicle to run quietly and without emitting any exhaust. If the State of Charge (SOC) of the battery falls below a preset level, the Internal Combustion (IC) engine is started. The alternator, which is connected to the rear wheel through a belt, electrically powers the vehicle and charges the battery simultaneously. On the other hand, if the IC engine has insufficient fuel, the vehicle operates in electric mode to ensure functionality. This intelligent system optimally manages the vehicle's energy in the most effective and reliable manner, even under the most uncertain conditions.

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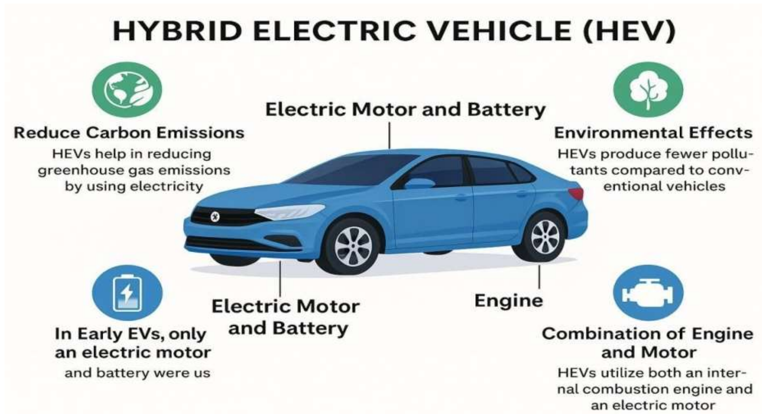

Fig. 1: Hybrid electric vehicle

II. Problem Statement

The popularity of electric vehicles (EVs) on the market is a result of the increased focus on alternative and sustainable means of urban transportation. However, conventional battery EVs (BEVs) are still expensive, have a limited driving range, long dwell times to charge, and are completely dependent on electric energy sources. Because of this, their use is especially problematic in rural areas where there is sparse, if any, charging infrastructure.
On the opposite side of the spectrum, internal combustion engine (ICE) vehicles contribute to the degradation of the environment. Therefore, it is imperative to have a unique, hybrid solution that utilizes features of both electric and IC engine technologies to address the aforementioned problems and improve sustainability.
This project intends to fill an existing research gap by creating an economical hybrid electric vehicle (HEV) consisting of a hub motor in the front wheel and a belt-driven internal combustion (IC) engine in the back wheel. Depending on the drive conditions, a selector switch provides the option to use either the IC engine or the hub motor. Along with the IC engine, an alternator, which is also connected to the rear wheel via a belt drive, serves to replenish the battery. The use of this hybrid combination results in a vehicle that operates consistently, is low in emissions and fuel consumption, and has the flexibility to cope with different driving situations.

III. Objectives and Scope

- To reduce carbon emissions and promote environmentally friendly transportation solutions.
- To design a hybrid electric vehicle (HEV) that combines an internal combustion engine and an electric motor for flexible operation.
- To use a hub motor for front wheel drive, enabling clean and efficient electric propulsion.
- To implement a belt-driven IC engine for rear wheel drive, ensuring mechanical simplicity and cost effectiveness.
- To develop a selector switch system that allows manual or automatic switching between engine and motor based on operating conditions.
- To ensure continuous vehicle operation even when fuel or battery levels are low by intelligently managing power sources.
- To integratean alternatorcoupled to the rearwheelvia beltto rechargethe battery during engine operation.
- To achieve cost efficiency by using simple, easily available automotive components.
- To provide are liable and adaptable hybrid vehicle suitable for both urban and rural environments.

- ➢ To contribute to the reduction of CO_2 emissions compared to conventional and fully electric vehicles by using power sources efficiently.

IV. DESIGN

An introduction of the various electronic components used in this project is discussed in this section. The basic working principle and specification of the hardware used in this project are provided.

A. List of Components

- ➢ Engine Specification: 110cc VS 124cc
- ➢ Hub motor
- ➢ Battery specification

Engine Specification: 110cc Vs 124cc

Figure-2 shows the 4-stroke internal combustion (IC) engine operates on a cycle consisting of four distinct strokes: intake, compression, power, and exhaust. These four strokes occur over two revolutions of the crankshaft. During the intake stroke, the piston moves downward, drawing in a mixture of air and fuel (in petrol engines) or only air (in diesel engines). In the compression stroke, the piston moves upward, compressing the mixture. This is followed by the power stroke, where combustion of the compressed mixture (ignited by a spark plug or fuel injection) pushes the piston downward, and generating power. Finally, during the exhaust stroke, the burnt gases are expelled from the cylinder as the piston moves upward again [6]-[7].

Table-1 shows engine type is widely used in automobiles, motorcycles, generators, and small machinery due to its efficiency and durability. Although the design of a 4-stroke engine is more complex and heavier than a 2-stroke engine, it possesses advantages in fuel economy, operation smoothness, and emissions. The main components include the cylinder, piston, crankshaft, camshaft, valves, and either a spark plug (in petrol engines) or fuel injector (in diesel engines). Its balanced performance and cleaner combustion make it a preferred choice for most modern vehicles.

Figure-2: Four-stroke engine

TABLE I: FOUR-STROKE ENGINE

Parameter	110cc Engine	124cc Engine
Engine Type	4-Stroke, SIEngine	4-Stroke, SIEngine
Displacement	109.51cc	124 cc
Cooling System	Air-Cooled	Fan-Cooled
Fuel Supply	Fuel Injection	Carbureted
Max Power	7.88bhp/5.88kW@8000rpm	8.29bhp/6.10kW@6500 rpm
Max Torque	9.05Nm@5500rpm	10.3 Nm@ 5000 rpm
Transmission	Automatic (V-Matic)	Manual

Hub-Motor

An example of a hub motor is shown in Figure-3. A hub motor is an electric motor that is built into the hub of a wheel. They are often used in electric bicycles, scooters, and some light-weight electric cars. Hub motors are used to provide power directly to the wheel, and therefore, do not require any chains or belts. There are two different types of hub motors. The first type is gearless (direct drive), and the second type is geared. Gearless hub motors tend to be very simple and durable, while geared hub motors are lighter and have better torque in low speeds. These types of motors tend to be quieter, very compact, and have a low need for maintenance. Hub motors do not usually have a significant negative impact on handling, but do tend to increase un-sprung weight. However, they are very reliable, very efficient, and easy to build into different types of transportation. They are very common in personal use transportation and urban transportation. Hub motor specifications are listed in Table-2 [8]-[9].

Figure-3: Hub-motor

TABLE II: HUB-MOTOR

Parameter	Specification
Rated Power	1500W (1.5 kW)*2
Power (Horsepower)	≈2.01 hp*2
Voltage	48V*2
Rated Current	31.25A
Speed Range (RPM)	5000–6500 rpm
Wheel Size	10 inches

Battery Specification

Figure-4 presents a 48V lithium-ion battery. This rechargeable battery is commonly found in electric vehicles such as e-bikes, scooters, and rickshaws, as well as in solar energy systems, back-up power systems, and others. Its construction involves multiple lithium-ion cells connected in series and subsequently in parallel. Offering a nominal voltage of 48 volts, this battery strikes a balance among power, efficiency, and size. Compared to traditional lead-acid batteries, these batteries provide an excellent choice in terms of high energy density, long module cycle life, low weight, and rapid charging. The capacity of 48V lithium-ion batteries is typically in the range of 10Ah to 20Ah and greater. The length of time for which the battery may power the device or vehicle is determined by its capacity. Safety of the battery is ensured by a Battery Management System (BMS) integrated into the battery, which monitors and controls the voltage and charging and discharging current of the battery to protect it from over voltage condition and damage. Due to these benefits, 48V lithium-ion batteries are becoming the standard in the energy storage and electric mobility field [10]-[11].

Fig-4: Battery

Total Motor Power
Each motor:1.5kW
Total: 1.5 kW×2 = 3.0 kW (3000W)
Voltage
Motorsare48V→Sobatterysystemshouldremain48V
Current Requirement
Each motordraws≈31.25A
Totalcurrent: 31.25A× 2 = 62.5 A

TABLE III: BATTERY SPECIFICATION

Parameter	Range
Battery Type	Lithium-ion
Nominal Voltage	48V
Capacity	60Ah (minimum)
Energy	2880Wh(48V× 60Ah)
Max Discharge Current	≥80A (to safely support 62.5 A load)
Charging Voltage	54.6V
Charging Current	6–10A (recommended)
Battery Weight	~12–15kg (depending on build)
Life cycle	1000–2000 charge cycles
Estimated Range	~50–80 km per charge (depends on usage)

V. METHODOLOGY

A. Block Diagram of Proposed System

Figure 5 shows the block diagram of the proposed system and shows the design and development of a hybrid electric vehicle (HEV) having a dual drive system where the vehicle is driven by an Internal Combustion (IC) engine and electric hub motors. The IC engine has been connected to a mechanical transmission system to give conventional drive to the wheels. Moreover, an alternator is coupled with the engine to convert some of the mechanical energy to electrical energy. The function of the IC engine is controlled and some information is sent to the Vehicle Control Unit (VCU) through the Engine Control Unit (ECU). The VCU is the main controller for managing the control and coordination among the various subsystems.

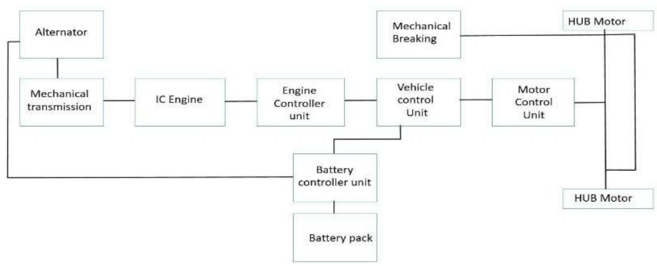

Figure 5: Block Diagram of Proposed System

A 48V lithium-ion battery pack generally supplies electrical drive to the vehicle and is controlled and managed by the Battery Control Unit (BCU). The BCU manages the charge and discharge cycle of the battery and thus maintains the safety and performance of the battery. The Battery Power is utilized by the Motor Control Unit (MCU) to drive the Hub motors. Hub motors are mounted on the wheels and are designed to be operated independently or in conjunction with the IC engine. The vehicle is equipped with mechanical braking to achieve complete stopping capability in all scenarios.

The dual drive hybrid system has an enhanced operational capacity that permits the system to run as an engine only, run as an electric drive only, or run using both drives as a hybrid system. Advantages of the system include improved fuel economy, lowered emissions, regenerative braking, and improved ride quality system. Inclusion of both electric and mechanical drives considerably increases the adaptability of the vehicle for both urban and highway applications making it more efficient for urban mobility and transportation with reduced energy consumption.

Step1: Concept Design and Vehicle Layout

This hybrid electric vehicle (HEV) concept integrates both an electric drive train and an internal combustion engine (ICE). The concept allows the vehicle to change between a fully electric vehicle (EV) and a fully ICE drive vehicle depending on the state of charge of the battery or the fuel level, thereby allowing the vehicle to have a greater range and enabling the vehicle to be more versatile. The front wheels are powered by hub (wheel) motors while the rear wheels are powered by a belt drive coupled to an internal combustion engine (ICE).

Step2: Chassis Design

Each of the major components is housed in a custom tubular chassis, which ensures appropriate safety and weight distribution. More space is allocated on the chassis design for safety and weight considerations for both of the power trains of the vehicle. Design of the chassis considers the mounting points for the engine, battery pack, alternator, motor controller, and wiring harness.

Step3: Calculations for Component Selection
The design of the vehicle has been aided by key calculations performed to determine the required power, and the required vehicle capacity which drives the selection of appropriate battery capacitance and system voltage. These calculations also determine the appropriate motor rating, as well as, the power and control systems, based on the anticipated vehicle performance.
Step4: Component Selection
The calculations made it clear which components were critical, which in this case were two 1500W (1.5kW) hub motors, an 110cc/124cc 4-stroke internal combustion engine (IC engine), a 48V 60Ah lithium-ion battery, an alternator, and controllers for both power sources. A drive mode control selector switch is also chosen.
Step5: Simulation of Controllers and Switching Action
Before implementation, it is necessary to simulate the engine controller, motor controller, and selector logic. These simulations help validate the switching action when interacting with the engine control and electric control modes under several conditions (e.g. low battery, low fuel, and/or increase in required vehicle acceleration).
Step6: Material Selection for Chassis
Some of the materials selected for Chassis fabrication were mild steel and chromoly steel. These materials were selected for their strength, weight, and price. These were also selected for their ease of fabrication, which is necessary for the production of brackets to hold the battery, the enclosure for the battery, and the engine supports.
Step7: Chassis Fabrication
Based on the designs in CAD, the Chassis was physically fabricated. A frame was formed by cutting and bending steel and welding along the necessary mounting points to help support structural integrity.
Step8: Component Assembly
The hub motors, engine, battery pack, alternator, motor controller, ECU, and switchgear were systematically mounted on the designed chassis. Alignment, especially for the belt drive that connects the engine to the rear wheel, was prioritized to encourage mechanical efficiency.
Step9: Engine Controller Development
Ignition timing, throttle inputs, Start/Stop control for the engine and the alternator were incorporated into the logic of a Switch with Hybrid Control. The control unit was built from scratch to manage the aforementioned functions.
Step10: Motor Controller Development
The software for the Motor Controller can be developed knowing that the controller will respond to the position of the throttle and the state of the battery and the selector switch. The controller has built-in safety features for overcurrent and overheating.
Step11: Engine Testing
The engine is tested independently with the ECU using the start and throttle controls and the belt drive and alternator. Tests confirm the alternator is functioning to charge and that performance is smooth with the engine integrated to the vehicle.
Step12: Motor Testing
When tested, each hub motor responds to commands for acceleration and braking when operating under load. The controller's response to each motor is tested at several levels of supplied voltage and current.
Step13: Hybrid Integration and Control Logic
The power from both sources is integrated, and a control algorithm allows both sources to be used simultaneously in a controlled manner.
Step14: Hybrid Mode Testing with Selector Switch
Testing confirms the engine starts when the battery is low; the motor operates when fuel is low, and all happens when in the Auto mode setting.
Step15: Final Road Testing and Validation
Testing with all intended passengers and cargo confirms the vehicle operates securely, controls switchable power sources as intended, and allows for an external engine alternator to recharge the battery.

VI. Work Flow

The workflow for designing and developing a hybrid electric vehicle is systematic. The first step in this method is the conceptual step, where the core problem is defined. Current electric vehicles have limits such as a short driving range and internal combustion engines have environmental drawbacks, which is where the proposal comes in. This proposal advocates for a hybrid where an electric hub motor drives the front wheels and a belt

driven IC engine drives the rear wheels. The addition of an IC engine equipped with an alternator to charge the onboard batteries provides energy autonomy.
Once the concept is finalized, the next step is the design phase. In this step, schematic designs and CAD models of the vehicle and the vehicle's chassis are drawn. At this time, calculations for the power and torque are done to aid in the selection of components that are appropriate and adequate. Load capability, the wattage of the motor, the battery and the engine's fuel, and the battery's voltage and capacity, are some of the important things that need to be considered in this phase.
The next step is to select components and materials where the adequate hardware is chosen based on the calculations. Some of the selected components are hub motors (1.5kW, 48V), an IC engine (110cc or 124cc), a 48V 60Ah battery, a compatible alternator, motor controllers and engine controllers, and a switching interface. The chassis material, which is either mild steel or chromyl, is also chosen to be a material that is durable and strong.
In the development of simulation and control processes, certain scenarios can be simulated like triggering motor functions when fuel levels are low, or switching to engine mode when the battery's state of charge is low. Logic control for both the motor and engine are designed and assessed in simulation environments. This allows for the control of power usage for safety and efficiency during actual use of the system.
When all control strategies have been validated, the system is ready for physical implementation. The first step of the fabrication process is manufacturing the chassis as designed in the CAD (Computer Aided Design) files. Tubes are cut to the lengths specified in the design and welded to create the chassis frame with the designed in mounting provisions for the engine, battery pack, alternator, and other components.
The assembly process involves the mounting of all major electromechanical components to the chassis. The engine, alternator and battery components are mounted to the rear of the chassis with the battery components mounted under the chassis. The Engine mounted components, the Controllers, Wiring Harnesses and Sensors facilitate the control and communication of the system.
The vehicle is then readied for the testing phase. The Engine is tested to determine if it starts as designed, drives the rear of the chassis, and charges the battery through the alternator. Each of the Hub Motors are tested to determine their ability to accept a throttle input and drive the system. The switching logic and selector switch are tested to determine if the logic is functional and operates as designed.
The final validation of the vehicle occurs following the successful completion of subsystem testing. This involves road testing the vehicle in a range of real world scenarios, including urban traffic, road gradients, and conditions of depleted battery and fuel levels, in order to assess the vehicle's performance, reliability, and safety. Engineering changes are made, if needed, to improve the vehicle capabilities. The documentation stage consolidates all engineering drawings and system dynamic behavior and performance data to a comprehensive final project report and presentation. This document, along with the system built, substantiates the realization of the goal to design and develop a hybrid vehicle system that is safe, reliable, and pollution free.

VII. IC ENGINE CONTROLLER BLOCK DIAGRAM

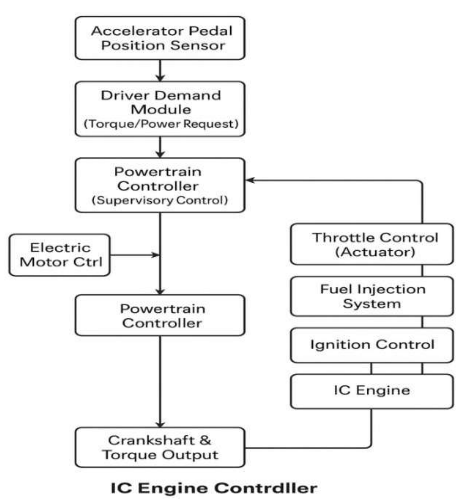

Figure-6: IC Engine controller

Figure-6 shows the IC engine controller in a hybrid electric vehicle (HEV) with a dual electric drive system begins with the accelerator pedal position sensor, whichdetects how much the driver presses the pedal andconverts this into an electrical signal. This signal is sent to the driver demand module, which interprets the input as a specific torque or power request. The request is then passed to the powertrain controller, which acts as the supervisory control unit. It evaluates various parameters such as battery level, vehicle speed, load conditions, and drive mode to decide how to distribute the power demand between the internal combustion engine and the electric motor.

If the electric motor is to be used, the electric motor control unit is activated to deliver the required torque through the hub motors. Simultaneously, if the IC engine needs to contribute power, the power train controller sends signals to the throttle control actuator, which adjusts the air intake, and to the fuel injection system, which injects the proper amount of fuel into the combustion chamber. The ignition control unit is responsible for the combustion cycle timing for the spark plugs and fuel injectors in the case of diesel engines. The output of the combustion event in the internal combustion engine is then transferred to the crankshaft in the form of torque. This mechanical energy output results in the propulsion of the vehicle, either by itself or in conjunction with the electric propulsion system. This hybrid propulsion system ensures an optimized fuel economy and vehicle performance in a seamless transition between the electric and internal combustion engine propulsion modes.

VIII. Motor Controller Simulationin Matlab

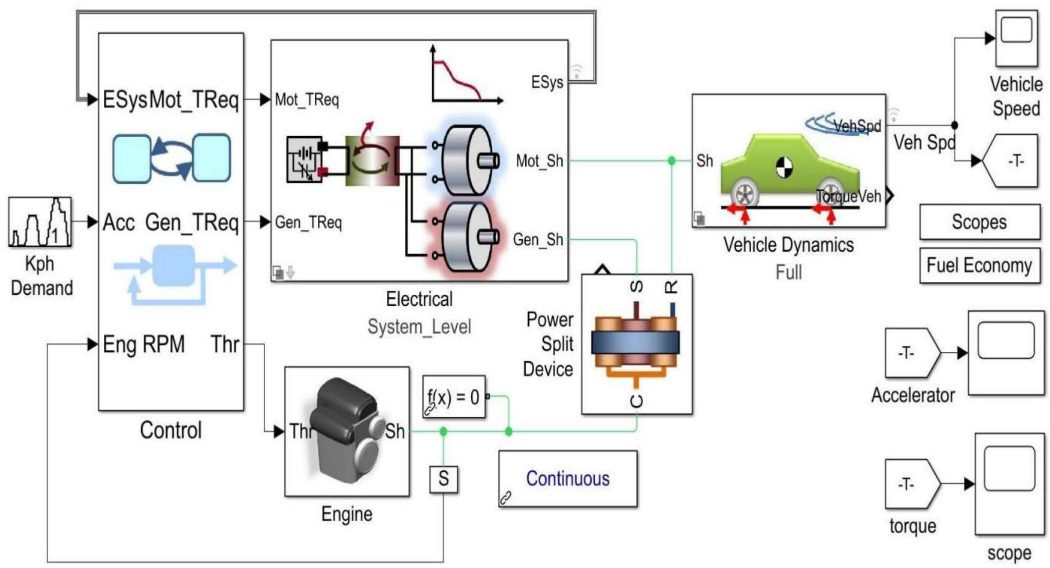

Figure: 7 motor controller simulation

Figure 7 shows a hybrid vehicle with a series-parallel power train architecture. The model of the vehicle includes both the electric and the mechanical components of hybrid propulsion. The model is also capable of simulating the dynamics of the vehicle, the interaction of the various components of control, and the various demands of a driver.

Starting from the left, the block marked “Kph Demand” represents the driver's demand for speed. This input, along with other inputs, is sent to the Control Block. The Control Block then outputs several key parameters including but not limited to Motor Torque Request (Mot_T Req), Generator Torque Request (Gen_T Req), Engine RPM, and Throttle Command (Thr). The Control Block then sends these parameters to the respective subsystems for actuation of the engine, motor, and generator.

In the Electrical System Level block, the model shows how the Electric Motor and Generator provide torque to the respective motor and generator to meet their demands. The propulsion torque delivered to the wheels by the motor flows through the mechanical shaft (Mot_Sh). The generator provides torque to charge the battery or provide propulsion to the motor, depending on the needs of the system at that time. This subsystem also shows the electrical power flow E Sys, and the torque flow to and from the engine, generator, and motor.

The Power Split Device, as indicated, is a critical component in series-parallel hybrids. It enables the division of the engine's torque for driving the wheels (mechanical propulsion) and for generating electricity through the generator. It uses a planetary gear set or similar mechanisms to link the engine (S), motor (R), and generator (C). This device makes it possible to integrate the use of both electric power and combustion power to provide continuous and efficient use of fuel.
The Vehicle Dynamics Full Block models the total motor and engine torque and how it moves the vehicle. It accepts shaft torque and generates vehicle speed (Veh Spd) and wheel torque (Torque Veh). This helps us examine the behavior of the power train in response to the different phases of driving (e.g. acceleration, steady cruising, and deceleration).
The output blocks (e.g. Vehicle Speed, Fuel Economy, Accelerator, and Torque Scopes) represent the system's instantaneous performance. The scopes are instrumental in evaluating vehicle performance and determining appropriate control strategies to minimize emissions and fuel consumption. This model creates a powerful, hybrid electric power train simulation for proof of concept and systems analysis.

IX. Sub System of Control

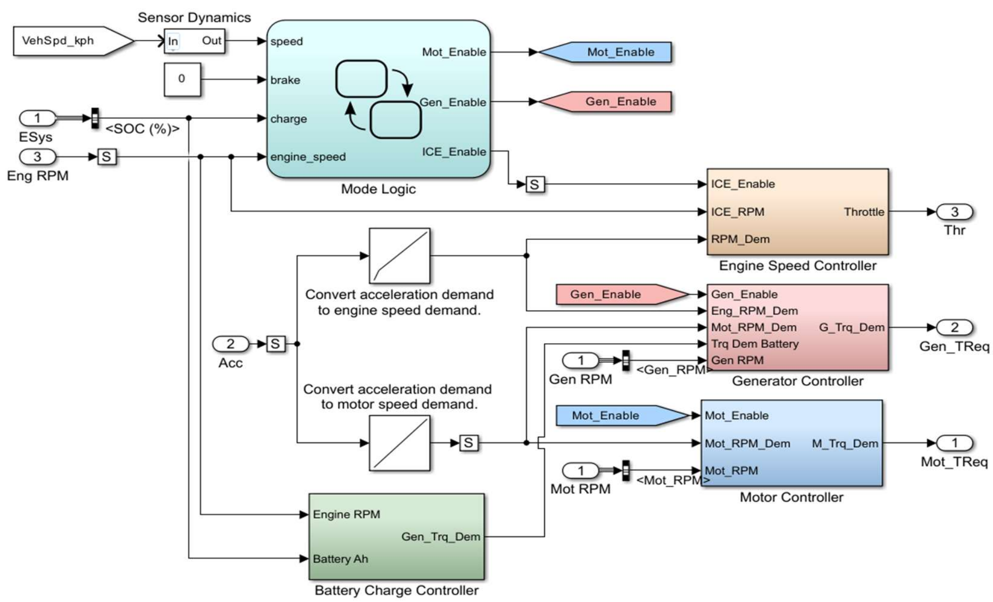

Fig-8: control subsystem

A. Sensor Dynamics

Figure 7 provides an abstraction of the Vehicle speed (Veh Spd_kph) signal at the control block and transforms it to an internal control signal within the block. This speed control signal, combined with the state of charge (SOC), engine RPM (Eng RPM) of the vehicle, helps determine the operating modes within the control scheme.

B. Mode Logic

The Mode Logic control block within the control scheme of the system allows the vehicle to operate in a certain manner depending on the vehicle speed, the status of the stop (brake) control, SOC, and engine speed. From these conditions of the vehicle, the block sends enable signals (Mot_Enable, Gen_Enable, ICE_Enable) to the motor, generator, and internal combustion engine (ICE). This ensures that, based on the operating mode of the vehicle (electrical, hybrid, charging, etc.), the appropriate source of power is made operational.

C. Engine Speed Controller

The block executes its function upon receiving the ICE enable signal with the desired RPM (RPM_Dem) and subsequently derives a throttle command (Thr) to the ICE. By this means, it regulates the ICE to effectively translate the driving demand by delivering the required ICE power.

D. Generator Controller

The Generator Controller dictates the operation of the generator. The controller is fed with a generator enable signal, speed command of the engine and the motor, battery torque command, actual generator RPM, and from these decides the generator torque (Gen_TReq) to be operated in the battery charging mode or in the provision of service auxiliary power mode.

E. Motor Controller

This block controls the operation of the motor. Upon enabling (Mot_Enable) the motor, it uses desired RPM and present RPM to determine the motor torque demand (Mot_TReq). This provides effective and responsive propulsion of the system.

F. Acceleration Demand Conversion

The driver's acceleration command (Acc) is processed by two distinct blocks, generating two separate speed requests: one for the engine and the other for the motor. This design allows for the division of labor among the power sources, thus optimizing the system's performance and efficiency.

G. Battery Charge Controller

This controller is responsible for maintaining the battery's energy at a healthy state. It handles the battery's state of charge by monitoring the battery's ampere-hour (Ah) data and the engine's RPM. It then calculates the required torque from the generator (Gen_Trq_Dem) to either reduce or maintain the battery's SOC, thus preventing the battery from degrading.

H. Summing Junctions (S)

Summation blocks (labeled S) have been incorporated in the diagram to combine several inputs: acceleration, SOC, and RPMs, among others. These blocks are used to consolidate several signals for the purpose of making decisions regarding mode selection, demand, distribution of RPMs, and torque.

X. MODE LOGIC

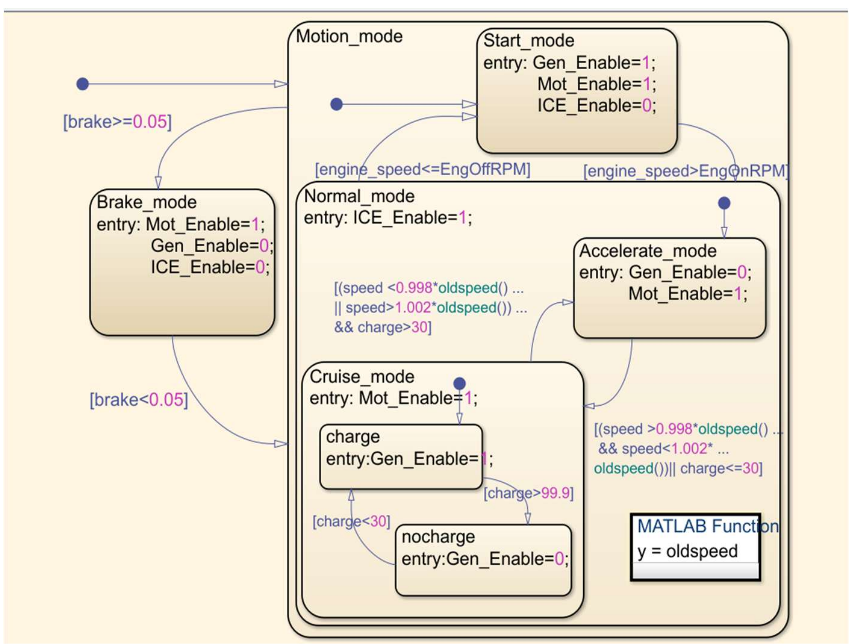

Fig-9: Mode Logic

In this chapter, Figure-9 shows the Mode Logic for this hybrid electric vehicle control system. The Mode Logic is designed to operate the system in the most appropriate mode by using real-time system data including brake input, engine and vehicle speed, and battery state of charge (SOC). The Motion_mode is the first of the control system operating modes. This mode incorporates all the control system dynamic states. The system enters the

Brake_mode when brake input is above the threshold of brake ≥ 0.05. In this mode, the motor is allowed to operate, and the generator and internal combustion engine (ICE) are disabled (Gen_Enable = 0, ICE_Enable = 0, and Mot_Enable = 1). The vehicle then stays in this mode until the brake input is less than the threshold of brake < 0.05. The control system then enters the Motion_mode, followed by Start_mode. In Start_mode, the generator and motor are enabled to prepare the vehicle for movement, and the ICE is disabled (ICE_Enable = 0).
When engine speed exceeds a given limit (engine_speed> Eng on RPM), the system goes into Normal_mode. In this mode, the internal combustion engine is the only engine used (ICE_Enable = 1). In this operating condition, the system uses an old speed() MATLAB function to compare the current speed with a historical record. If the current speed is high, or the state of charge (SOC) is low, the system goes into the Accelerate_mode, where the motor is enabled, and the generator is disabled to allow additional torque. If SOC is sufficient and speed is not high, the system goes into Cruise_mode, where the motor is enabled (Mot_Enable = 1) and the generator is disabled. Within Cruise_mode, if SOC is less than 30%, the system goes into the Charge sub-mode, where the generator is enabled (Gen_Enable = 1) to charge the battery. If SOC is equal to or greater than 99.9%, the system goes into the No Charge sub-mode, where the generator is disabled (Gen_Enable = 0) to not take away from the system. This mode logic is designed to optimize system performance, while balancing energy consumption and battery health.

XI. Vehicle Dynamic Full

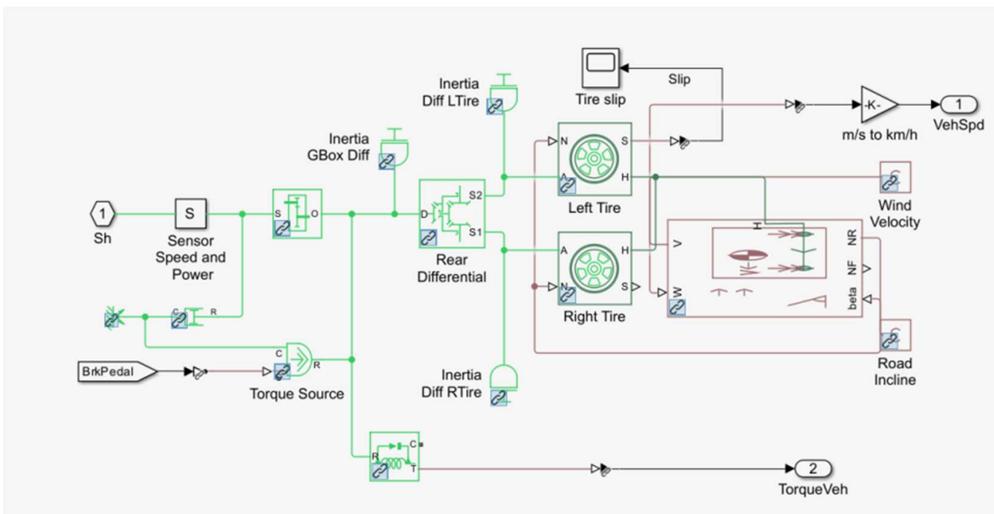

Fig-10: Vehicle Dynamics

Figure-10 in the appendix shows the configuration of the vehicle longitudinal dynamics model built in the Simulink environment with logical and physical interactions in a vehicle's drive train and the road environment. The system includes a Torque Source and employs throttle and brake (including Brk Pedal) signals. The generated torque is divided into driving and braking components before being driven through a number of physical system components to realize an actual vehicle response. The torque is then passed to the GBox and rear drive train (represented by the Inertia G_Box Diff block). This block is the rotational inertia of the gearbox output shaft and is important to model the delays and responses of the drive train.
The torque is then passed to the Rear Differential which passes it to the left and right wheels. The differential has a logic system for torque split and mechanical loss which passes torque to inertia blocks for the left and right tires—Inertia Diff LTire and Inertia Diff RTire—representing the rotating masses of the tires. These blocks are important to model the angular acceleration and losses of dynamics of the wheels. Connected to these are the Left Tire and Right Tire subsystems which model tire-ground interactions and perform calculations for tractive forces, slips, and rotational speeds. The output of the tire subsystems contributes to the total longitudinal force to move the vehicle.
In a Tire Slip detection subsystem, slip is calculated by measuring the relative motion between the wheel speed and vehicle speed. This data is vital to traction control, the Anti-lock Braking System (ABS), and other related vehicle control systems. The Sensor Speed and Power block receives shaft (Sh) inputs and calculates the

mechanical power and rotational speeds, which are subsequently fed back into the system. These values greatly assist the system in formulating and managing the dynamic torque and energy of the system.
Wind velocity and the incline of the road, which create a resistive effect on the vehicle, are also incorporated into the model. These are shown as vectors that illustrate the wind and the angle of incline (beta). When combined, resistive and propulsive forces are applied to a vehicle body subsystem that simulates longitudinal acceleration of the vehicle and outputs its velocity in both m/s and km/h (Veh Spd).
At the output port labeled Torque Veh, the total amount of torque generated or demanded by the vehicle is captured. This data can be used for feedback into control logic or be analyzed to study the vehicle's performance. This model is especially useful for the simulation of the power train, validation of control strategies, and the testing of energy efficiency of hybrid and electric vehicles because it captures the intrinsic mechanical and external control dynamics of a real-world vehicle, even under a variety of different conditions.
RESULT: Simulation Output:

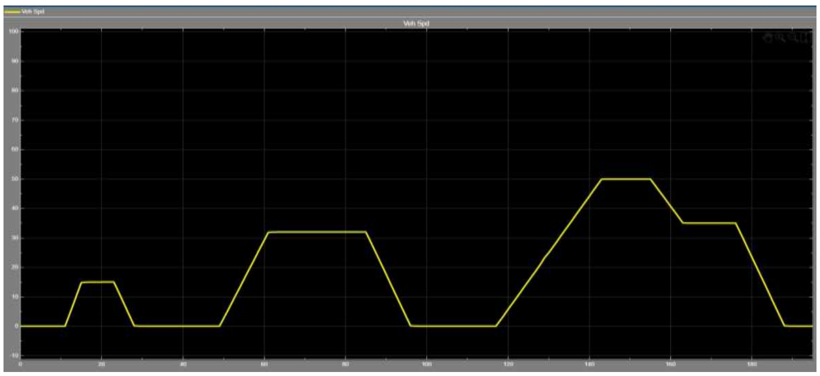

Figure-11: vehicle speed

Figure-11 shows the vehicle speed (in km/h) plotted over time, displayed as a step-like yellow waveform. This indicates the vehicle's response to speed demand throughout the test cycle. The waveform begins at a low speed of approximately 10 km/h, briefly rises to 25 km/h, and then holds steady before declining. This indicates the vehicle has decelerated and/or is in an idle state. Between 60 and 61 seconds, the speed of the vehicle increases sharply to 60 km/h and then holds steady for a brief period. From approximately 70 to 80 km/h, the waveform represents step-wise increases and a subsequent step-wise decrease. The waveform represents the typical driving cycle of a vehicle, which includes the acceleration, cruising, and deceleration phases. The dual-drive system represents motor control with power management, which allows the system to respond with speed demand references and maintain speed with minimal fluctuation. This is evident by the rapid and stepless increase of the vehicle's speed and the temporary step-wise decrease

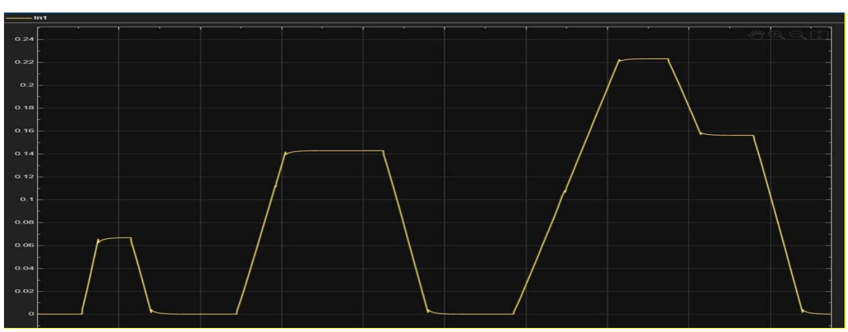

Figure-12: Acceleration

Control input signal from the accelerator pedal between 0 and 0.24 (normalized) is presented in Figure-12. It is directly related to the speed signal since it corresponds to the driver's demand. In the beginning, the signal has a small positive slope that corresponds to the small positive slope of the speed signal. A positive slope from the signal is observed in the 0.11 to 0.13 range in the 60 km/h speed region, indicating the intent of the driver to further accelerate. After a complete release of the pedal, the signal is decreased to near 0, and the driver's demand for acceleration is shown by a significant increase of the signal value during the 2nd speed signal ramp. This waveform shows that the control system correctly interprets the driver's intent and transforms it into commands for traction. The zero-level sections of the signal correspond to the coasting and braking and are observed to have a good correlation to the timing of the speed signal.

Figure-13: Engine torque

Figure-13 depicts variations in engine torque. There is a significant degree of variability in the waveform reflecting the requirements. The ICE (Internal Combustion Engine) is engaged based on the requirements of the vehicle and the selected mode of the hybrid. During the initial phase of ICE engagement, during acceleration from a stationary position, there are a number of spikes recorded, exceeding 200 Nm. This is likely the high demand for torque to overcome a resisting force when driving from rest (the inertia of the whole vehicle) and/or when driving on an incline. During latter sections of driving, in a steady state condition, the spikes were followed by a relatively constant value of torque, with a number of spikes recorded at 0 Nm, and in some instances, carrying negative values. This may mean that the ICE was turned off or that the vehicle was in a condition of constant motion and the system was operating in regenerative braking. In higher phases, of up to 25 m/s and greater, there were a number of spikes indicating demand for high acceleration which was surging. The requirement of torque for deceleration and the surging stopped when the vehicle was in a stopped condition. A series of surges and a relatively constant demand are characteristics of a series-parallel hybrid configuration of a vehicle.

XII. CONCLUSION

Design and Development of a Hybrid Electric Vehicle with Dual Drive System" is the title of the project. The project created the base of knowledge and skills required for the development of hybrid vehicles. Some of the important outcomes of the project include the design of a custom chassis, the simulation of a motor controller in MATLAB, the design of an IC engine controller, and the selection and specification of a hub motor, a lithium ion battery, and an IC engine. The planned structure and the design of the control systems were aligned, and the proposed dual drive of a hub motor shaft in the front, and a belt driven IC engine in the rear, was integrated. The design for the control systems was also integrated.

The motor controller simulation showed that power can be supplied to the hub motors based on throttle and battery conditions. The simulation validated the logic of having smooth acceleration and safety features to protect against over current. The control flow within the IC engine controller is illustrated in the integration diagram. It manages the throttle, ignition, and fuel injection control in accord with the vehicle control unit (VCU). The finalized component specifications of the motors, batteries, and engines were selected based on performance calculations and conditions of the applications, ensuring safety and effectiveness of the system.

Physical integration and testing were not part of the current phase, but the project builds a base for a functioning hybrid vehicle from the conceptual and simulation foundations. The results of the chassis design, simulation, and the control design and architecture provide the base for the integration of the control design, the fabrication, and the testing in the next development phases.

ACKNOWLEDGMENTS

Iwould like to express our sincere gratitude to Department of Electrical and Electronics Engineering, SJCE, JSS Science and Technology University for providing us with the necessary resources and environment for conducting this study. Special thanks to our team for their dedicated contributions and collaborative efforts throughout this literature survey.

REFERENCE

[1] Sendhilnathan A, Smart Hybrid Electric Vehicle, IEEE, Dr. N.G.P Institute of Technology, 2017.
[2] Dr. K. V. Vidyanandan, Overview of Electric and Hybrid Vehicles, Power Management Institute, NTPC Ltd.
[3] Vasudo Virulkar, Modelling and Simulation of Electric and Hybrid Electric Vehicle, Government College of Engineering, Amravati, 2020.
[4] M. Viswanath, A Literature Review on Hybrid Electric Vehicles, Hindusthan Institute of Technology, Coimbatore, 2018.
[5] C. Ellers, "The Evolution and Design of an Operational Hybrid/Electric Drive System," SAE Technical Paper 901530, 1990.
[6] I. Soliman, F. U. Syed, and M. Yamazaki, "Control of Electric to Parallel Hybrid Drive Transition in a Dual- Drive Hybrid Power train," SAE Technical Paper 2010- 01- 0819, 2010.
[7] D. H. Kim and Y. Park, "Modeling and Design of Hybrid Control System for Dual Hybrid Electric Vehicle Drive trains," SAE Technical Paper 2000- 05- 0046, 2000.
[8] Atriya Biswas et al., "A review of the design process of energy management systems fordual- motor battery electric vehicles," Renewable and Sustainable Energy Reviews, Vol. 193, 2024.
[9] S. Ge, S. Hou, and M. Yao, "Electromechanical Coupling Dynamic Characteristics of the Dual- Motor Electric Drive System of Hybrid Electric Vehicles," Proceedings of the IMechE, Journal of Automobile Engineering, March 2024.
[10] Xinyang Wu et al., "Towards Optimal Energy Management Strategy for Hybrid Electric Vehicle with Reinforcement Learning," arXiv preprint, May 2023.
[11] Maryam Razi et al., "Design and Comparative Analyses of Optimal Feedback Controllers for Hybrid Electric Vehicles," arXiv preprint, April 2020