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Series-Parallel Hybrid Electric Vehicle Parameter Analysis using MATLAB

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Abstract: In this paper, a MATLAB based Simulink model of a Series-Parallel Hybrid Electric Vehicle is presented. With the advent of Industry 4.0, the usage of Big Data, Machine Learning, Internet of Things, Artificial Intelligence, and similar ground-breaking domains of technology have usurped manual supervision in industrial as well as personal scenarios. This is aided by the drastic shift from orthodox and conventional Internal Combustion Engine based vehicles fuelled by fossil fuels in the order of petrol, diesel, etc., to fully functional electric vehicles developed by renowned companies, for example Tesla. Alongside 100% electric vehicles are hybrid vehicles that function on a system based on the integration of the conventional ICE and the modern Electric Propulsion System, which is referred to as the Hybrid Vehicle Drivetrain. Designs for modern HEVs and EVs are developed on computer software where simulations are run and all the essential parameters for the vehicle's performance and sustainability are run and observed. This paper is articulated to discuss the parameters of a series-parallel HEV through an in-depth MATLAB Simulink design, and further the observations are presented.
Keywords: ICE (Internal Combustion Engine), HEV (Hybrid Electric Vehicle), Drivetrain, MATLAB, Simulink, PSD (Power Split Device), Vehicle Dynamics, SOC (State-of-Charge)

I. INTRODUCTION

Hybrid Electric Vehicles are developed by the combination of the conventional Internal Combustion Engine, and a modern fully Electric Propulsion System. Unlike Plug-in HEVs, the process of recharging of the battery is carried out primarily and solely by regenerative braking in HEVs, and the electric powertrain hence is integrated with the system to increase the vehicle performance and achieve better fuel economy. With sources of fuel depleting all over the world, the presence of HEVs and EVs is gradually incrementing on the roads, with leading automobile companies like Toyota, Volkswagen, BMW, etc., developing state of the art, modern vehicles with commendable auxiliary functions, alongside bewildering performance with respect to conventional vehicles.

In a HEV, optimization methodologies like dynamic programming are utilised to monitor fuel economy. It is a non-causal procedure that gives optimum results assisted by controllers offering the computational and memory resources [1]. Power electronics plays an essential role in the development of power converters that regulate the flow of power between the different components in the drivetrain, and allows the system to handle the electric loads from auxiliary and primary components [2]. As of recent times, alternative fuel resources are studied in order to replace fossil fuels not only to aid the depleting resources, but also due to their harmful environmental effects [3]. With power electronics and new alternative fuels being studied and prepared for operation in HEVs and EVs, it can be understood how these vehicles are the pragmatical answer for commercial super-ultra-low-emission vehicles. Power flow studies and proper emission systems are being designed to ensure the same [4].

Hence, due to their unparalleled efficiency and performance statistics, HEVs have been gaining high popularity globally, which is why incorporating and updating the existing systems with technology from Industry 4.0 is a necessity to sustain market appeal and furthermore, is essential for user interaction [5]. Multiple configurations are further discussed in the next segment, like the parallel HEV design utilised in the hybridization of Mercedes A-Class, and factors like State-of-Charge and cost-fuel consumption rates can be observed in detail by running simulations on virtual systems, hence making it rudimentary [6]. Smart Grid technologies are based on big data and IoT fundamentals, and often overseen, have a deep connection with respect to plug-in electric vehicles that include an external port which allows the battery to charge itself for commutation purposes. Interlinked with the Smart Grid, the recharging process can be completely automated and monitored at ease, while excess energy stored can be reserved for future purposes [7]. The Vehicle-to-Grid technology is based on the bi-directional flow of energy between the grid and the HEV or EV, resulting not only in superior and easier recharging processes, but also aiding the grid by peak load shaving, load levelling, etc.

With the major configurations for the HEV having their own set of pros and cons, it is imperative to understand the working and their characteristics before incorporating the drivetrain into a vehicle. Vehicles have their own requirements and limitations; hence it becomes necessary to choose between these configurations to suit the needs accordingly.

In the next section, the configurations are presented and the Series-Parallel design is discussed at length.

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II. DESIGN AND METHODOLOGY

HEVs have multiple configurations for the drivetrain, that come with their own set of pros and cons. Each of these configurations is suited for an HEV with respect to its performance and the requirements kept in consideration while the vehicle is designed. The configurations include series, parallel, series-parallel, and complex hybrid designs, that depend on their differing energy convertor source for the provision of propulsion power.

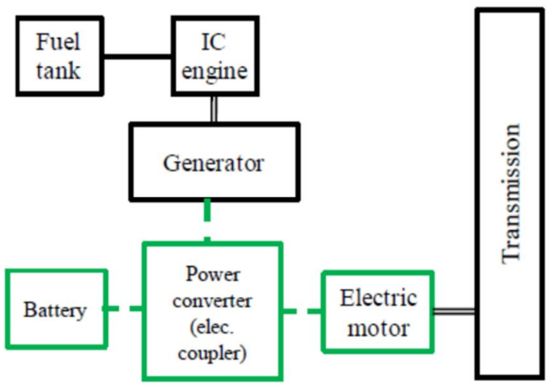

Fig. 1 Series Hybrid Drivetrain

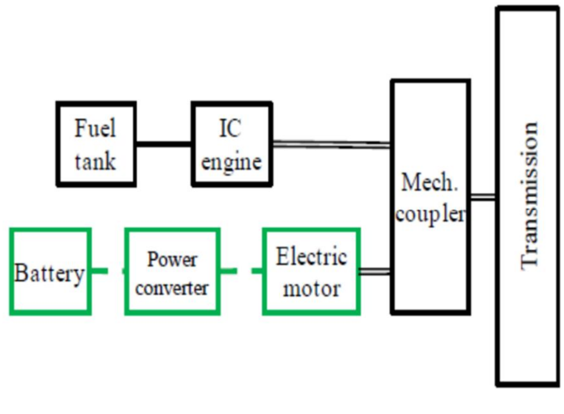

Fig. 2 Parallel Hybrid Drivetrain

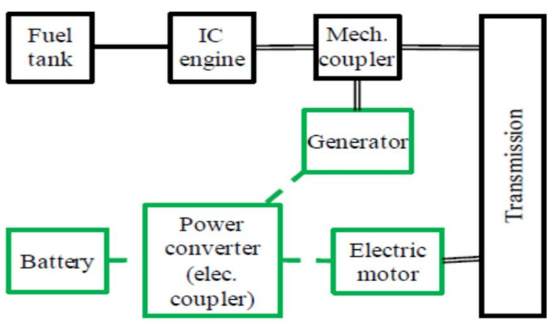

Fig. 3 Series-Parallel Hybrid Drivetrain

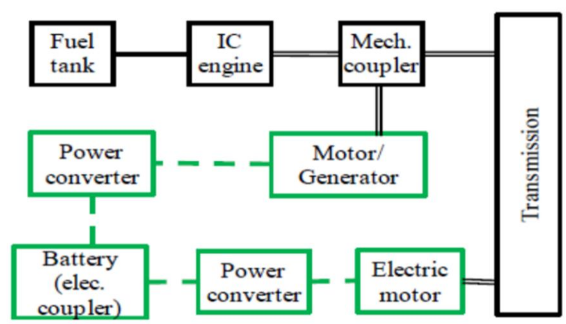

Fig. 4 Complex Hybrid Drivetrain

Fig. 1 depicts a Series Hybrid Drivetrain that utilises the coupling between the ICE and the generator, thereby allowing the system to produce electricity for propulsion, hence the ICE is the prime mover in this configuration that drives the generator to deliver power to the battery and propulsion motor. The mechanical decoupling with the wheels lets the ICE function optimally, resulting in nearly ideal torque-speed characteristics, eliminating multi-gear transmission. Although, the series configuration requires a lot of space and hence is well-suited for only heavy vehicles, for example military vehicles. In Fig. 2, it is visible how the both the ICE and motor can operate the wheels by transferring power due to the coupling of the driveshaft with two clutches. Furthermore, regenerative breaking allows the motor to act as a generator to charge the battery. It is a compact design in contrast to series drivetrain, and due to the dual power supply system, energy loss is minimum, although the complexity is high.

The Series-Parallel Drivetrain in Fig. 3 requires an electric machine and incorporates the aforementioned designs. The engine is capable to drive directly as in parallel, but upon effective disconnection the electric motor becomes the prime mover as in series. This is observed in the Toyota Prius model. With near optimum efficiency, at lower speeds the vehicle functions in series mode, while the engine takes over to decrease energy loss at high speeds. Overall performance and fuel consumption levels are optimum in this case, and the power split device integrates the ICE and the electric motor drive, allowing the user to power the car by either or both, resulting in an intelligently designed gearbox with modern technologies offering a smart user interface to manage auxiliary functions and primary functions in a facile and more efficient manner. The Complex Hybrid Drivetrain in Fig. 4 is similar to the series-parallel configuration, with a bi-directional power flow in the motor and a unidirectional flow in the generator, although deemed less efficient due to its higher complexity and the requirement of an additional power converter to regulate the flow.

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Further, the MATLAB Simulink model is discussed, consisting of 5 major components or sub-systems, including the control system, the engine design, vehicle dynamics, and the power split device. The breakdown for each of the components is discussed in the next sub-sections.

A. Control System

Fig. 5 depicts this subsystem that includes the connections between the battery charge controller that is integrated with the user handled mode logic. Using sensors and depending on vehicle and engine configuration, the control system allows user to control engine speed for throttle. The generator and motor too are controlled completely using this subsystem for acceleration conversion according to speed demand.

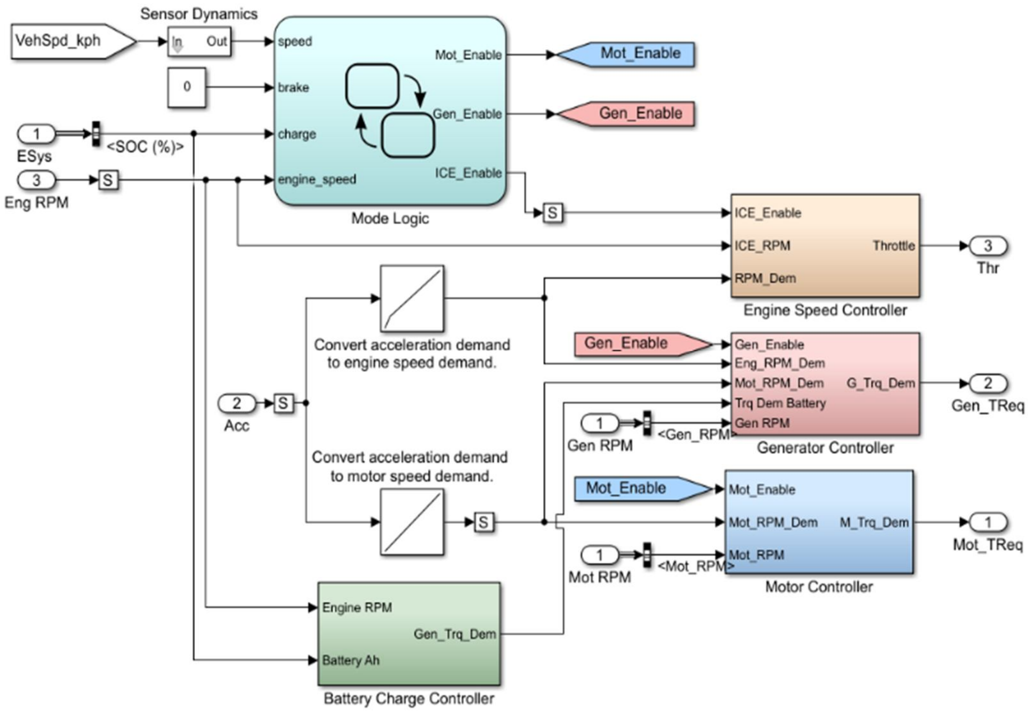

Fig. 5 Control Sub-System

B. Engine System

This includes an integration between throttle power and the engine shaft inertia. With the control system in place, the engine can be controlled according to the user's demand. This is integrated with the smart user interface that lets the user take overall manual command over the control and monitor system for the vehicle. Fig. 6 displays the same.

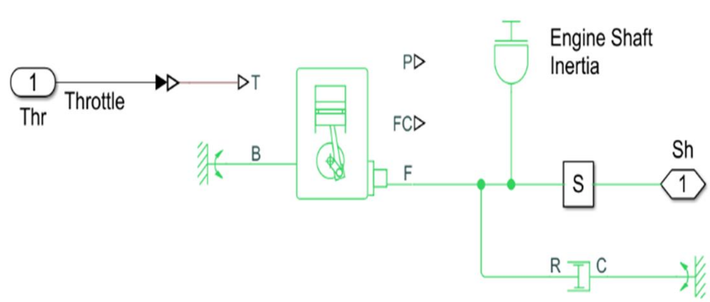

Fig. 6 Engine Sub-System

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C. Electrical System

Fig. 7 displays the system, and it is available readily in Simulink library packages and is essential for the battery system and the configuration of motor and generator requirement. The electrical propulsion system is powered by the PSD depending on user and this integration brings the motion of the vehicle.

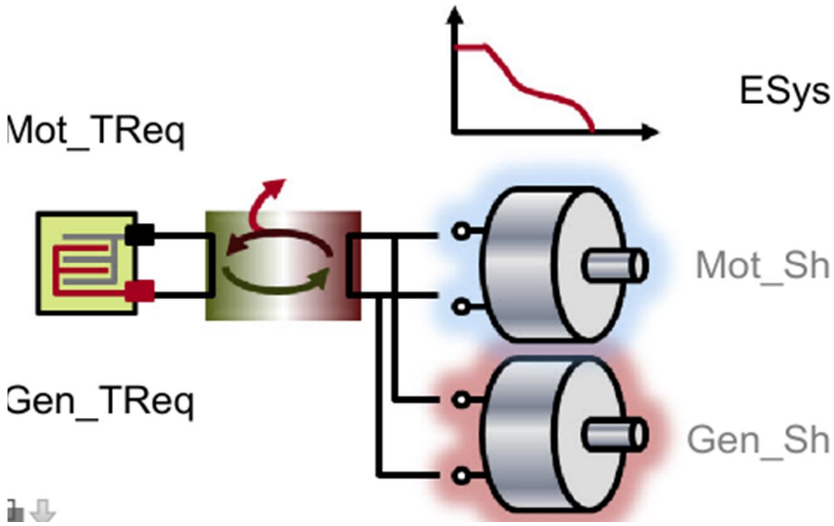

Fig. 7 Electrical Sub-System

D. Vehicle Dynamics

The vehicle dynamics shown in Fig. 8 are what define the motion of the EV when all systems are working perfectly in sync as the user requires. It has two states, one being idle and the other being in motion. The motion state as shown in the figure on the right, includes required sensors and gearboxes to define motion of each of the tire configurations. The inertia difference and tire slip are also taken in consideration, all coming from the torque source produced by the other subsystems. Further, wind velocity and road incline are taken as crucial factors for the vehicle's motion, and the unit has been converted from m/s to km/h.

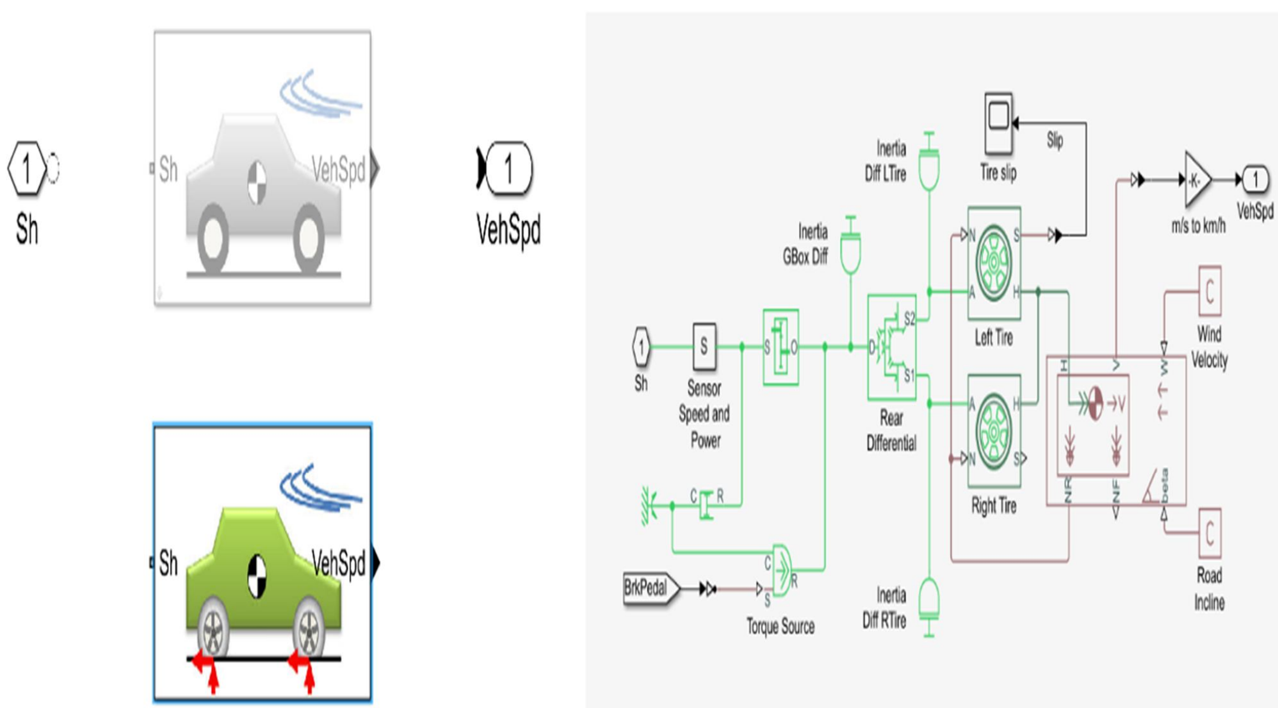

Fig. 8 Vehicle Dynamics Sub-System

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E. Power Split Device

This is one of the most important components in the EV, as the power distribution is dependent on the PSD, as shown in Fig. 9. According to user, the power is sent to the ICE or the electric drive that further drives the wheels as aforementioned. This leads to lesser energy losses, higher efficiency and better control.

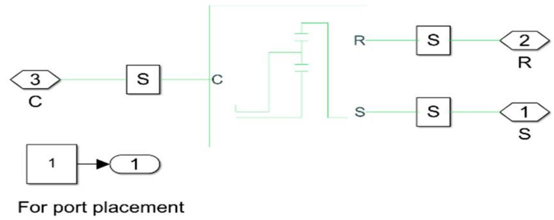

Fig. 9 PSD Sub-System

All the subsystems hence after connection, depending on the general block diagram for the series-parallel configuration, form the final Simulink model in Fig. 10. Upon simulation, graphs for vehicle speed v/s time, electrical subsystem voltages, motor and generator, and engine parameters can be visualized. Furthermore, using SSC Explore, we can also determine more intricate graphs for vehicle dynamics, sensors, etc.

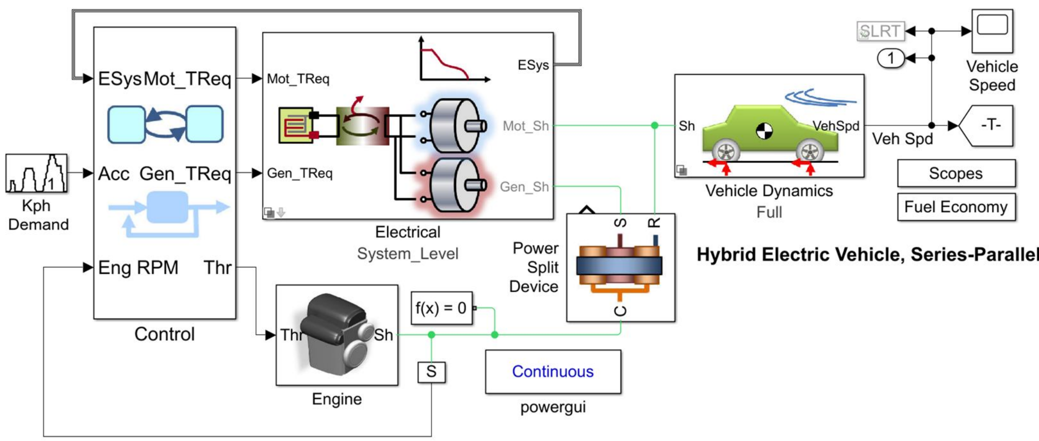

Fig. 10 Final Series-Parallel HEV Simulink model

III. RESULTS AND DISCUSSION

After running the drive cycle simulation for the design for the series/parallel EV, a number of crucial performance graphs can be visualized from the scopes and from SSC Explore. In this section, a few of the essential graphs for a vehicle from its manufacturing and test phase, with a fuel efficiency check.

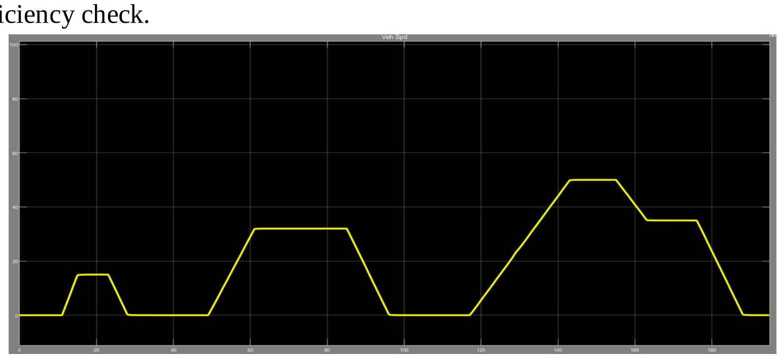

Fig. 11 Speed v/s Time

In Fig. 11, the vehicle accelerates and maintains constant speeds at different points in time as well as deaccelerates to stay in idle modes. From this drive cycle, it is observed that the vehicle reached a highest speed of 50 km/h at approximately 142 seconds in a total drive time of 200 seconds.

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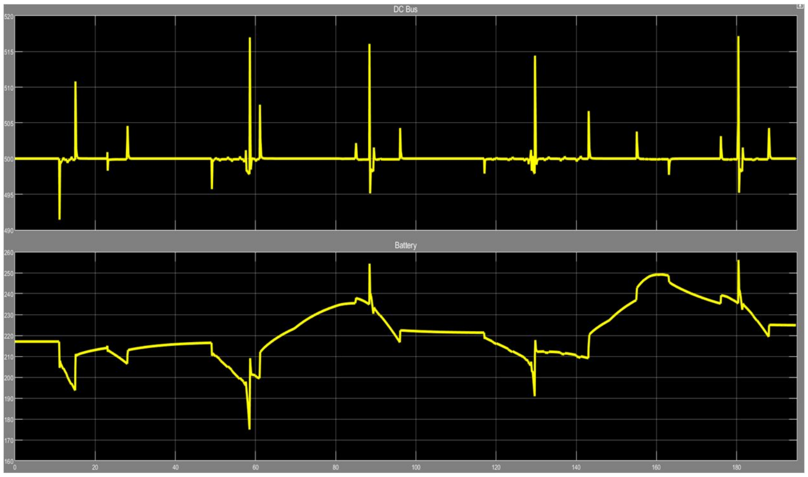

Fig. 12 Electrical Subsystem Voltages

The DC bus voltage along time and the battery voltage in ideal form give a symmetric graph throughout the cycle, maintaining constant power over torque as output. This is an ideal, desirable motion of the vehicle.

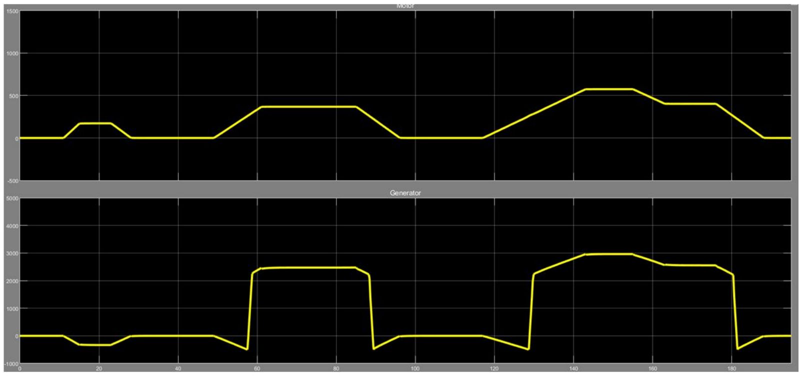

Fig. 13 Motor and Generator graphs

In correspondence to the speed characteristics, the rpm for motor and generator over time keep fluctuating as the user accelerates and deaccelerates over the entire drive cycle. At higher speeds, the motor and generator need to run at higher capacity, hence indicating the rise in rpm depicted in Fig. 13.

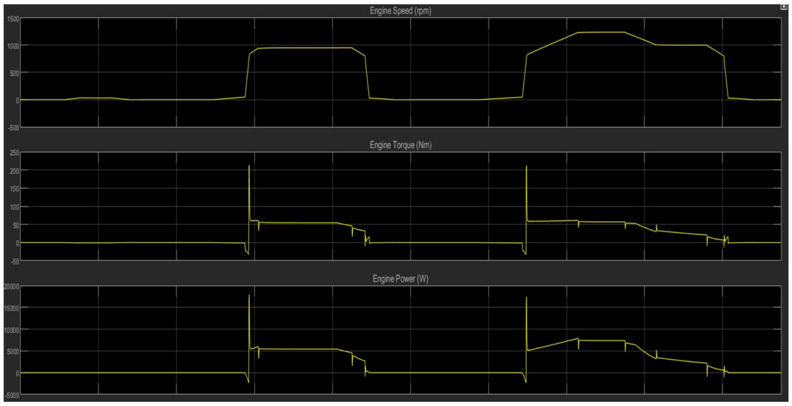

Fig. 14 Engine Parameters

This scope portrays several engine parameters, precisely Engine speed, torque and power. As this is the ideal case, all three graphs are in perfect sync as the power completely gives 100% efficiency for torque, therefore speed fluctuates according to the other factors.

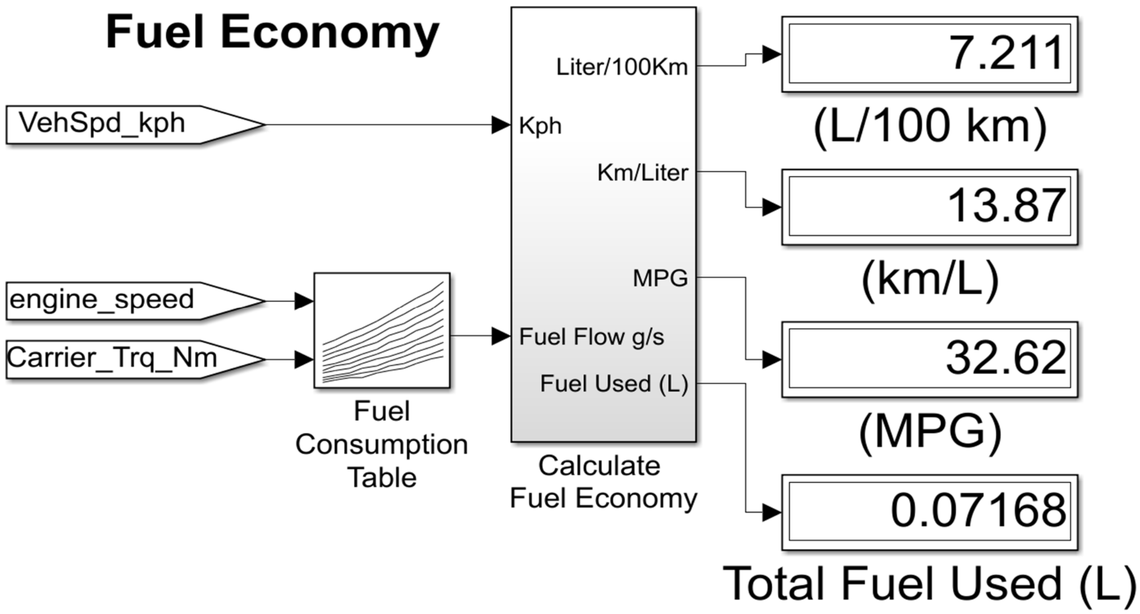

Fig. 15 Fuel Efficiency

Display scopes for the post cycle simulation show total fuel usage and other parameters by utilising the fuel consumption table and a subsystem to calculate the fuel economy over the complete cycle. Further, we can visualize many other graphs for each of the subsystems in SSCexplore. These include intricate graphs for the Control System, Engine, Power Split Device, Battery, Vehicle Dynamics and more.

Through the graphs, the characteristics of the vehicle's motion are mapped and analysed to deduce certain observations. Unlike the other configurations, i.e.; series and parallel, this utilizes an additional electric machine making the control complex. The power split divides the engine power for generator and mechanical gear system separately increasing overall efficiency. From the cycle graphs for vehicle speed characteristics, it is observed that the speed increases steadily and is constant at certain points since the time frame and motion is set to random. At approximately 140 seconds, top speed is reached in this particular cycle and then the vehicle deaccelerates. For DC bus and battery voltages, a symmetric graph is visualized indicating the expected consistency. Further, engine parameters and fuel efficiency are pictured using values calculated from the source code in MATLAB script.

IV. CONCLUSION

The simulations were run successfully and hence the results were analysed and discussed, that led to a concluding point that states multiple reasons for the series-parallel hybrid drivetrain design to be considered as an optimum and efficient system for HEVs in the long run. Aided by the new technologies developed every day, HEVs can be integrated with IoT and Machine Learning algorithms that would enhance the process of commutation and also lead to higher control and maintenance of the vehicle. The smart user interface as discussed in the previous sections, allows the user to ensure all the systems and operations functioning in the vehicle are automated, yet can be managed with his/her ultimate manual supervision. The presence of the PSD brings an integration between the ICE and the electric motor, allowing the wheels to be driven by them simultaneously, or independently. Furthermore, highly intelligent vehicles are developed at Tesla that run on voice control and are fully equipped to drive the user to their respective destination. With the reserves of fossil fuels depleting drastically on a global scale, it is essential to turn to HEVs and EVs rather than conventional vehicles, since the former are the future of worldwide transportation.

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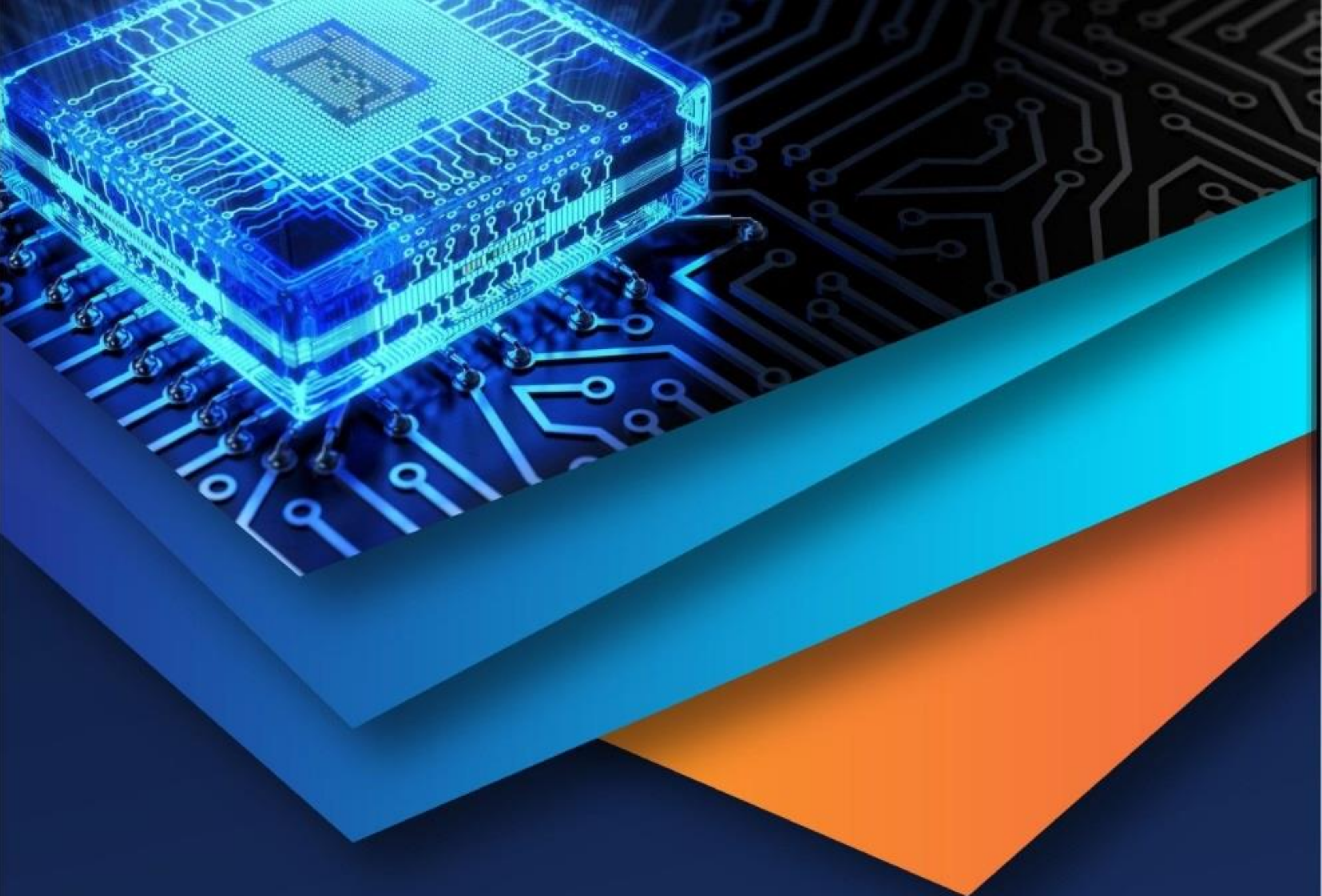

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