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Article

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Modelling and simulation of hybrid technology in vehicles

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Abstract

This study focuses on the performance results obtained from comparing two variants of naturally aspirated petrol engines to a petrol engine with hybrid electric assist using MATLAB Driveline. The comparative study analyses the power output obtained from the simulations. The new era of hybrid electric technology can provide performance comparable to naturally aspirated engines is the main focus of this paper.

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Keywords: ERS — Energy Recovery System; MGU-K — Motor Generator Unit — Kinetic; MGU-H — Motor Generator Unit — Heat; KERS — Kinetic Energy Recovery System; ES — Energy Store

1. Introduction

Increased electrification in the vehicles using battery assisted hybrid systems aids in the performance of the vehicle like K. Muta, M. Yamazaki, and J. Tokieda [1] have discussed, this is due to the use of external components in addition to the internal combustion engine to enhance the output produced, and just like in production cars, these changes are made in the name of efficiency and environmental awareness. Gao and David Wenzhong [2,3] argued that the modelling and simulation capabilities of existing tools such as Powertrain System Analysis Toolkit (PSAT), Advanced Vehicle Simulator (ADVISOR), PSIM, and Virtual Test Bed are demonstrated through application examples. Since power electronics is indispensable in hybrid vehicles, the issue of numerical oscillations in dynamic simulations involving power electronics is briefly addressed. To study the performance of the hybrid system and compare it to that of the naturally aspirated engine, simulations are made in the MATLAB Driveline software, this was inspired by the works of Rohit M [4] who has used MATLAB to simulate different vehicle parameters and test them, this report shows the different conventional performance methods and the new era of hybrid electric performance alternatives and compares the results obtained from two model simulations, being lesser in displacement the hybrid setup provides equivalent performance as that of a much larger engines. This shift to new hybrid electric technology is done to have a better impact on the environment as studied by Ojas M. Govardhan

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[5]. The work that has been done by various researchers and manufacturers is the basis of the technology that will be used for the future of hybrid research.

2. Modelling and simulation of naturally aspirated engines

The model is designed in MATLAB under the SIMSCAPE Driveline dropbox, this dropbox is accessed using the siLibraryBrowser in the Command Window. A menu will pop up on the screen, choose the desired options from the menu and start development of the model. A six cylinder engine with a cubic capacity of 3.5 L model with a generic engine whose parameters are set as below and a four cylinder engine with a cubic capacity of 2.5 L, is mated to an eight speed automatic gearbox in both models. The gearbox is connected to a differential which sends power to the wheels. Fig. 1 shows the layout of all components for the four cylinder model and similarly the model for the six cylinder is created.

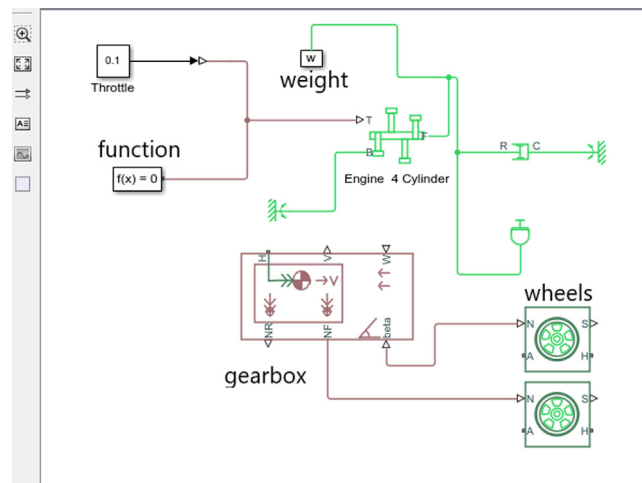


Fig. 1. Layout of four cylinder model.

The parameters in both models are set so as to simulate the vehicle under different conditions, the parameters that are set for this simulation are as follows, seen in Fig. 2

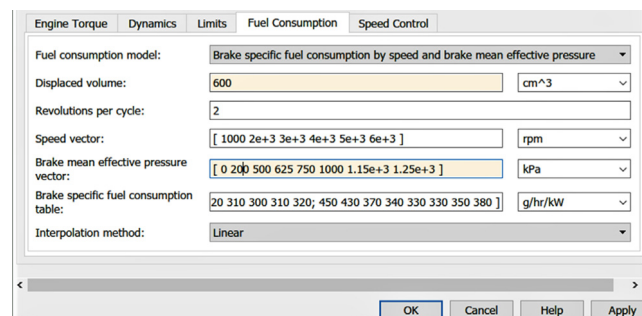


Fig. 2. Engine parameters.

- Speed Vector
- Power Vector
- Displaced Volume
- Brake Mean Effective Pressure (BMEP)
- Brake Specific Fuel Consumption (BSFC)

2.1. Speed vector

This essentially sets the different speeds of the engine in RPM, the model must perform under, the three cases taken here are acceleration, constant velocity and deceleration. The vehicle is put to test under all these conditions using the speed vector. Since the RPM's in performance vehicles are very high, the speed vector here is taken accordingly.

[500 1000 2000 3000 4000 5000 6000 7000]

2.2. Power vector

The power vector determines the amount of power produced at different operating speeds that is the RPM of the engine, this works in conjunction with the speed vector. The power vector is either determined in terms of W or kW. Since the RPM's in performance vehicles are very high, the power vector here is taken accordingly

2.3. Displaced volume

The displaced volume is the swept volume of the engine where the piston moves from Top Dead Centre to the Bottom Dead Centre in one rotation of the crankshaft, it is generally measured in cubic centimetres (cc or cm³), The displaced volume taken for the simulation is 600 cm³ for both the four cylinder and six cylinder models.

2.4. Brake Mean Effective Pressure (BMEP)

Brake Mean Effective Pressure (BMEP) is an effective method for comparing the performance of different engines and their power ratings. The definition of BMEP is: The average (mean) pressure which would produce the measured (brake) power output.

$$BMEP = 2\pi nT_e / ncVd \quad (1)$$

T_e = torque in newton-metre

n = number of revolutions per second

nc = number of revolutions per power

Vd = displacement volume in cubic metre

2.5. Brake specific fuel consumption (BSFC)

Brake specific fuel consumption compares engines of different sizes to see which is most fuel efficient. It helps to determine which engine uses least amount of fuel while producing high power. The BSFC and BMEP are set.

$$BSFC = \text{Fuel consumption per unit time} / \text{Brake Horse Power} \quad (2)$$

2.6. Simulation and results

The scopes toolbox generates a similar plot for both the models under the same conditions of acceleration, deceleration and constant velocity. This plot is the Power (kW) vs Time (t) graph, due to the three conditions set we get acceleration, deceleration and constant velocity, the vehicle responds differently under different conditions. The power peaks just above 150 kW which is equivalent to around 200 HP for the 2.5 L four cylinder model and 200 kW which is equivalent to around 248 HP for the six cylinder model.

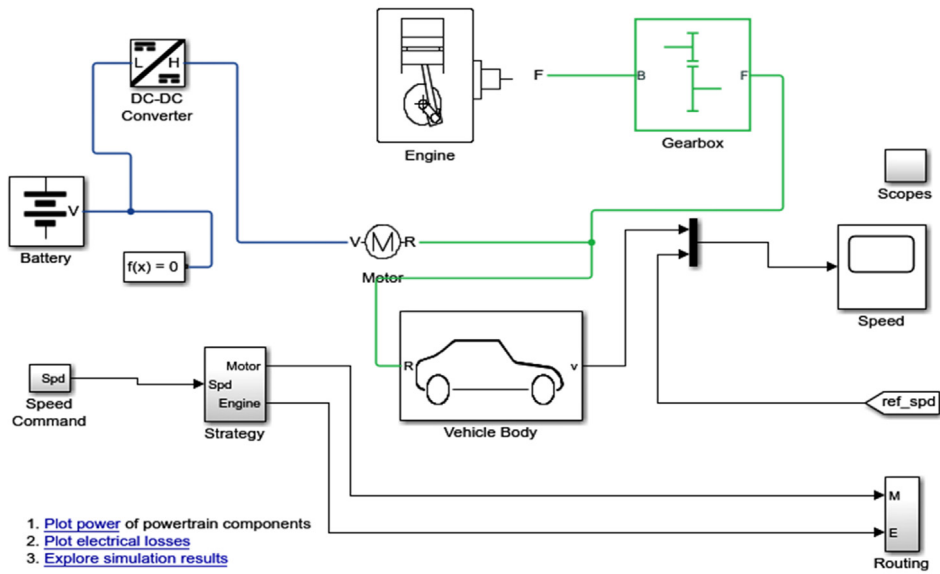


Fig. 3. Layout of hybrid model.

3. Modelling and simulation of a hybrid system

The three cylinder internal combustion engine with a displacement of 1.5 L with a similar speed and power vector as that of the naturally aspirated engine, is mated with a torque converter type gearbox, the engine is connected to an electric generator which in turn is connected to an electric motor. The layout is shown in Fig. 3. PID controller is also used, the proportional–integral–derivative controller (PID controller) is a control loop feedback mechanism (controller) mainly used in control systems. A PID controller calculates an error value as the difference between a measured process variable and a desired output.

The controller attempts to minimize the error in outputs by adjusting the different process control inputs. A DC-to-DC converter is used and it is an electromechanical device that converts or amplifies the voltage from a source of direct current (DC) to another, A DC–DC converter is generally used to increase the potential of the battery therefore allowing a smaller sized battery pack and a more powerful electric motor. The electric motor provides power to the wheels working in conjunction with the three cylinder engine. The peak power for the engine is 160 HP. The battery itself produces 70 HP. The total power output from the setup is around 230 HP.

The combined power output from the motor and the internal combustion engine is equivalent to a six cylinder engine, therefore the hybrid setup is more favourable as it provides better performance at the same time as consuming lesser amount of fuel and reducing the environmental impact.

The simulation plots in Fig. 4 are obtained for the motor power, it shows that the motor spins between 65–70 rad/s at peak load which is equivalent to 650 rpm. The vehicle is set under three different loads that include constant speed, acceleration and deceleration. Fig. 5 shows the overall plot, which is the Power (kW) vs Time (t) plots for the engine, battery and the electric motor under the three set conditions of acceleration, deceleration and constant velocity. The vehicle utilizes power stored in the battery, in this simulation it is assumed that the battery is pre-charged and is charged up by renewable energy as well, but to develop a hybrid vehicle with even fewer emissions a source of renewable energy can be implemented into the system.

The source of renewable energy that best fits this application would be solar panels, the panels can be placed on the roof, hood and boot of the vehicle so that they can occupy a large surface area where greater amount of sunlight can hit the panels. The battery in the simulation is a 70 kW/h battery, the average driver drives an estimate of 60 kilometres per day which is around 12 kW/h of electricity required by the battery, if a solar panel produces 1 kW/h of electricity in one day, a total of 12 solar panels is required to charge the battery for the average commute, the rest of the electricity can be charged using the regenerative braking.

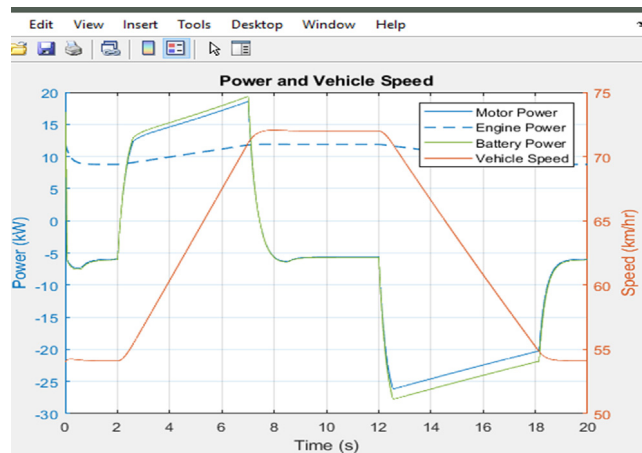


Fig. 4. Electric motor plots.

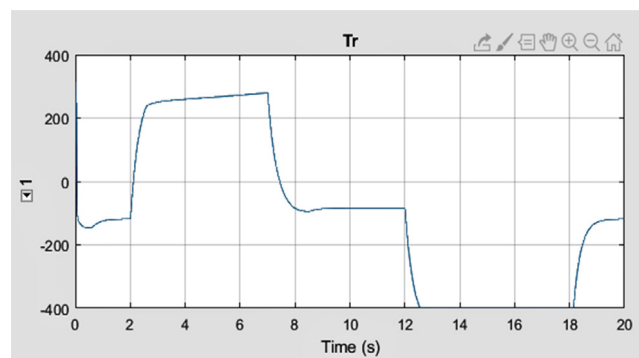


Fig. 5. Overall power plots.

4. Conclusion, results and future scopes

In the conducted simulation using MATLAB Driveline, we achieve results which prove that using a hybrid electric vehicle is a much superior option as compared to a vehicle using a much larger conventional internal combustion engine.

The main advantages of using a hybrid setup we have obtained from this simulation are –

1. Better fuel economy
2. Power at lower RPM's
3. Lesser harmful emissions

The power peaks just above 150 kW which is equivalent to around 200 HP for the 2.5 L four cylinder model whereas the six cylinder petrol engine with a cubic capacity of 3.5 L and other specified conditions produces a peak power of 248 HP, the maximum torque is just more than 200 Nm and the engine speed is around 830 rad/s = 7925 rpm.

The petrol three cylinder series hybrid engine has a cubic capacity of 1.5 L makes a peak horsepower of 180 HP at 6500 RPM. The internal combustion engine works in accordance with a 70 HP in series to give a combined horsepower rating of 240 HP.

These results show that a much smaller sized engine with a hybrid drive advantage can produce power similar to that of a much larger sized engine. This study shows that with the advancement in different hybrid systems, the automotive industry is shifting focus towards a greener initiative by producing vehicles with smaller engines that provide same performance levels as that of much larger engines, governing bodies like the FIA introduce new

rules every year so that the technology used in those high performance vehicles can make its way into normal production cars. The next step would be to learn more about and eventually work on the technologies that have untapped potential and use this knowledge in providing a greener tomorrow.

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