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Research Article

Design and Simulation of Split Parallel Hybrid Electric Vehicle

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Abstract

The hybrid vehicles combine the prospective features of the performance of conventional and battery powered engines. This work is to investigate the performance of Split Parallel Hybrid Electric Vehicle (SPHEV) under two sample test drive and urban test drive. The various key parameters of simulation, namely power rating of engine, traction motor, generator and Peak Power Source (PPS) are derived for a standard commercially available vehicle. The powertrains used for vehicle are Mechanical and Hydraulic hybrid types. The increased fuel prices, stringent pollution norms and need of improved efficiency are key factors to explore electric hybrid power-trains. The system parameters for SPHEV mainly include the A well-designed parametric component of SPHEV will substantially power the vehicle for defined drive conditions.

Keywords: *SPHEV, Hybrid Vehicle, USD, Series and Parallel Hybrid, Battery System for SPHEV.*

1. Introduction

The hybrid vehicle technology gives almost satisfactory solutions to all the problems faced regarding efficiency, emission requirements and overall performance of the vehicle at reasonable cost. Hybrid the word itself says blend of two or more power sources. The hybrid electric vehicles combine the advantage of ICE and electric vehicles. The term Hybrid here represents that there's been more than one power source used to propel the vehicle. The hybrid vehicles are normally categorized into series and parallel. There are various configurations of hybrid vehicles classified according to power flow from power source to driven wheels. The three basic configurations of hybrid electric vehicles are namely Series; Parallel and Series-Parallel.

In-order to overcome the disadvantages of series and parallel hybrid a new configuration called Split-parallel hybrid electric vehicle also known as Series-parallel hybrid vehicle has been developed. The Split Parallel Hybrid Electric Vehicle (SPHEV) is one of the effective solutions to cope up with stringent emission norms as well as increasing fuel costs. The A split power hybrid electric vehicle utilizes both an internal combustion engine as well as electric motor for driving the vehicle. The SPHEV optimally combines advantages of both series and parallel hybrid vehicle. The planetary gear unit serves as the engine power split device, which splits the engine power into two parts: one part goes to the battery or directly to the traction motor through a generator and a second part goes to the drive wheel through the transmission. The ECU, which is undistinguished part of SPHEV, decides based on various driving modes which power source to activate. The planetary gear is used to decouple the engine speed from the vehicle speed. This feature integrates the advantages of both series and parallel hybrid system. In this configuration the engine is allowed to directly supply the power to drive wheels or it can be switched off so that electric motor can drive the wheel.

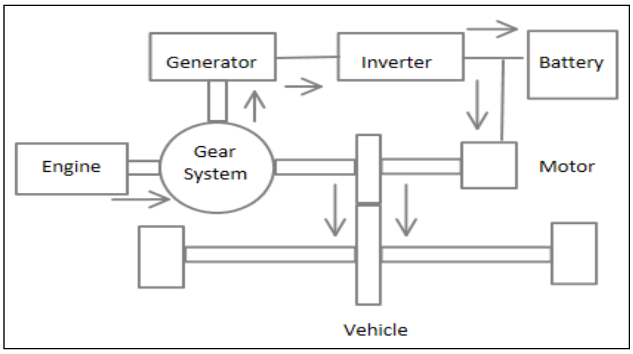

Fig.1 The Split Parallel Hybrid Power train

It is also evident that design and modelling of SPHEV is complex process as speed coupling device such as planetary gear and toque coupling device such as axle-fixed shaft are involved. The design of Engine, Generator, Motor, Batteries and Power Split device play a significant role in efficient design and functioning of SPHEV.

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2. Design Requirements

The manufacturer design specifications of commercially available passenger vehicle are listed in Table 1 and Table 2 shows the performance specification for SPHEV.

Table 1 Design Specifications

Sr	Dimensions	Reference Values
1	Kerb Weight (Kg)	1130
2	Overall Width (mm)	1686
3	Overall Length (mm)	4282
4	Overall Height (mm)	1468
5	Wheelbase (mm)	2486
6	Track Front (mm)	1474
7	Track Rear (mm)	1444
8	Tyre	175/65R 14

Table 2 Performance Specifications

Parameter	Desired Values
Acceleration	0-100 km/h in 13 sec
Maximum Speed	160 km/h

2.1 The Power of Engine

The engine is one of the primary power sources of the drive train. Thus, calculating the engine power first ensures the vehicle to accomplish the specified mission in SPHEV. The engine also accounts for the efficiency losses in transmission. For driving the SPHEV at constant high speed on highway, engine power should be sufficient enough to overcome the rolling resistance and aerodynamic drag which can be expressed as:

$$P_e = \frac{V_{\max}}{1000\eta_t}(Mgf_r + \frac{1}{2}\rho AC_d V_{\max}^2)$$

η_t = Transmission efficiency = 0.9

f_r = coefficient of rolling resistance = 0.013

Cd = Coefficient of drag= 0.26

Substituting the values in equation, the maximum engine power at engine shaft is found out to be 42.95 kW.

2.2 The Power of Generator

Generator is connected to the sun gear and its torque is proportional to the engine torque, as expressed as

$$T_c = -(k+1)T_s$$

K is planetary gear ratio = 2.6

The maximum torque of the engine is around 98.03 N-m Thus torque of generator is given as

Tg >= 27.23 N-m and Pg = 27.82 kW

2.3 The Torque of the Motor

The function of Traction motor in SPHEV is to provide the peak power source to overcome all the SPHEV dynamic resistance (inertial load in acceleration) and enhance the vehicle acceleration performance measured by time to accelerate from 0 to 100 km/h in 13 seconds. The acceleration is given by,

$$\frac{dv}{dt} = \frac{(v_2 - v_1)}{(t_2 - t_1)} = \frac{27.77}{13} = 2.14 m/s^2$$

The motor maximum torque is given by the following relation,

$$T_m = \frac{P_m \text{x}60\text{x}1000}{2\pi N_b} = 273.11 \text{ N-m}$$

2.4 Peak Power Source (PPS)

The PPS design mainly includes the calculation for power capacity and energy capacity (M Eshani, Yimin GAO and Ali Emadi, 2010). Based on these design factors PPS rating is calculated.

The power capacity design for PPS has further two cases.

1) Normal driving scenario the total power capacity of battery and generator should meet the traction motor power demands.
2) Extreme case, i.e. full load accelerating driving scenario, where traction motor utilizes full power of the battery and generator produces maximum power for acceleration purpose

Considering the extreme case scenario for PPS design, the terminal power supplied by the PPS must be greater than or equal to traction motor power, given by relation,

$$P_{pps} \geq \frac{P_m}{\eta_m}$$ Motor efficiency assumed 0.9

Substituting the values in equation, the PPS Power capacity rating = 43.822 kW

Energy capacity of PPS is given by following relation,

$$E_{pps} = \frac{\Delta E_{\max}}{\Delta SOC}$$

To calculate energy capacity of PPS energy variation in drive cycles must be known. The energy variation in PPS is expressed as,

$$\Delta E = \int_0^T P_{pps} dt$$

State of Charge (SOC) of the battery is defined as available capacity expressed in percentage of some reference. For efficiency reasons chemical batteries have an optimal SOC operating range in between 0.4 – 0.7 (M Eshani, Yimin GAO and Ali Emadi, 2010). Assuming to maintain SOC in-between SOCtop=0.99, and SOCbottom=0.3 for vehicle control logic discussed in further SPHEV modelling section. Thus, SOC variation = 0.69.

E_{pps} =1.53 kWh

The battery terminal voltage = 201.6 Volts

Hence the current = 7.59 Ah

$$I_b = \frac{E_{pps}}{V_b} = \frac{1529.42}{201.6}$$

Li-Ion (Lithium Ion) battery pack of 43.85 kW is preferred with efficiency greater than 95%

3. Simulation

The performance was simulated with above values for essentially two cases namely sample drive cycle and urban drive cycle. The various outputs are compared and discussed as below.

3.1Sample Drive Cycle

The Acceleration input pattern as shown in Figure 2 was generated in order to study the performance criteria of the developed SPHEV, Battery SOC and Power required from different power sources. In the pattern acceleration ramp up from 0 to 2.13 m/s2 in 13 seconds and from 13 sec to 100 sec the acceleration remains constant as if like applying full load acceleration condition.

The developed SPHEV was tested under above pattern and it was found that the SPHEV reaches 100 km/h in 11.2 sec as shown result in Figure 3. During acceleration phase only motor was providing the demanded power of 37.75 kW. Battery SOC at the end of the test cycle was found out to be 0.96. Thus satisfy the performance criteria for the designed SPHEV.

3.1 ECE Test Cycle

ECE cycle an urban drive cycle, also known as UDC. It represents city driving condition with low vehicle speed, low engine load and low exhaust gas temperature. The maximum speed of the ECE cycle was 50 km/h. Figure 4 shows the reference ECE test cycle. Total distance covered by SPHEV in this cycle is 1.013 Km. In this drive cycle, initially till 11.2 sec there was no acceleration for SPHEV. From 11.2 sec till 15 sec SPHEV was accelerated from 0 to 15 km/h.

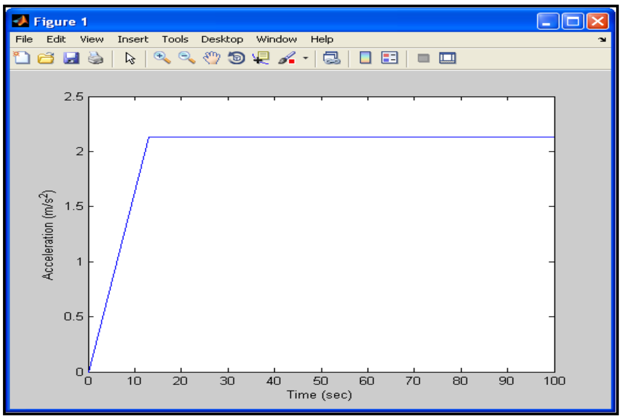

Fig.2 Acceleration Input pattern for Sample Drive Cycle

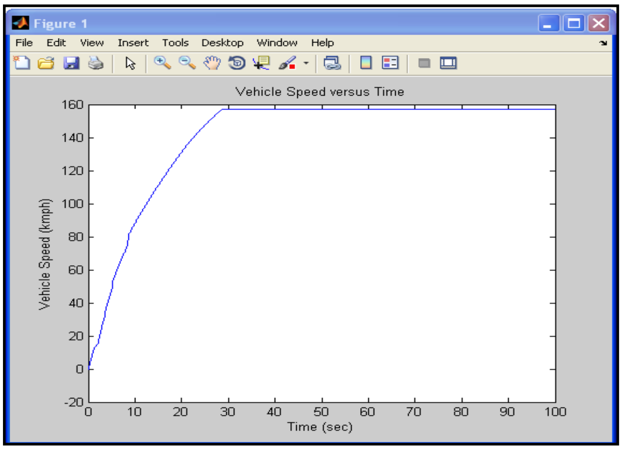

Fig.3 Vehicle Speed vs Time

After this SPHEV was subjected to constant acceleration at 15 km/h for 8 sec, and decelerate to 0 km/h in 2 sec during this period engine requires 8.8kW of Power and battery SOC once again comes to 0.997.

The SPHEV then gets acceleration from 0 to 32 km/h in 15sec, thereafter remains constant at 32 km/h till further 26 sec. During this phase Motor requires 35 kW of power and engine requires 20 kW of power respectively. Finally SPHEV was accelerated from 0 km/h in time 116 sec to 50 km/h at 144 sec, which requires motor power 30 kW and battery SOC found at this point was 0.99 at the end of test cycle. Figure 5 shows that Vehicle Speed (Result) closely follows the reference vehicle speed cycle as shown in Figure 4.

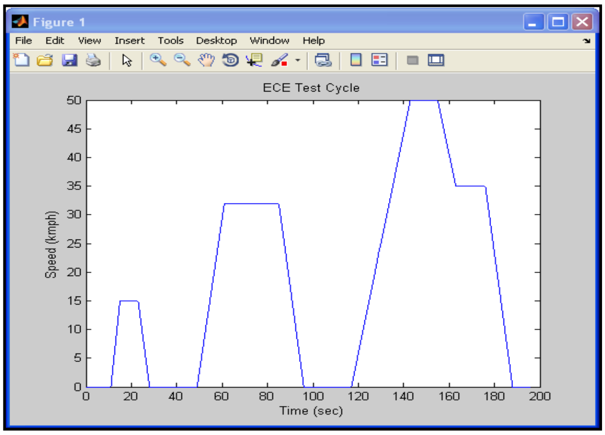

Fig.4ECE Test Drive Cycle

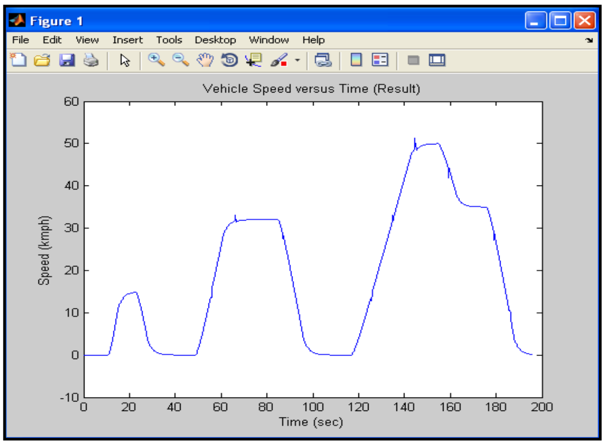

Fig.5 Vehicle Speed Vs Time (ECE)

Conclusions

The power of the engine required for simulation is based on vehicle mass, vehicle maximum speed and gear ratio. Similarly the power split device model required for simulation is depending on planetary gear ratio. The simulation of the performance under two drive cycles, indicates the following deductions.

1. Peak power source which is Li-Ion battery pack used for simulation purpose depends on traction motor power, maximum SOC.
2. The simulation is tested for designed SPHEV with 42.99 kW, Diesel Engine and Electric traction motor of 39.44 kW, European Cycle with flat road.
3. For Sample Drive Simulation vehicle attained speed of 100 km/h in 13 seconds under test conditions of flat ground with constant acceleration of 2.13 m/s^2 also under same conditions it accelerated to maximum 157.36 km/h.

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