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Analysis of Series Hybrid Electric Vehicle with Auxiliary Power Unit

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Abstract

Hybrid electric vehicles represent a promising future direction for the transportation sector in terms of decreasing the reliance on fossil fuels while simultaneously decreasing emissions. Energy used for driving is fully or partially shifted to electricity leading to lower emission rates.In this regard, the use of a power generator and motor as the primary power source for an automobile is very attractive. This thesis develops model of a series hybrid vehicle with a power generator as its Auxiliary Power Unit (APU). Simulation using the model helps to provide an understanding of the interaction and flow of power. Moreover, electrical power sharing between the APU and the Electrical Storage System (ESS) is shown. Conclusion is also discussed.

Index terms— traction motor, control strategy, tractive effort etc.

1 Introduction

Hybrid Vehicle, as defined by Technical Committee 69 (Electric Road Vehicles) of International Electro Technical Commission, is one in which propulsion energy during specified operational missions is available from two or more kinds or types of energy stores, sources or converters with at least one store or converter onboard. A more specific definition of a hybrid electric vehicle is given as a hybrid vehicle in which at least one of the energy stores, sources or converters can deliver electric energy.

a) Hybrid Vehicle Architectures

The parallel configuration illustrated in figure **??**.1 also represents a typical design, where both the ICE and the electric motor can provide torque to drive the wheels.

2 Series Hybrid Drive Train

Although there are many possible configurations for a series hybrid drive train, a traction motor propels the vehicle. The motor delivers high torque at low speeds and low torque at high speeds. The motor gives a constant torque for variable speed up to the 'base speed' of the motor; beyond the base speed, the torque of the motor decreases with increase in the speed. The traction motor is powered by a battery pack and/or an engine generator unit. The engine/generator unit either helps the batteries to power the traction motor when load power demand is large, or charges the batteries when the load power demand is small. The motor controller is used to control the traction motor to produce the power required by the vehicle. Hence the motor supplies the extra power to meet the load demand. (P pps). At point B, the power required is less than the power produced by the engine /generator at its optimal operating point. In this case, this surplus power that is being produced by the ICE can either be used to charge the peaking power source else the engine is operated in its non-optimal region, to supply just the traction power. Point C has negative (braking power) which is more than the braking power that the motor can alone produce, hence hybrid braking is used. Here, the electric motor produces its maximum braking power and mechanical brakes are also applied in addition. Point D represents the commanded braking power that is less than the maximum braking power that the motor can produce.

3 Design

For designing the hybrid electric vehicle we need to consider vehicle maximum mass, front area, maximum velocity, acceleration time, trans-mission efficiency, traction motor efficiency, generator efficiency, aerodynamic drag coefficient,rolling resistance coefficient, tire radius and air density. For a four passenger carry able vehicle, normally the maximum mass is 1200-1500Kg.When a vehicle runs, then a resistance is created by air. This resistive force act against car speed is proportional to vehicle front area, aerodynamic drag co-efficient, air density and vehicle speed. To overcome from this resistive force, traction motor has to consume certain amount of its total consumed power. We take temperature of air is normally 25°C and so air density 1.184 kg/m 3 (at 1 atm). Weight of the vehicle, M V =1500Kg(with 4 passenger),Front area of the vehicle, A f = 2.0 square meters, Transmission efficiency (? t)=90%, Traction motor drive efficiency (? m)= 85%,Generator efficiency (? g)= 90%,Aerodynamic drag coefficient (C D) = 0.3,Rolling resistance coefficient (f r) = 0.01,Tire radius = 0.3 meters,Air density (? a) = 1.184 kg/cubic meters,Acceleration time (from 0 to 100 km/h) = 10 Seconds,Grad ability more than 5% at 100 km/h.,Maximum speed = 160 km/h.

4 a) Design of Traction Motor

The power rating of the traction motor is determined by using the equation:P t = ?? ?? 2?? ?? (V f 2 + V b 2) + 2 3 M V gf r V f + 1 5 ? a C D A f v f 3

In this case, we know that,M V = Vehicle mass = 1500 kg.,t a = Acceleration time in seconds = 10 seconds.V f = Final Speed of the Vehicle in m/s = 160 km/h.V b = Final speed corresponding to motor base speed.

The motor base speed and the maximum speed of the motor are related by a factor 'x'.

5 X =

Motor max .Velocity

6 Motor base velocity

The factor 'x' is arbitrarily chosen to have a value of 4, the ratio between maximum vehicle velocity (V f) and V b will be 'x' = 4 The Motor power thus calculated will be 82.5 KW. Hence the value of V b can be calculated. The values of C D, A f , f r ,? a have already been specified. The motor maximum speed is chosen to be 5000 RPM. Correspondingly the motor base speed is 5000/4 that is 1250 RPM .Motor power = 2 ? × Motor base speed × Ratedmotor torque.The motor torque thus calculated is found out to be 630 Nm. Thus the specifications of the traction motor are as follows: Motor power = 82.5 KW. Motor rated torque = 630 Nm. Motor base Speed = 1250 RPM. Motor maximum Speed = 5000 RPM. Gear ratio, i g = 3.53,Transmission efficiency, ? t = 90%,Tire radius, r = 0.3m So, rated tractive effort will be 6.2 kN.To check if the motor is able to meet the gradability condition, the tractive effort of the vehicle is plotted with the vehicle resistance (aerodynamic drag + rolling resistance + the hill climbing). Considering a 5% grade, the engine power needed to support the vehicle at this speed, considering transmission efficiency to be 90%, motor drive efficiency to be 85% and the generatorefficiency to be 90%.P g = ?? 1000 ?? ?? ?? ?? (M v g f r + 0.5 ? a C D A f V 2)kW.Using this eqh n our desired generators power rating is 29KW. Consider that drive cycle is about 16 hour. At this condition P ave will be approximately 26.45kW.

7 e) Power Rating of Peaking Power Source

Since the power rating of the generator and the traction motor has been decided, the rating of the peaking power source can be easily calculated.

8 Capacity

The S.O.C is decided to vary from 0.6 to 0.4. Hence ?SOC = SOC top -SOC bott = 0.2. Also, the energy capacity of the PPS is decided to vary from 1.5 kWh to 1 kWh. Hence ?Emax = 0.5kWh. Having decided how much the state of charge as well as the energy rating of the peaking power source, its energy capacity can be calculated. The equations are listed below.P t = ?? ?? 2?? ?? (V f 2 + V b 2) + 2 3 M V gf r V f + 1 5 ? a C D A f v f 3,

Motor power =2? × Motor base speed × Rated motor torque . [1] [2]

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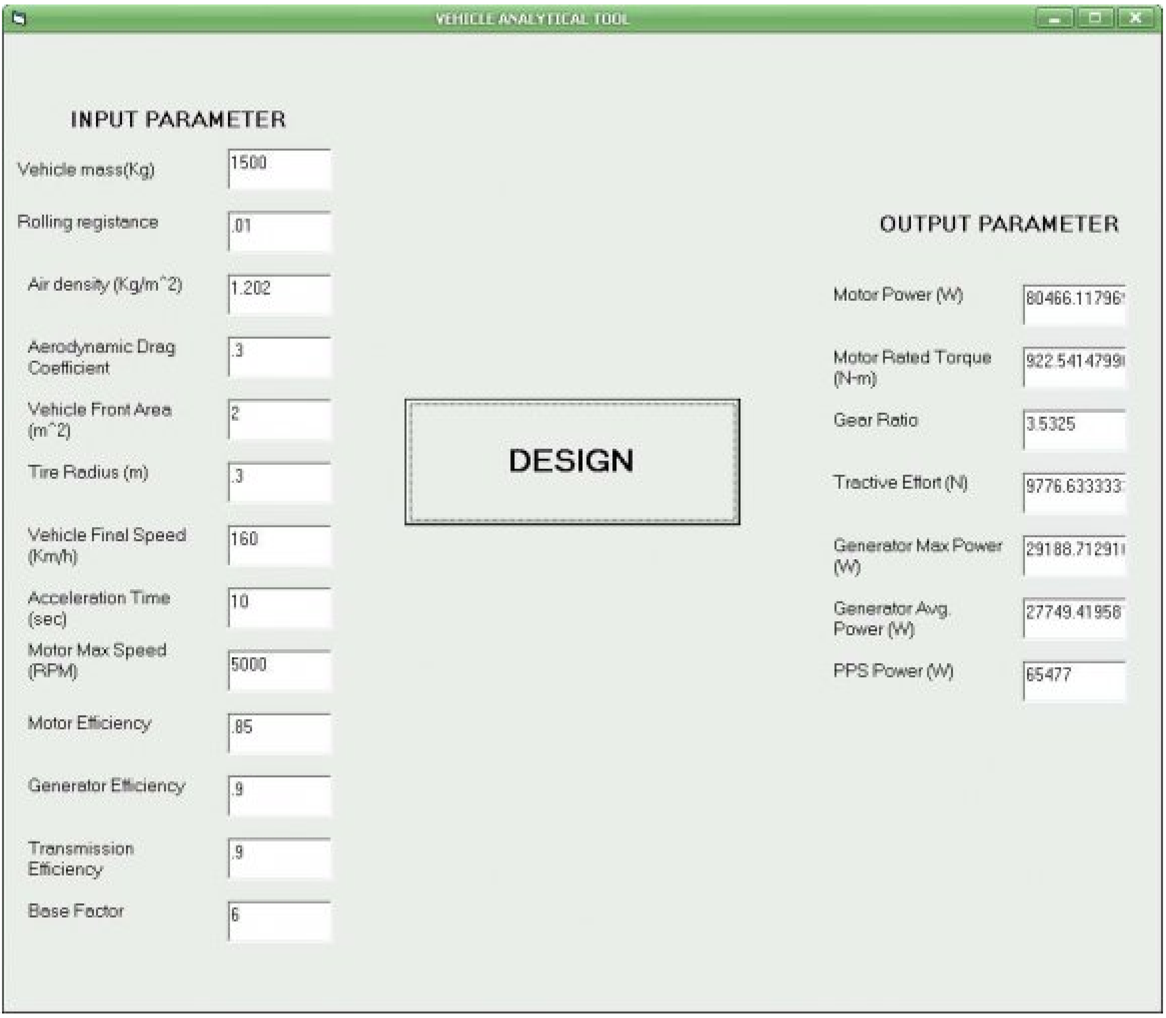
Figure 1: Figure 1 . 1 :



INPUT PARAMETER

Vehicle mass(Kg)	1500
Rolling registance	.01
Air density (Kg/m^2)	1.202
Aerodynamic Drag Coefficient	.3
Vehicle Front Area (m^2)	2
Tire Radius (m)	.3
Vehicle Final Speed (Km/h)	160
Acceleration Time (sec)	10
Motor Max Speed (RPM)	5000
Motor Efficiency	.85
Generator Efficiency	.9
Transmission Efficiency	.9
Base Factor	6

OUTPUT PARAMETER

Motor Power (W)	80466.11796
Motor Rated Torque (N-m)	922.5414799
Gear Ratio	3.5325
Tractive Effort (N)	9776.63333
Generator Max Power (W)	29188.7129
Generator Avg. Power (W)	27749.41958
PPS Power (W)	65477

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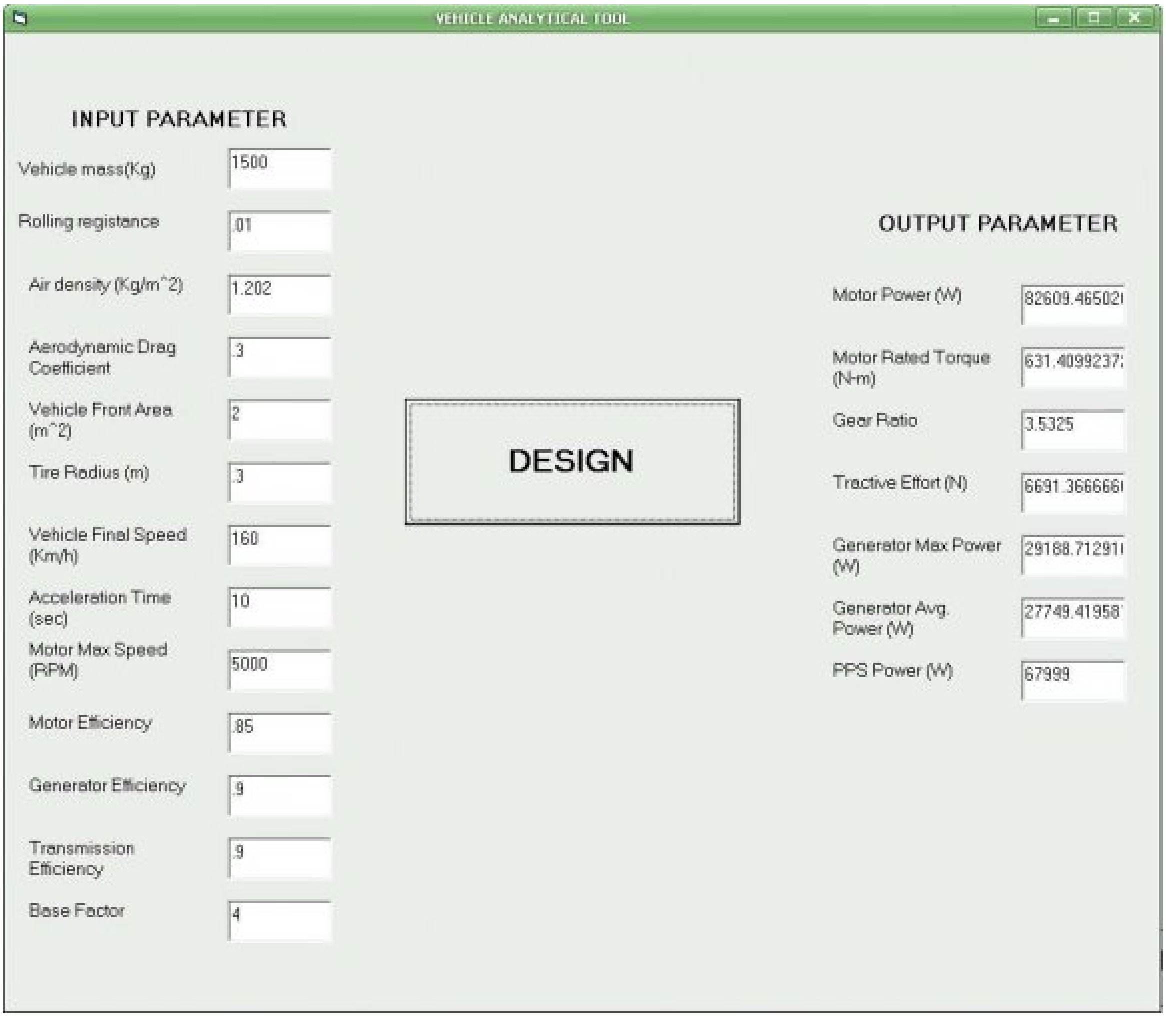
Figure 2: Figure 2 . 1 :



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Vehicle Final Speed (Km/h)	160
Acceleration Time (sec)	10
Motor Max Speed (RPM)	5000
Motor Efficiency	.85
Generator Efficiency	.9
Transmission Efficiency	.9
Base Factor	4

Motor Power (W)	82609.46502
Motor Rated Torque (N-m)	631.4099237
Gear Ratio	3.5325
Tractive Effort (N)	6691.366666
Generator Max Power (W)	29188.71291
Generator Avg. Power (W)	27749.41958
PPS Power (W)	67999

Figure 3:

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: Drag coefficients for some passenger vehicles[20]

Vehicle (class)	C D	C D × A f (m^2)
VW Polo (class A)	0.37	0.636
Ford Escort (class B)	0.36	0.662
Open Vectra (class C)	0.29	0.547
BMW 520i (class D)	0.31	0.649
Mercedes 300SE (class E)	0.36	0.785

From this table, we can consider our vehicle's front area is 2m 2 and hence drag co-efficient is approximately 0.3.

Figure 4: Table 3 . 1

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2 : Air density at various temperatures[20]

T in °C	? in kg/m 3 (at 1 atm)	T in °C	? in kg/m 3 (at 1 atm)
-25	1.423	5	1.269
-20	1.395	10	1.247
-15	1.368	15	1.225
-10	1.342	20	1.204
-5	1.316	25	1.184
0	1.293	30	1.164

Figure 5: Table 3 .

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Tire Type	Coefficient of Rolling Friction
Low rolling resistance car tire	0.006 -0.01
Ordinary car tire	0.015
Truck tire	0.006 -0.01
Train wheel	0.001

We consider our desired rolling co efficient is 0.01.As motors & generators efficiency are normally 80% to 90%, we consider motor efficiency as 85% and generator efficiency as 90%. Table 3.4: Various types of gear with their efficiency[20]

Name of gear	Efficiency	Name of gear	Efficiency
Spur Gears	90%	Helical Gears	80%
Sprocket Gears	80%	Bevel Gears	70%
Rack and Pinion	90%	Worm Gears	70%

Figure 6: Table 3 .

.1 Summary

In this chapter, a series hybrid electric vehicle was designed. By calculation we find that, our designed vehicle require a traction motor which takes a maximum power of 82.5 kW and the rated torque produced by it is 630Nm. Rated tractive effort of the vehicle that is the traction motor is approximately 6.2 kN. Maximum By clicking DESIGN button we can get all our desired output parameters.Any one input parameters can be changed easily for various design condition.

Here for example we change the base factor X=6 and again design tool window is shown with all the inputoutput parameters.

generation power by the generator is 29 kW is required in flat road and the average power generated in urban road is approximately 26.5 kW. Rest power needed for the traction motor is supplied by the PPS i.e, battery. Maximum power rating of the PPS is 68 kW and energy capacity of PPS is 2.5 kWh.

.2 This page is intentionally left blank

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