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MID-SEMESTER REPORT

By

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Firstly, we are grateful to **Department of Electrical Engineering, BITS-Pilani Hyderabad Campus** for offering us a Design Oriented Project (D.O.P) as a course in our curriculum.

We would like to express our sincere gratitude to Assistant Professor **Dr. Alivelu Manga Parimi**, Department Of Electrical Engineering, BITS –Pilani Hyderabad Campus for giving us the opportunity to carry out a project in this esteemed organization.

We would also like to thank ma’am, our mentor and our Project Guide for suggesting us the project and providing us valuable guidance and support throughout our work.

ABSTRACT

In this project, we intend to develop a fuzzy logic based controller for hybrid electric vehicle. Until the mid-semester we have understood fuzzy logic and its Matlab interface. A thorough understanding of the IEEE paper “Fuzzy Logic Control for parallel Hybrid Vehicles” has been achieved. Matlab based simulation models have been developed for vehicle speed, electric motor, battery, and a one-dimensional model of internal combustion engine which form the important components.

As we proceed to the next phase we will design a fuzzy logic based controller to optimize the operational efficiencies of all components. And in effective determine the energy split between the two powerplants; electric motor and internal combustion engine.

1. Fuzzy Logic

The concept of Fuzzy Logic (FL) was conceived by Lotfi Zadeh, a professor at the University of California at Berkley, and presented not as a control methodology, but as a way of processing data by allowing partial set membership rather than crisp set membership or non-membership. This approach to set theory was not applied to control systems until the 70's due to insufficient small-computer capability prior to that time. Professor Zadeh reasoned that people do not require precise, numerical information input, and yet they are capable of highly adaptive control. If feedback controllers could be programmed to accept noisy, imprecise input, they would be much more effective and perhaps easier to implement.

FL offers several unique features that make it a particularly good choice for many control problems.

1) It is inherently robust since it does not require precise, noise-free inputs and can be programmed to fail safely if a feedback sensor quits or is destroyed. The output control is a smooth control function despite a wide range of input variations.

2) Since the FL controller processes user-defined rules governing the target control system, it can be modified and tweaked easily to improve or drastically alter system performance. New sensors can easily be incorporated into the system simply by generating appropriate governing rules.

3) FL is not limited to a few feedback inputs and one or two control outputs, nor is it necessary to measure or compute rate-of-change parameters in order for it to be implemented. Any sensor data that provides some indication of a system's actions and reactions is sufficient. This allows the sensors to be inexpensive and imprecise thus keeping the overall system cost and complexity low.

4) Because of the rule-based operation, any reasonable number of inputs can be processed (1-8 or more) and numerous outputs (1-4 or more) generated, although defining the rulebase quickly becomes complex if too many inputs and outputs are chosen for a single implementation since rules defining their interrelations must also be defined. It would be better to break the control system into smaller chunks and use several smaller FL controllers distributed on the system, each with more limited responsibilities.

5) FL can control nonlinear systems that would be difficult or impossible to model mathematically. This opens doors for control systems that would normally be deemed unfeasible for automation.

Rule Matrix

Linguistic variables are used to represent an FL system's operating parameters. The rule matrix is a simple graphical tool for mapping the FL control system rules. It accommodates two input variables and expresses their logical product (AND) as one output response variable. To use, define the system using plain-English rules based upon the inputs, decide appropriate output response conclusions, and load these into the rule matrix.

Membership Functions

There is a unique membership function associated with each input parameter. The membership functions associate a weighting factor with values of each input and the effective rules. These weighting factors determine the degree of influence or degree of membership (DOM) each active rule has. By computing the logical product of the membership weights for each active rule, a set of fuzzy output response magnitudes are produced. All that remains is to combine and defuzzify these output responses.

Fuzzified Output

The inputs are combined logically using the AND operator to produce output response values for all expected inputs. The active conclusions are then combined into a logical sum for each membership function. A firing strength for each output membership function is computed. All that remains is to combine these logical sums in a defuzzification process to produce the crisp output.

Defuzzification

The logical product of each rule is inferred to arrive at a combined magnitude for each output membership function. This can be done by max-min, max-dot, averaging, RSS, or other methods. Once inferred, the magnitudes are mapped into their respective output membership functions, delineating all or part of them. The "fuzzy centroid" of the composite area of the member functions is computed and the final result taken as the crisp output. Tuning the system amounts to "tweaking" the rules and membership function definition parameters to achieve acceptable system response.

We worked with the following Matlab toolboxes for control theory using fuzzy logic

1)FIS(Fuzzy Inference System) Editor
2)Membership function editor
3)Rule Editor
4)Rule viewer5)Surface viewer

2) Study of "Fuzzy Logic Control for Parallel Hybrid Vehicles"- Niels J. Schouten, Mutasim A. Salman, and Naim A. Kheir-IEEE TRANSACTIONS ON CONTROL SYSTEMS TECHNOLOGY, VOL. 10, NO. 3, MAY 2002

Objective:- The search for improved fuel economy, reduced emission and affordable vehicles, without sacrificing vehicle performance, safety, reliability, and other conventional vehicle attributes has made the hybrid technology (both thermal and electrical motorization) one of the challenges for the automotive industry. Hybrid systems, using a combination of an internal combustion engine (ICE) and electric motor (EM), have the potential of improving fuel economy by operating the ICE in the optimum efficiency range and by making use of regenerative braking during deceleration.

Hybrid electric Vehicle
A hybrid vehicle is a vehicle that uses two or more distinct power sources to move the vehicle. The term most commonly refers to hybrid electric vehicles (HEVs), which combine an internal combustion engine and one or more electric motors. However, other mechanisms to capture and use energy are included.

Electric Motor
An electric motor is an electric machine that converts electrical energy into mechanical energy.In normal motoring mode, most electric motors operate through the interaction between an electric motor's magnetic field and winding currents to generate force within the motor. In certain applications, such as in the transportation industry with traction motors, electric motors can operate in both motoring and generating or braking modes to also produce electrical energy from mechanical energy.

Internal Combustion Engine
An internal combustion engine (ICE) is an engine where the combustion of a fuel occurs with an oxidizer (usually air) in a combustion chamber that is an integral part of the working fluid flow circuit. In an internal combustion engine the expansion of the high-temperature and high-pressure gases produced by combustion apply direct force to some component of the engine. The force is applied typically to pistons, turbine blades, or a nozzle. This force moves the component over a distance, transforming chemical energy into useful mechanical energy.

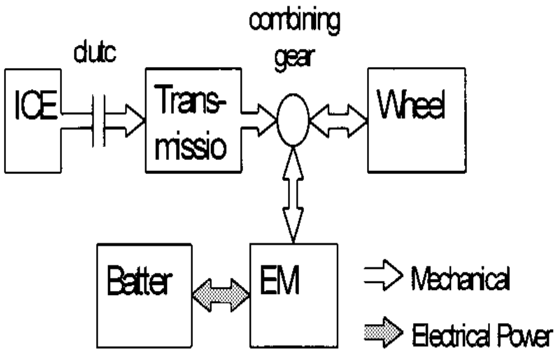
There are three different types of hybrid systems:-

• Series Hybrid: In this configuration, an ICE-generator combination is used for providing electrical power to the EM and the battery.

• Parallel Hybrid: The ICE in this scheme is mechanically connected to the wheels, and can therefore directly supply mechanical power to the wheels. The EM is added to the drivetrain in parallel to the ICE, so that it can supplement the ICE torque.

• Series-Parallel Combined System: Toyota Prius is an example of this so-called dual system..

BASICS OF PHVs



(Block diagram of the parallel hybrid vehicle.)

For both the upstream and downstream configuration, there are five different ways to operate the system, depending on the flow of energy:

1) Provide power to the wheels with only the ICE;

2) Only the EM; or

3) Both the ICE and the EM simultaneously;

4) Charge the battery, using part of the ICE power to drive the EM as a generator (the other part of ICE power is used to drive the wheels);

5) Slow down the vehicle by letting the wheels drive the EM as a generator that provides power to the battery (regenerative braking).

ENERGY MANAGEMENT STRATEGY

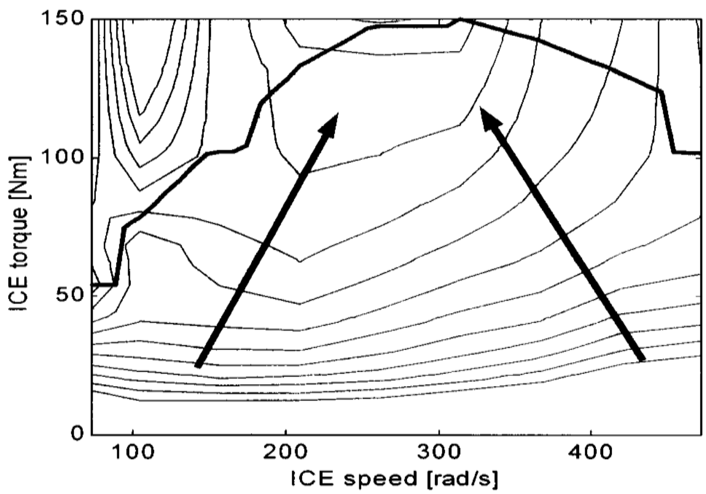
The energy in the system should be managed in such a way that:

1) The driver inputs (from brake and accelerating pedals) are satisfied consistently (driving the PHV should not “feel” different from driving a conventional vehicle).

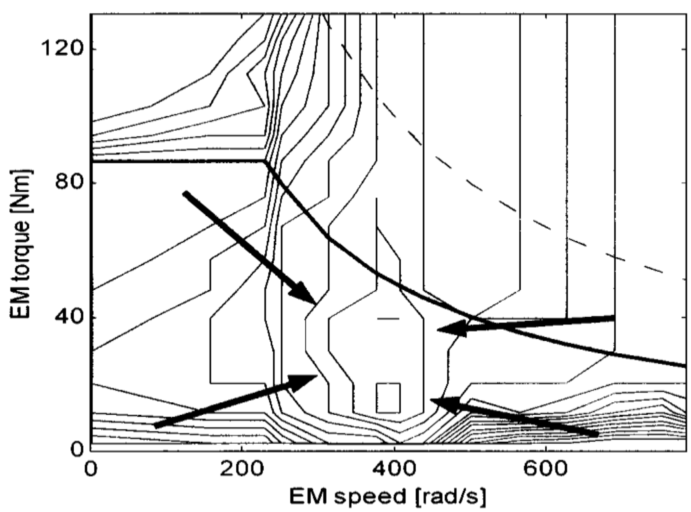
2) The battery is sufficiently charged at all times.

3) The overall system efficiency of the four basic components (ICE, EM, battery, and transmission) is optimized.

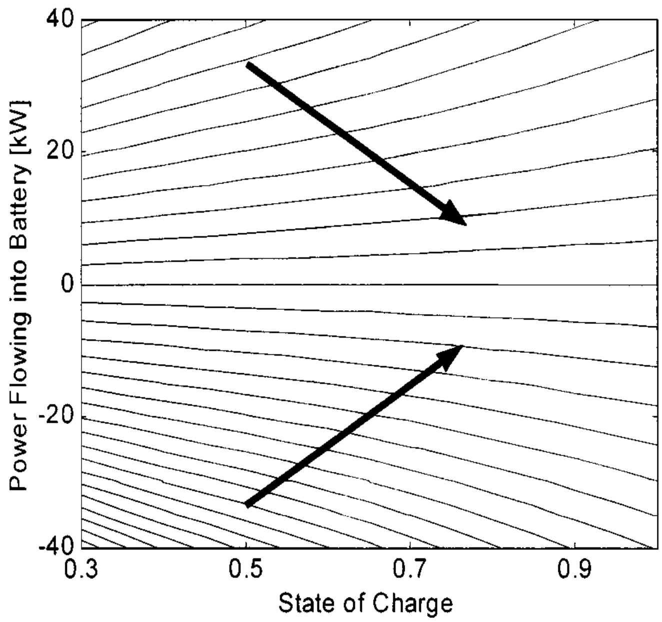
A. Efficiency Maps



The above figure presents a contour plot of the efficiency of a generic CIDI engine in the speed-torque plane. Superimposed on the contour plot is the optimal efficiency curve. For a given ICE power level, the optimal efficiency curve defines the optimal operating point in the speed-torque plane. Once the optimal speed and torque are known, the torque is controlled by varying the throttle angle and the speed by shifting gears of the automated manual transmission (note that for a given vehicle speed, a higher gear number will result in a lower engine speed).

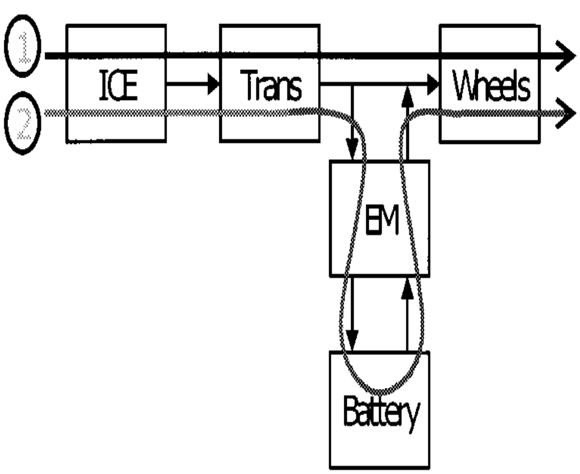


The EM speed is directly related to vehicle speed, because it cannot be controlled by gear shifting. Therefore, the EM efficiency can only be optimized, by optimizing the power at a given EM speed. The efficiency is optimal for EM speeds between 320 and 430 rad/s. The optimal power for this region is approximately 10 kW.

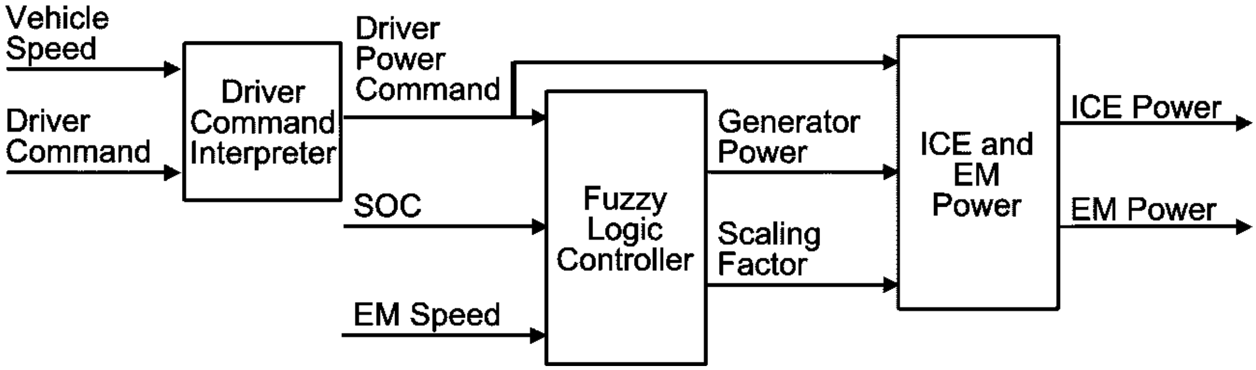


The above figure presents a generic efficiency plot of an advanced battery in the state of charge (SOC)-power plane. It can easily be seen that the battery operates most efficiently for high SOC and low power levels. For power-split control, this indicates that the SOC should be as high as possible by frequently charging at low power level. In this study, it is assumed that the highest admissible SOC is 0.9 for charging, and 0.97 for regenerative braking.

B. Power Split Strategy



Now that the efficiency characteristics of the components are known, it is possible to formulate the power-split strategy. The difference between using the ICE or the EM to drive the wheels is explained in Fig. 5. When the ICE is used (path 1), the energy flows directly from the ICE through the transmission to the wheels. When the EM is used (path 2), energy first flows from the ICE through the transmission to the EM, operated asa generator, for charging the battery; later the energy will flow from the battery to the EM, operated as motor, to the wheels.

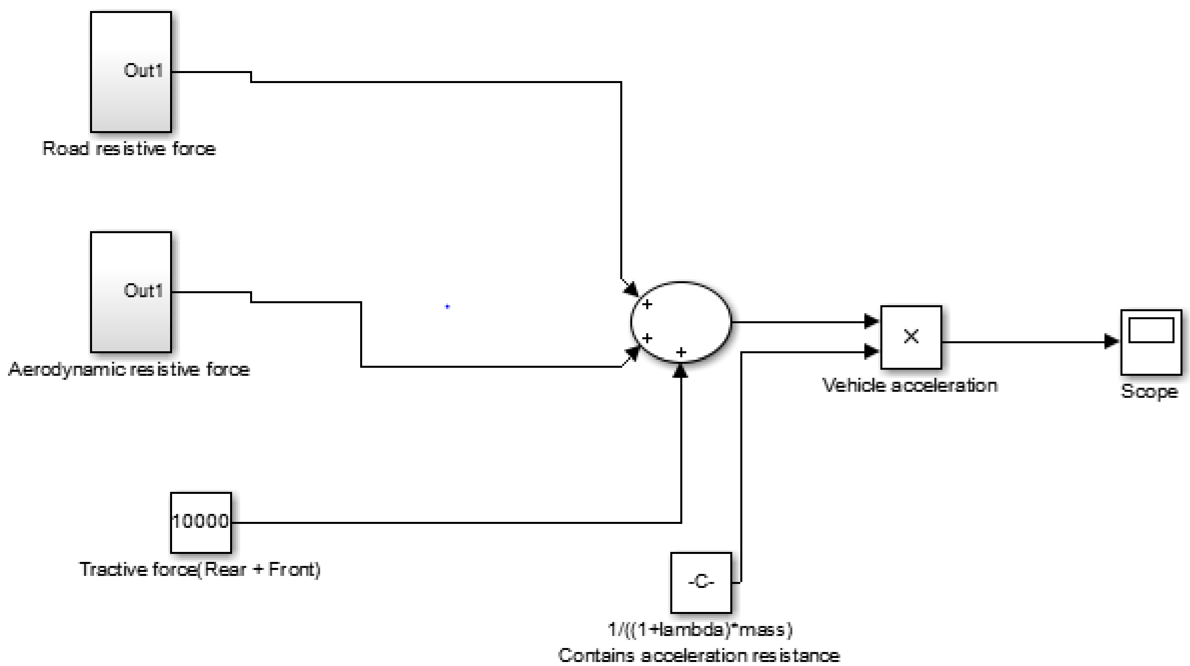


(Simplified diagram of the power controller.)

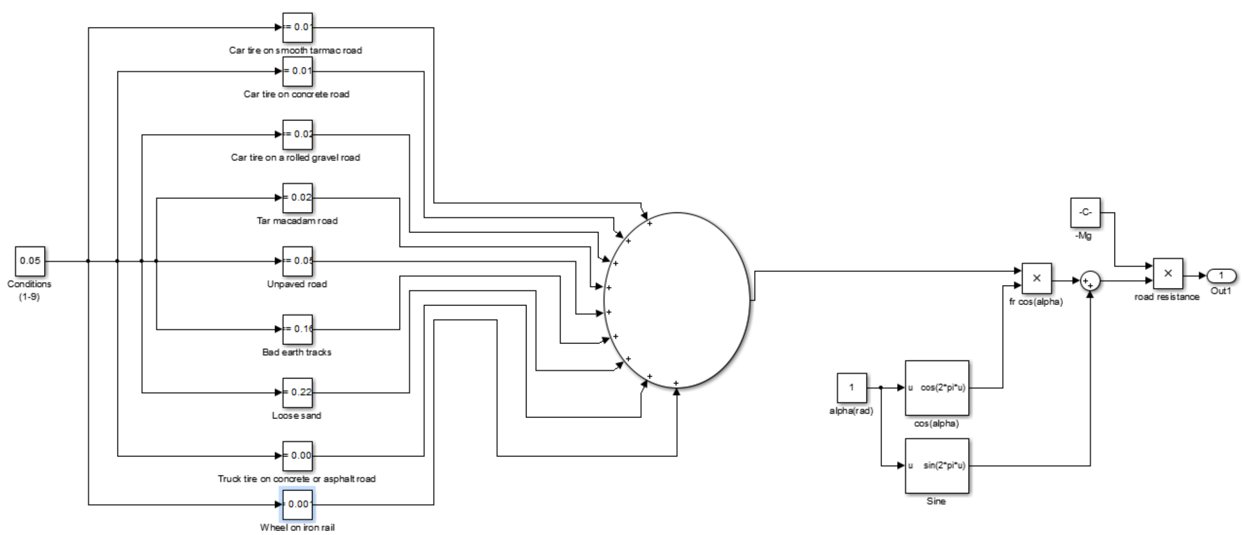
The first block converts the driver inputs from the brake and accelerator pedals to a driver power command. The signals from the pedals are normalized to a value between zero and one (zero: pedal is not pressed, one: pedal fully pressed).The braking pedal signal is then subtracted from the accelerating pedal signal, so that the driver input takes a value between 1 and -1.The negative part of the driver input is send to a separate brake controller that will compute the regenerative braking and the friction braking power required to decelerate the vehicle.
The controller will always maximize the regenerative braking power, but it can never exceed 65% of the total braking power required, because regenerative braking can only be used for the front wheels.The positive part of the driver input is multiplied by the maximum available power at the current vehicle speed. This way all power is available to the driver at all times. The maximum available power is computed by adding the
maximum available ICE and EM power. The maximum available EM and ICE power depends on EM/ICE speed and EM/ICE temperature, and is computed using a two–dimensional look-up table with speed and temperature as inputs. However, for a given vehicle speed, the ICE speed has one out of five possible values
(one for each gear number of the transmission). To obtain the maximum ICE power, first the maximum ICE power levels for those five speeds are computed, and then the maximum of these values is selected. Once the driver power command is computed, the fuzzy logic controller (Fig. 6) computes the optimal generator power for the
EM in case it is used for charging the battery and a scaling factor for the EM in case it is used as a motor. This scaling factor is (close to) zero when the SOC of the battery is too low. In that case the EM should not be used to drive the wheels, in order to prevent battery damage. When the SOC is high enough, the scaling factor equals one.

Matlab modeling using the equations corresponding to working of the following components:-

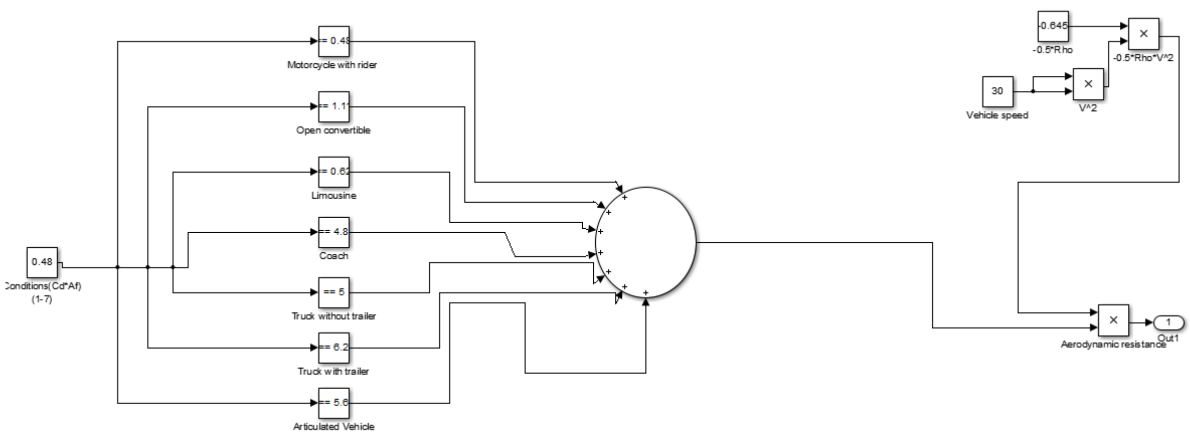
1) Vehicle Speed



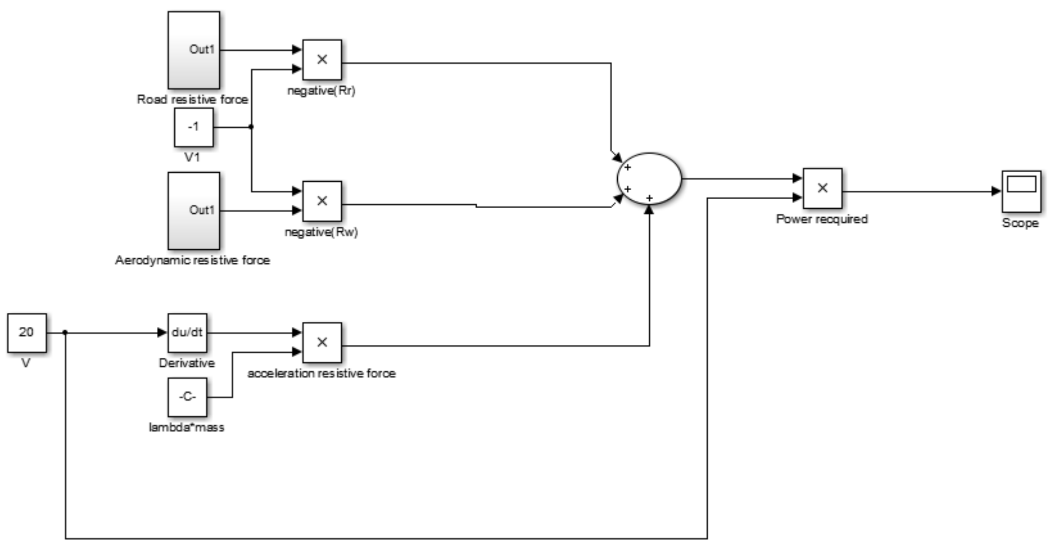
Resistive Force:



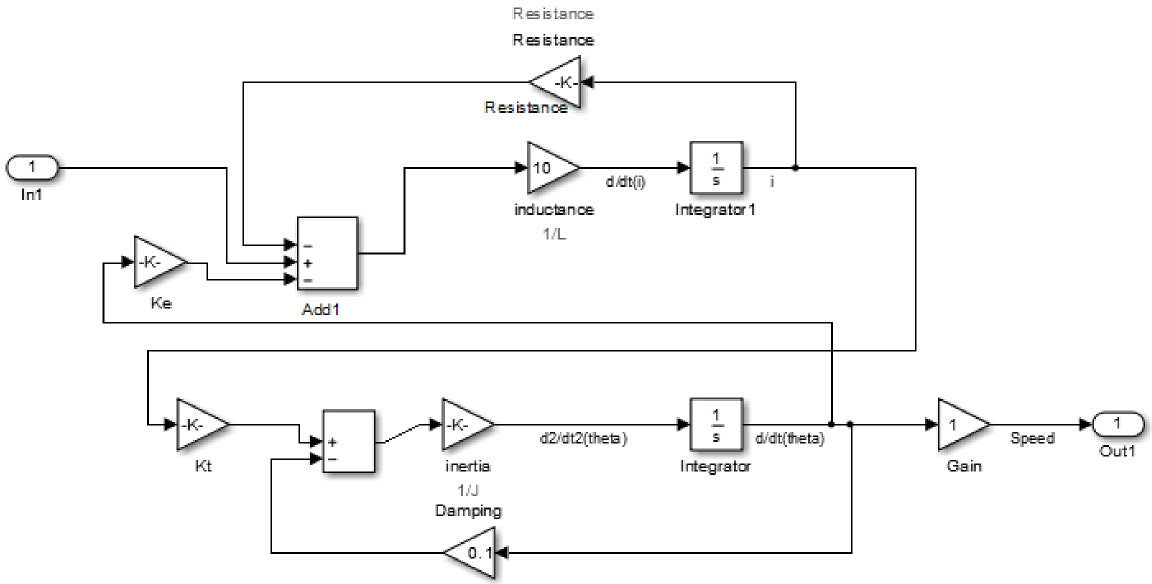
Aerodynamic Resistive Force



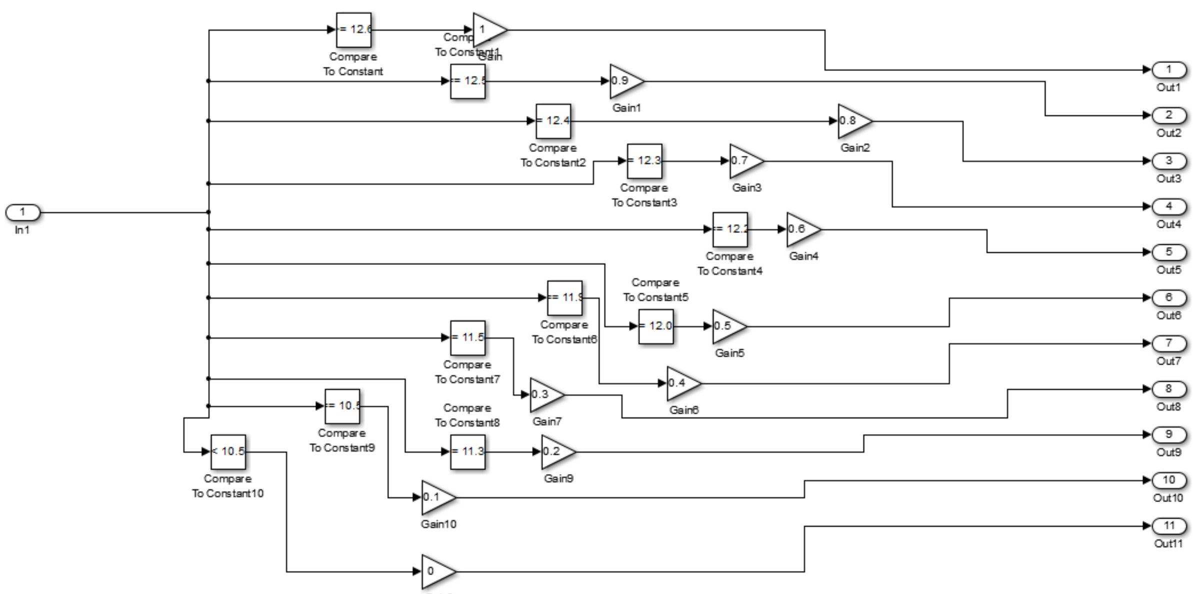
2) Power Required



3) Electric Motor



4) State of charge (S.O.C) of Battery



The above diagram forms the Voltage->SOC block.

5) One-Dimensional modeling of Internal Combustion Engine.

```
%A program to calculate and show the curves for compressible and
%incompressible flow, temperature and density, flow for exhaust gas
%and to compare the two methods for calculating the Mach number.
%Model Dimensions:
%Bore B 84*10-3 m
%Stroke S 90*10-3 m
```

```
%Inlet Ø di 54*10-3 m
%Inlet port Ø dip 27*10-3 m
%Exhaust port Ø dep 27*10-3 m
%Exhaust Ø de 54*10-3 m
%Conrod length c 0.250 m
%Inlet length Li 0.10 m
%Exhaust length Le 2.00 m
%General values used:
%Density of air ?atm 1.2 kg*m-3
%Temp of air Tatm 293 K
%Atmospheric pressure Patm 101*103 Pa
%Gamma (ideal gas) ? 1.4
%Gas constant R 287

clear all
close all
clc

M = 0 : 0.01 : 3.0; %a vector which represents all the mach numbers

rpm = (1/(8.484*10^-5))*M.*(1+0.2*M.^2).^-3;

dens = 1.2*(1+0.2*M.^2).^(-2.5);

temp = 293*(1+0.2*M.^2).^(-1);

rpm_ex = (1/(4.9637*10^-5))*M.*((1+0.2*M.^2).^-3);

Incomp = M*(343*60/(0.09*pi))*(27/84)^2;

figure (1)

plot(M,rpm)
axis([ 0.0 3.0 0.0 10000.0]);
title('rpm as a function of mach number');
xlabel('mach number');
ylabel('rpm');

figure (2)

subplot (2,1,1);
plot(M,dens)
axis([ 0.0 1.0 0.0 2.0]);
title('density as a function of mach number');
xlabel('mach number');
ylabel('density [kg/m^3]');
```

```
subplot (2,1,2);
plot(M,temp)
axis([ 0.0 1.0 200.0 300.0]);
title('temp as a function of mach number');
xlabel('mach number');
ylabel('temp [K]');

figure(3)

plot(M,rpm_ex)
axis([ 0.0 3.0 0.0 15000.0]);
title('rpm as a function of mach number (exhaust)');
xlabel('mach number');
ylabel('rpm');

figure (4)

plot(M,Incomp,M,rpm)
axis([ 0.0 3.0 0.0 10000.0]);
title('Incompressible and compressible');
xlabel('mach number');
ylabel('rpm');
```

Outputs are:-

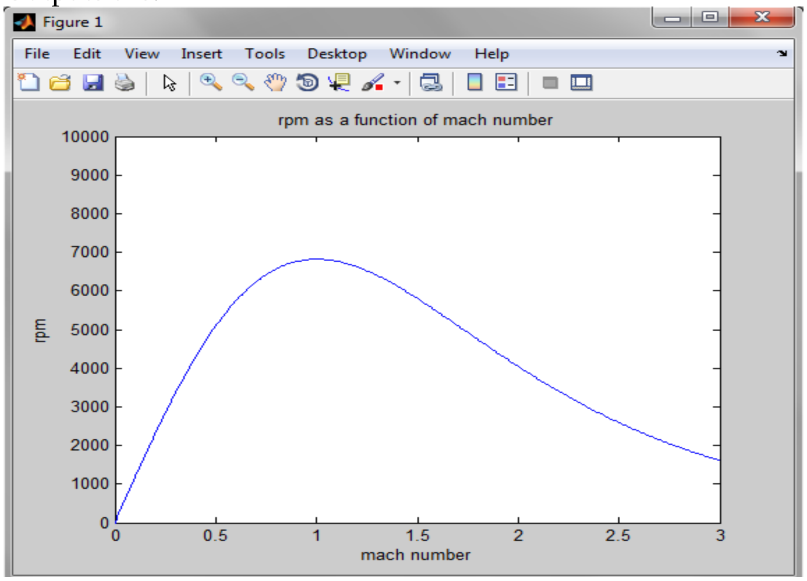


Figure 1
File Edit View Insert Tools Desktop Window Help
rpm as a function of mach number
rpm
mach number
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
0.5
1
1.5
2
2.5
3

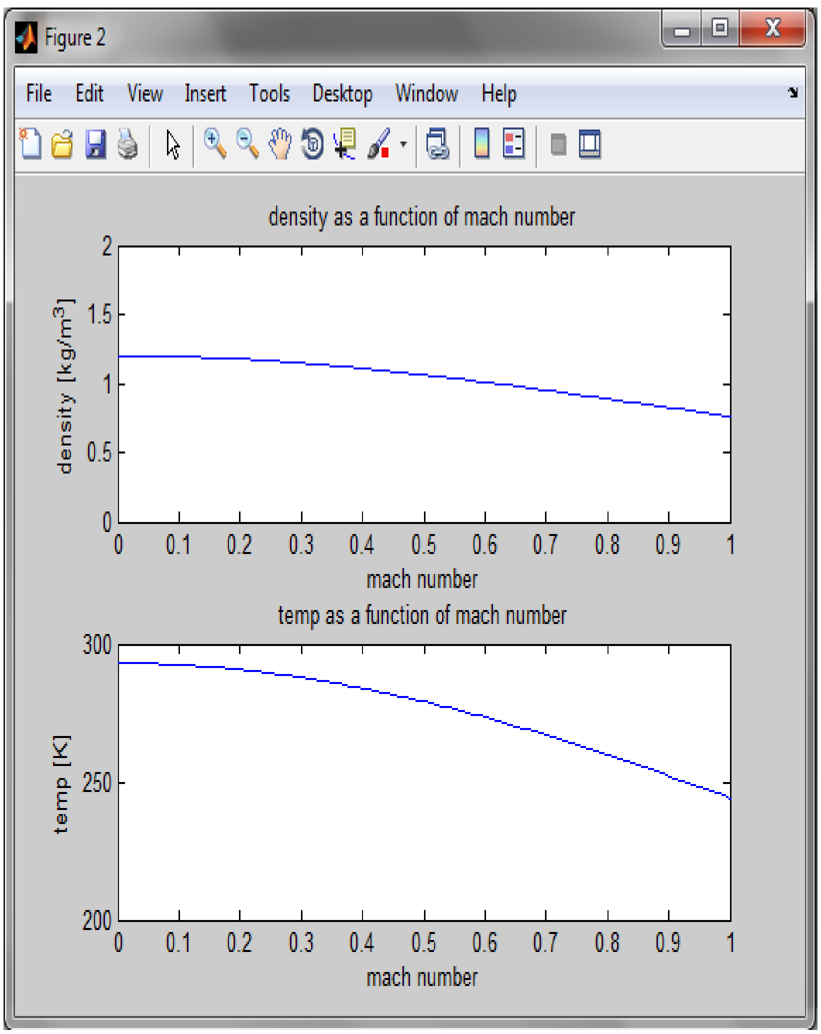


Figure 2
File Edit View Insert Tools Desktop Window Help
density as a function of mach number
density [kg/m3]
mach number
temp as a function of mach number
temp [K]
mach number
300
250
200

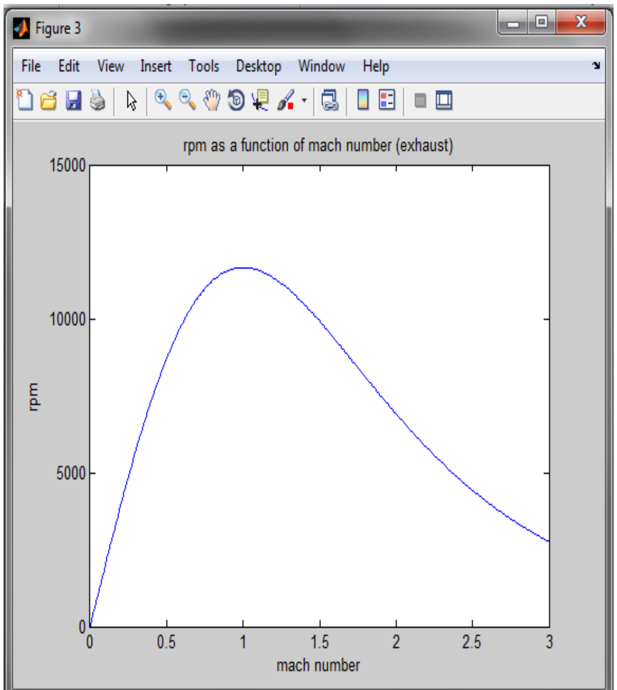


Figure 3
File Edit View Insert Tools Desktop Window Help
rpm as a function of mach number (exhaust)
15000
10000
5000
0
rpm
0
0.5
1
1.5
2
2.5
3
mach number

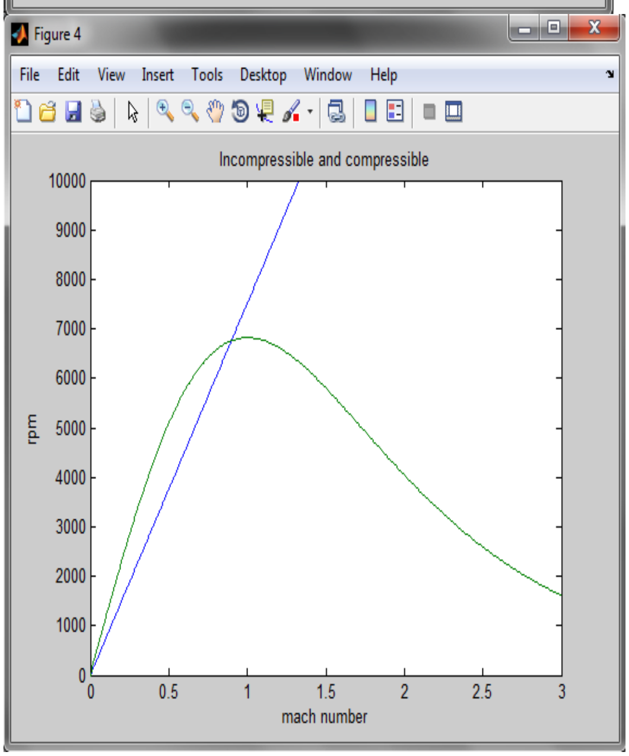


Figure 4
File Edit View Insert Tools Desktop Window Help
Incompressible and compressible
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
rpm
0
0.5
1
1.5
2
2.5
3
mach number

References:

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2) www.seattlerobotics.org/encoder/mar98/fuz/flindex.html

3) www.wikipedia.org

4) Niels J. Schouten, Mutasim A. Salman, and Naim A. Kheir "Fuzzy Logic Control for Parallel Hybrid Vehicles" *(IEEE Transactions on control systems technology*, Vol. 10, No. 3, May 2002)

5) NPTEL course Introduction to Hybrid and Electric Vehicles.

6) http://www.mech.kth.se/~hanno/CliveLewisFordjupningarbete.pdf