December 2013
IJMIE
Volume 3, Issue 12
ISSN: 2249-0558

DEVELOPMENT OF PLUG-IN HYBRID ELECTRIC TWO WHEELER

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ABSTRACT*-This Plug in Hybrid Two wheeler is designed to minimize energy consumption and pollution levels (CO2), while at the same time having similar performance of conventional IC Engine Vehicles. Electric Power to this vehicle is being provided by a BLDC Motor which in turn is powered by a Lead acid battery. Motor and Battery selection criteria for a Hybrid Vehicle are addressed. (Aero, Lateral, Rolling, Gradient).This vehicle primarily acts in three modes Hybrid Mode, Electric Motor only and IC Engine only mode. It starts with electric motor and continues up to 30kmph and switches to IC Engine above the same threshold limit. Switching between these modes is carried out with the help of Control System(primarily Relays&Micro-controllers).Also a MATLAB Code for Hybrid vehicle Simulation is derived and its inferences are being clearly analyzed to stipulate the advantage of Hybrid propulsion system.*

Keywords: *Plug in Hybrid,MATLAB Simulation,BLDC Motors(Brushless DC),Hybrid Control System, Hybrid Motor selection, Hybrid Battery Selection, CO2 Emission Level Reduction.*

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I.OBJECTIVE:

The main objective of this study is to develop a Plug-in Hybrid Electric Two Wheeler, capable of minimizing the energy consumption and pollution levels, while at the same time having the performance of conventional ICE vehicles and to demonstrate the benefits of all-electric range and fuel economy improvements. The objective also focuses on the carbon dioxide emission reduction from the two-wheelers. To achieve the objective, certain modification is done on the conventional two-wheeler, and modeling, simulation and theoretical estimation studies are performed.

Also the study aims:

- To model a simple MATLAB vehicle simulation model for sizing of powertrain components and to convert conventional two-wheeler into a plug-in hybrid electric two-wheeler prototype model
- To develop a control system and thereby implement an energy management strategy for the Two wheeler based on driving pattern
- To assess the reduction of CO_2 emissions by two-wheeler segment by deploying electric or plug-in hybrid technology

II. METHODOLOGY:

To achieve the above objectives, the following methodologies are used.

1) Power requirement calculations are done for the selection of the various components like Hub motor,Battery etc.
2) A MATLAB simulation model was developed for evaluation of power, energy requirements, State of charge and Running cost for a plug-in hybrid electric two-wheeler using Indian driving patterns.
3) The control system was developed with a novel energy management strategy and the conventional two-wheeler was converted into a plug-in hybrid electric two-wheeler.

III. VEHICLE SELECTION:

Mopeds have better advantage in terms of weight and space constraints. So we have selected TVS XL SUPER for our study.

IV. MOTOR SELECTION:

A. Calculating Total Resistance:

The first stage of the design process involved in measuring the total force requirement of the two-wheeler is mentioned below.

The formulae for calculating total resistance is ,

- $F_{total} = F_{aero} + F_{roll} + F_{la} + F_{grad}$ (N)
- $F_{aero} = C_d \cdot A \cdot \rho \cdot v^2 \cdot 0.5$ (N)
- $F_{roll} = m \cdot g \cdot C_{rr}$ (N)
- $F_{la} = m \cdot a$ (N)
- $F_{grad} = m \cdot g \cdot \text{sine}(\theta)$ (N)

Where ,

F_{la} is the acceleration force required

F_{aero} is the aerodynamic force induced

F_{roll} is the rolling resistance encountered.

F_{grad} is the gradient resistance

F_{res} is the total resistance

F_{tr} is the tractive effort required at the wheels.

Maximum speed in electric mode is taken to be 40kmph with an acceleration of 0.44m/s^2.

Based on above calculation,

Total Resistance, F_{tr} = 123.09 N

B.Calculating Motor Power Requirements:

Since our vehicle is a Plug-in HEV, the motor should be capable of supplying the total power requirement of the vehicle without overheating.

Wheel radius r = 0.35m is selected based on vehicle manual.

Final drive ratio (fixed gear ratio),

G = 1.0

N_{wheel} = 303.2 rpm

N_{motor} = N_{wheel} * G= 303.2rpm

Torque at wheel = 15.29 Nm

Motor Power = 485.84W

C.Motor Specification For the selected BLDC motor:

60V 500W 16 INCH ALLOY RIM:

Rated voltage : 60V

Rated power : 500W

Controller current limit : 28A

No load speed : 420 rpm

Controller Specification: 60V with 12 MOSFETs

V. BATTERY SELECTION:

From Tractive effort calculation:

Power = F_{res} x V = 487.61W

Assuming the range of the vehicle as 40Km in electric mode,

Time taken to cover 40 Km = 40/21=1.90hr (Avg. Speed = 21km/hr)

Energy E=926.49Wh.

Hence the requirement is a traction battery that can supply a total energy of at least926.49 Wh. (After accounting for other losses and efficiency of the battery itself)

The choice of the battery is a 20Ah battery working in 60 V DC supply.

Now the total energy available in the battery is as follows,
Total Energy in Battery = Capacity of battery (Ah) x Voltage.
Therefore the total energy available in the Battery is 1200 Wh.

VI. CONTROL SYSTEM:

Speed below 30 kph:

- The vehicle speed is detected by the speed sensor (proximity sensor) and the signals are sent to the signal conditioning unit.
- The signal conditioning unit converts the pulses from the sensor into an equivalent (0 to 5V) range.
- The micro controller keeps the ignition relay switched ON throughout the mode.
- The relay operating the starter motor is switched OFF.
- As there is no sufficient voltage from the alternator to the stop pin of the microcontroller, the hubmotor is supplied with power.

Speed crosses beyond 30 kph:

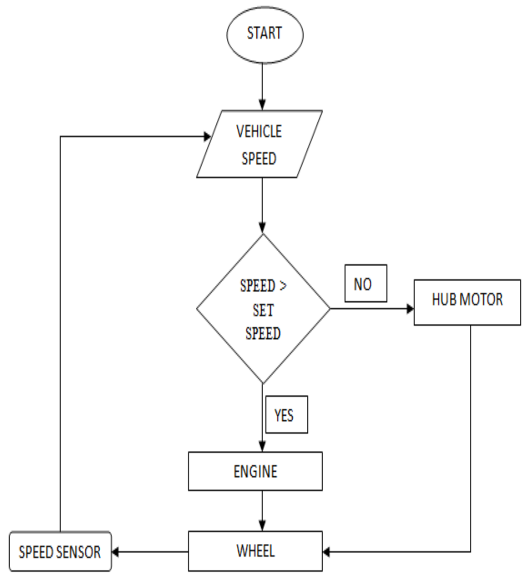
- The vehicle speed is detected by the speed sensor (proximity sensor) and the signals are sent to the signal conditioning unit.
- The micro controller keeps the ignition relay switched ON throughout the mode.
- The relay operating the starter motor is switched ON for 5 seconds.
- Its again turned OFF after for 5 seconds to avoid excess cranking.
- The engine spins and gains speed to generate sufficient emf (12-14 V). This is fed to the stop pin of motor controller. And supply to the hub motor is cut off.

Speed crosses below 30 kph:

- The vehicle speed is detected by the speed sensor (proximity sensor) and the signals are sent to the signal conditioning unit.
- The micro controller keeps the ignition relay switched OFF for 5 seconds (This is to turn off the engine) and is again turned ON.
- The relay operating the starter motor is switched OFF.

- The emf from alternator reduces and comes below 12V which makes the motor controller to resume back its power supply to the motor.

Hybrid Mode:



- There are two keys in this system. One to turn on the electric motor and the other one to control IC engine. In a hybrid mode both the keys are turned on.
- The vehicle moves initially using the electric motor and accelerated upto the set speed.
- As soon as the vehicle crosses the set speed the IC engine is cranked using a starter motor and there after it uses the power of IC engine to drive the vehicle.
- As the engine spools up the emf from the alternator is greater than 12V which is fed to the stop pin of the motor controller. This ensures cut off of power supply to the motor.

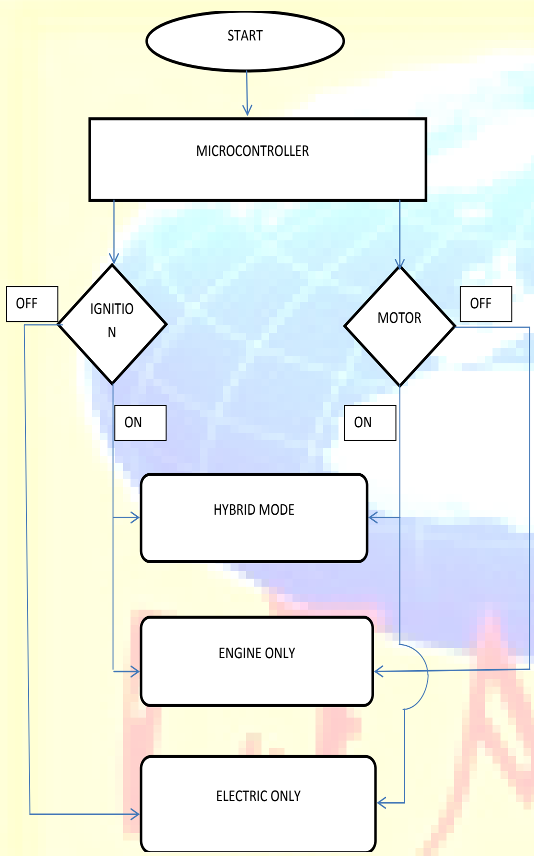
Electric only mode:

- In this mode the electric motor's key alone is turned on and the IC engine is turned off.
- The vehicle accelerates beyond set speed and as the IC engine switch is turned off there is no trigger to crank the engine and hence the vehicle continues to drive in the electric mode.

IC Engine only mode:

- Converse to the electric only mode, the IC engine switch is turned on and hub motor is turned off.
- The vehicle is mobilised from the beginning using the engine. Its either cranked using the starter motor or by mechanical means.
- There is continues flow of current to the stop pin and hence there are no chances of the hub motor to turn ON.

FL OW CHART FOR MODE SELECTON:



VII.SIMULATION AND RESULTS:

MATLAB Simulation

System modeling and simulation analysis can reduce the development costs and shorten the development cycle. To properly simulate the performance of a plug-in hybrid electric two-wheeler, a MATLAB based computer model was created based on the physical properties of a vehicle. The simulation model calculates the energy and power requirements of the plug-in hybrid electric two-wheeler based on driving pattern. The simulation also helps in estimating the state of charge of the battery and fuel consumption of engine during hybrid mode, engine mode and all electric modes. Based on this simulation, one can estimate the running cost of vehicle in all the three modes as mentioned above.

Based on the input data's from the IDC curves such as the velocity and acceleration of the vehicle with the corresponding time in seconds, total resistance forces acting on the vehicle can be calculated. With the resistance values known at each instance of a second, the corresponding tractive force, instantaneous power requirement and hence the total energy demand can be estimated at each instance. The key factors that influence the deployment of plug-in hybrid electric two-wheeler for the desired all-electric range are the driving cycle and energy storage device. The influence of other drive-line components on the vehicle performance and cost are not considered in the simulation.

Simulation Methodology with Codes:

The important steps in the simulation process are as follows along with the simulation codes used in MATLAB:

- The required physical parameters for the simulation are taken from the userand stored with the corresponding variables

```
m=input('Enter the mass of the Vehicle(kg)');
D=input('Enter density of air(kg/m^3)');
Cd=input('Enter coefficient of drag');
Crr=input('Enter coefficient of rolling resistance');
g=input('Enter the value of acceleration due to gravity(m/s^2)');
Ar=input('Enter the frontal area of the vehicle(m^2)');
a=input('Enter the road inclination(Deg)');
Rw=input('Enter the radius of wheel(m)');
Vn=input('Enter the battery voltage(V)');
Id=input('Enter the distance travelled in a cycle)(m)');
Se=input('Enter the specific energy of the battery(Wh/kg)');
Q=input('Enter the capacity of the battery(Ah)');
```

- Then the IDC parameters like time with corresponding velocities and acceleration are read from the Microsoft excel file as shown

```
A=xlsread('IDC','A1:A108');%Acceleration values taken from IDC table
V=xlsread('IDC','B1:B108');%Velocity values taken from IDC table
t=xlsread('IDC','C1:C108');%Time values taken from IDC table
```

- Similarly the specific fuel consumption at particular rpm values and corresponding power are read from excel file as follows

```
sfcrpm=xlsread('SFC','A1:A11');%rpm values with corresponding sfc
power=xlsread('SFC','C1:C11');%POWER CORRESPOND TO RPM
sfc=xlsread('SFC','B1:B11');%sfc values for corresponding rpm
```

- A loop is initialized and iterated for driving cycle data values of aerodynamic resistance, rolling resistance, acceleration resistance, gradient resistance, tractive force, and power demand are calculated using the formulae.

```
for i=1:108
Fa(i)=0.5*D*Cd*Ar*(V(i))^2;%Aero Resistance(N)
Fg=m*g*sin(a);%Gradient Resistance initial(N)
Fr=m*g*Crr;%Rolling Resistance initial(N)
Fac(i)=m*A(i);%Acceleration Resistance initial(N)
Fti(i)=Fa(i)+Fg+Fr+Fac(i);%Total Tractive Force initial(N)
Twi(i)=Fti(i)*Rw;%Torque at the wheel initial(Nm)
Pdi(i)=Fti(i)*V(i);%Power demand initial(Nm/s)
end
```

- The usable energy required at every instant is calculated by multiplying the integral of power values with the corresponding difference in time.

```
for j=2:108
    Pdfi(1)=abs(Pdi(1));
    Pdfi(j)=Pdfi(j-1)+abs(Pdi(j));
end
for i=2:108
    Eri(1)=Pdfi(1)*t(1);
    Eri(i)=Pdfi(i)*(t(i)-t(i-1))/3600;%Energy required(Wh)
end
```

- The hybrid control strategy is executed through the following coding and the corresponding fuel consumption of engine and state of charge of battery are determined

```
for i=2:108
    wrpm(i)=(V(i)*60)/(2*3.14*Rw);
    erpm(i)=wrpm(i)*4;
    if (V(i)>8.33)
        for j=2:9
            if (erpm(i)<sfcrpm(j))
                FC(i)=FC(i-1)+(sfc(j)*power(j)/3600);
                IH(i)=IH(i-1);
                HSOC(i)=HSOC(i-1);
                j=9;
            end
        end
    else IH(1)=z(1);
        IH(i)=IH(i-1)+z(i);
        HSOC(1)=(Q-(IH(1)*t(1)/3600))/Q;
        HSOC(i)=(Q-(IH(i)*((t(i)-t(i-1))/3600)))/Q;
        FC(i)=FC(i-1);
    end
end
```

Then the fuel consumption during the engine only mode of operation is as follows

```
for i=2:108
    wrpm(i)=(V(i)*60)/(2*3.14*Rw);
    erpm(i)=wrpm(i)*4;
    for j=2:9
            if (erpm(i)<sfcrpm(j))
                EFC(1)=0
                EFC(i)=EFC(i-1)+(sfc(j)*power(j)/3600);
                j=9;
            end
    end
end
```

- Similarly the state of charge of battery during complete electric operation is as follows

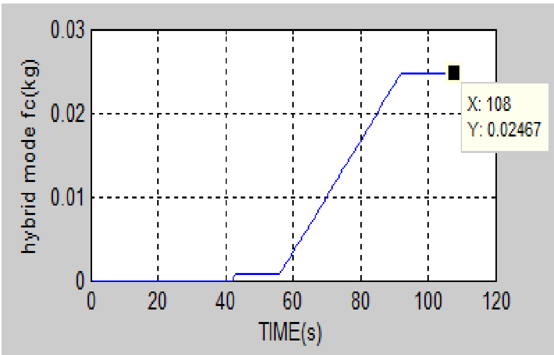
```
for j=2:108
    I(1)=z(1);
    I(j)=I(j-1)+z(j);
end
for i=2:108
    SOC(1)=(Q-(I(1)*t(1)/3600))/Q;
    SOC(i)=(Q-(I(i)*((t(i)-t(i-1))/3600)))/Q;
end
```

INDIAN DRIVING CYCLE DATA

Parameters	**Units**	**IDC (6 Cycles)**
Total time	Seconds	648
Distance covered	Km	3.948
Average Speed	km/h	21.93
Max. Speed	km/h	42
Maximum Acceleration	m/s^2	0.65
Maximum Deceleration	m/s^2	0.63
Idling	% time	14.81
Acceleration	% time	38.89
Constant Speed	% time	12.04
Deceleration	% time	34.26

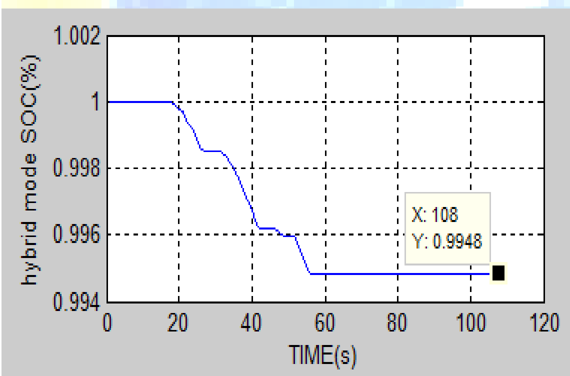
Results:

Hybrid mode:



Fuel Consumption In Hybrid Mode

The above graph shows that the fuel consumption of the engine running in hybrid mode is found to be 24.67g for every 108 s of operation according to INDIAN DRIVING CYCLE



Battery State Of Charge In Hybrid Mode

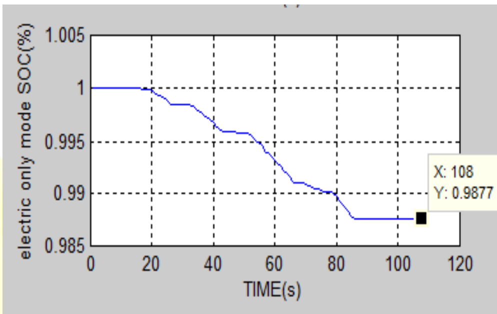
Similarly the state of charge of the battery drops to 99.48% from 100%, which shows that for every 108 s of vehicle operation according to Indian driving cycle battery charge depletes of about 0.52%

From the above two results the cost of running can be calculated as follows

Running cost=fuel consumption per km* cost per liter+
no. of units consumed per km* cost per unit
run_cost=(FC(108)*95)+(IH(108)*Vn*t(108)*1/3600000);

And the running cost with this hybrid mode of configuration is found out to be Rs 3.01 per km in Indian driving condition.

All electric mode:



Battery state of charge in all electric mode

From the above graph the reduction in state of charge of the battery is found to be of about 1.23% for 108 s in Indian driving cycle.

With this data the cost of running in All Electric mode is found to be Rs 1.8per km

Similarly the maximum range that could be covered in all electric range with battery state of charge not dropping below 20% can be calculated as follows,

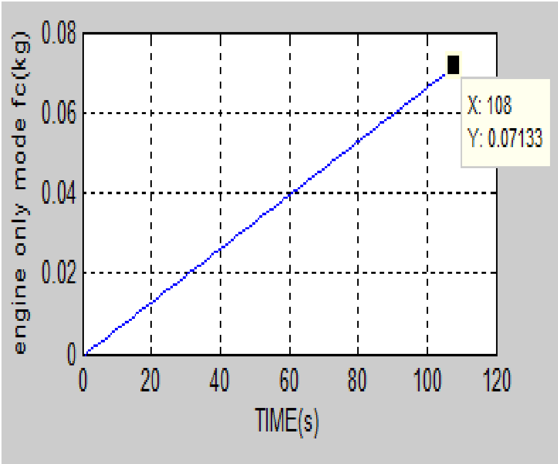
For 1.23% to drop it takes 108 seconds

For 80% of charge to drain it takes 7025 seconds

Within 7025 seconds of running time about 65 IDC cycles gets completed each of 108 seconds which covers a distance of about 48 km.

Thus the range in all electric mode is 48 km per every full charging.

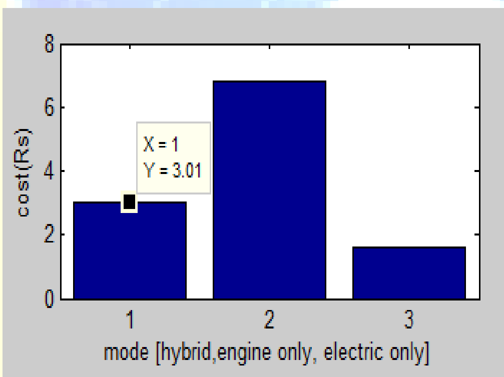
Engine only mode:



Engine Fuel Consumption In Engine Only Mode

With the above mentioned fuel consumption of 71.33 g per liter the running cost is found to be of about Rs 6.5 per km following IDC

Comparison between different modes:



Running cost comparison in all the three configurations

The above graph shows that the running cost comparison between all the three types of configuration. It is clear that the running cost of a hybridized two wheeler is far lower than that of a IC engine powered vehicle.

VIII . CONCLUSION:

From MATLAB modeling and simulation using Indian driving cycle, several conclusions are obtained as follows:

- The MATLAB simulation helps in deciding the powertrain components for plug-in hybrid electric two-wheeler suitable for different required configuration with reference to driving cycle
- From the results obtained above it is found out that the running cost of the hybradised vehicle is much lower compared to that of the actual IC engine vehicle.
- And engine is also found to be running for only about 40% of entire driving range and that too in its most efficint range of operation, which also implies that there is a considerable reduction in its emission levels.
- Similarly the drawbacks in performance characteristics of electric vehicles like range, maximum cruise speed, acceleration and gradability are overcomed by the vehicle which could be drive in only engine configuration.

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