SPHEV Design using PI/PD/PID Controller

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Abstract— This paper deals with the increasing oil price and mounting environment concerns, cleaner and sustainable energy solutions have been demanded. At present transportation constitutes a large portion of the energy consumed and pollution created. One of the efficient solutions is the existence of vehicle that works on both fuel energy and electrical energy with optimized performance. HEV with different structures such as series, parallel, series parallel has been studied so far. HEV is consists of mainly two design elements mechanical and electrical. Mechanical design part includes ICE Car Dynamics while Electrical part includes Controller Design and Electrical Subsystem. This dissertation work especially focuses on the controller design of HEV. HEV control section includes four different rudiments to be controlled. These are engine speed controller generator controller motor controller and battery controller. In this work we have considered design of proportional integral (PI), proportional derivative (PD), proportional integral derivative (PID)for analysis of engine, motor and generator performance. This leads to the development of component models of the physical system such as the power distribution system and mechanical driveline. We also show the development of an energy management strategy for several modes of operation including the full electric hybrid and combustion engine modes. Finally we show how an integrated environment facilitates the combination of various subsystems and enables engineers to verify that overall performance meets the desired requirements. In this dissertation work design of electrical part i.e. control design and ESS design has been carried out. The designed SPHEV has been analyzed with the step change accelerator profile for the PI, PD, PID using performance measures such as rise time settling time peak time and peak overshoot.

Key words: Electric Vehicle, Hybrid Electric Vehicle, Matlab Modeling, Control Vehicle

I. INTRODUCTION

In recent years a major interest in HEV has arisen globally because of pressing environmental concerns and skyrocketing price of oil. Representing a revolutionary modification in vehicle style philosophy hybrid vehicles surfaced in many various ways. However they share the hybrid power train that combines multiple power sources of different nature including conventional ICE, batteries, ultra capacitors, or hydrogen FC. These vehicles with on board energy storage devices and electric drives allows braking power to be recovered and ensures the ICE to operate only in the most efficient mode thus improving fuel economy and reducing pollutants.

The United Nations estimated that over 600 million individuals in populated area worldwide were exposed to traffic generated air pollution. So traffic connected air pollution is drawing increasing concerns worldwide. Hybrid electric vehicles hold the potential to significantly scale back GHG emission and different gas pollution. A fuel cell HEV which only produce water and heat as emissions during operation makes pollution more controllable by centralizing GHG emission and air pollution to the hydrogen production method at giant scale producing facilities. ICE based hybrids on the the opposite hand, will improve the fuel economy and reduce tailpipe emission by additional economical engine operation. The improvements come from regenerative braking motion down the ICE whereas stationary and permitting a smaller more efficient engine that isn't needed to follow the power at the wheel as closely as the engine in a conventional vehicle must. In an emission result comparison of the Toyota (HEV) and Toyota Corolla it was reported that the only produced 71% of CO2, 4% of CO and 0.5% of compared with the Toyota Corolla. The Corolla is one of most effective typical vehicles on the market.[1]

II. OBJECTIVE OF THE WORK

Around the world we are experiencing a strong upward trend in oil demand and tight supply. Maintaining a secure energy provide becomes an ongoing concern and a high priority. The US DOE states that over fifteen million barrels of crude oil are being consumed within the nation of that 69% are for the transportation sector. The transport energy consumption worldwide also are still rise speedily. In 2000 it had been 25% on top of in 1990 and it's projected to grow by 90% between 2000 and 2030. Many HEV projects reported fuel economy improvement from 20% to 40%. thus HEV provides a promising solution to relieve the energy shortage. In 1970 many auto mobile manufacturers such as GM, Ford and Toyota began to develop electric vehicles powered by batteries due to the oil shortage. The interest in hydrogen fuel cell cars has arisen as a result to address the range problem associated with battery power cars. However with more than 15 of intensive development there are still not any fuel cell hybrid cars on market mainly due to the high manufacturing cost. In 1997 Toyota introduced the primary ICE primarily based HEV to the Japanese market. Ever since an increasing number of HEV have become accessible.

From the above survey it is noted that there is a large scope for analysis and development within the field of HEV. It has been decided to explore the problems related to design of HEV particulary design of controller which works as brain of HEV.

III. HEV CLASSIFICATIONS

One of the most common ways to classify HEV is predicated on configuration of the vehicle drive train. During this section three major hybrid vehicle architectures introduced are series, parallel and series parallel. Until recently several HEV in production are either series or parallel. In terms of mechanical structure these two are primitive and comparatively simple. A series parallel power train brings in more degrees of freedom to vehicle engine operation with added system complexity.

A. Series Hybrid Configuration

One of the basic types of HEV is series hybrid. In this configuration the ICE is used to generate electricity in a generator. Electric power produced by the generator goes to either the motor or ESS. The hybrid power is summed at an electrical node the motor. Early on in the latest development of the hybrid vehicle many automotive OEMs explored the likelihood series hybrid vehicle. Some of the most notables are the Volvo ECC and BMW 3 Series. Despite the early research and prototypes the possibility for series hybrids to be ordinarily employed in transport applications looks to be remote. The series hybrid configuration tends to have a high efficiency at its engine operation. However the summed electrical mode has tied up the size of every component. The weight and cost of the vehicle is increased due to the large size of the engine and the two electric machines needed. The dimensions of the power electronic unit are additionally excessive. The configuration of fuel cell HEV is also technically in series.

B. Parallel Hybrid Configuration

The parallel hybrid is another HEV type that has been closely studied. In parallel configurations each the engine and also the motor provide traction power to the wheels which suggests that the hybrid power is summed at a mechanical node to power the vehicle. As a result, each of the engine and also the motors can be down sized creating the parallel architecture more viable with lower prices and better efficiency.

The parallel hybrid vehicles usually use the constant gearboxes of the counterpart standard vehicles either in automatic or manual transmissions. Based on where the gearbox is introduced in the power train there are two typical parallel HEV architectures named pre transmission parallel and post transmission parallel respectively.

In a pre-transmission parallel HEV the gearbox is located on the most drive shaft after the torque coupler. thence gear speed ratios apply on each the engine and also the electric motor. The power flow is summed at the gearbox. On the other hand in a post transmission parallel hybrid the gearbox is located on the engine shaft prior to the torque coupler. The gearbox speed ratios only apply on the engine.

C. Series Parallel Configuration

In the series parallel configurations the vehicle can operate as a series hybrid a parallel hybrid or a combination of both. This design depends on the presence of two motor generators and the connections between them which may be each electrical and mechanical. The mechanical connections between the engine and electrical machines are sometimes accomplished by planetary gears called as PSDs.

One advantage of a series parallel configuration is that the engine speed can be decoupled from the vehicle speed. This advantage is partially offset by the additional losses within the conversion between mechanical power from engine and electrical energy. There area unit variety of variations of series parallel configurations. A most renowned one is the Toyota THS design that was first used on a Toyota. Today, most hybrid vehicles at the production stage have been either of parallel or series configuration, as the series parallel design is a smaller amount mature in its development. buta review of the literatures from both academic and commercial sources reveals that the present state of the art of hybrid technology employs the series parallel configuration. [2],[3]

IV. Hybrid Electric Vehicle Design

A diagram of one possible HEV architecture is shown in Figure 1 the arrows represent possible power flows. Designs can also include a generator that is placed between the power splitter and the battery allowing excess energy to flow back into the battery conceptually the hybrid electric vehicle has characteristics of both the electric vehicle and the ICE vehicle. At low speeds it operates as an electric vehicle with the battery supplying the drive power. At higher speeds the engine and the battery work together to meet the drive power demand the sharing and the distribution of power between these two sources are key determinants of fuel efficiency.

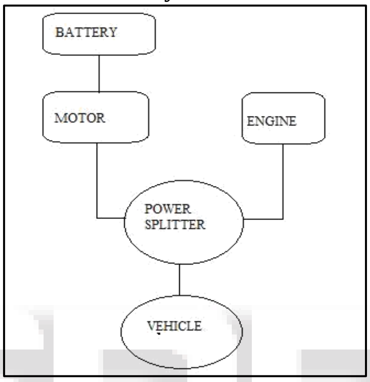


Fig. 1: Components of a hybrid electric vehicle

Note that there are many other possible designs given the many ways that power sources can work together to meet total demand.

A. Design Steps

The key problems in HEV design are typical of classical engineering issues that involve multilayer, multi domain compleness with tradeoffs. Here we have a tendency briefly the key aspects of the part design. [4]

1) Engine Design

The key parts of engine design are very similar to those of a traditional ICE. Engines used in an HEV are typically smaller than that of a traditional vehicle of the similar size and the size selected will depend on the total power needs of the vehicle.

2) Battery Design

The main concerns in battery design are capacity, discharge characteristics and safety. Traditionally a higher capacity is associated with increase in size and weight. Discharge characteristics determine the dynamic response of electrical components to extract or supply energy to the battery.

3) Motor

Motors generally used in HEV systems are DC motors, AC induction motors, or PMSM. In this list the PMSM has the highest power density and the DC motor has the lowest.[5]

4) Power Splitter

A planetary gear is an effective power splitter that allows power flows from the two power sources to the driveshaft. The engine is typically connected to the sun gear while the motor is connected to the ring gear.

5) Vehicle Dynamics

The focus is on friction and aerodynamic drag interactions with weight and grade ability factors accounted in the equations. Following parameters has been considered so far has the design of the HEV has been concerned. The parameters are for motor, generator, controller and vehicle dynamics etc.

V. Controller Design

In process control applications more than 95% controllers namely PI, PD and PID are in use. Their easily comprehensible principles and relatively simple implementations have been the main reason for their wide use in process industry. But in conventional control linear approximation of the plant parameters has some disadvantages such as the linear approximation becomes computationally impractical if the plant is advanced and extremely dynamic. Additionally there are difficulties in adapting itself to dynamic plant parameters. Thus conventional controllers have drawbacks of approximating the properties of the system and are very sensitive to variations within the method parameters.

A. *PI Controller*

If the closed loop system exhibits a sustained error in steady state integral action is necessary. The integral action will increase (decrease) the control signal if there is a positive (negative) error even for small magnitudes of the error. Thus a controller with integral action will always return to the reference in steady state. The PI controller is represented by

$$U_{PI}(k) = K_P\left(e(k) + \frac{1}{T_I}\Delta e(k)\right) \quad (5.1)$$

Where T_I is the integral time Δe (k) is incremental error and U_{PI} is output of PI controller.
Eq. (5.1) may be written as

$$U_{PI}(k) = \left(K_P e(k) + K_I \Delta e(k)\right) \quad (5.2)$$

Where K_I represents the integral gain.

B. *PD Controller*

In some of the plant dynamics it will take some time before a change in the control signal is noticeable in the plant output and the proportional controller will be equally late in correcting for an error. Derivative action helps to predict the long error and the PD controller uses the derivative action to improve closed loop stability.

The PD controller is described as

$$U_{PD}(k) = K_P[e(k) + T_D\, ce(k)] \quad (5.3)$$

Where K_P, T_D are the proportional gain and derivative time while e(k), ce(k) are error and change in error respectively. U_{PD} is output of PD controller. Eq. (4.3) may be written as

$$U_{PD}(k) = [K_P e(k) + K_D\, ce(k)] \quad (5.4)$$

Where K_D is derivative gain.[10]

C. *PID Controller*

PID controller combines the advantages of PI and PD controller. Mostly PID controller is used for large number of industrial applications. For slow processes such as temperature control it will gives improved performance. The PID controller is represented as

$$U_{PID}(k) = K_P e(k) + K_I \Delta e(k) + K_D ce(k) \quad (5.5)$$

U_{PID} is the output of the PID controller.

In our study we have used PI, PD and PID controller for motor speed controller for studying the effect of the controller on the SPHEV performance. The value used for controller parameters are given in table 1.

Parameter	**Value**
Motor	
Stator Resistance (Ω)	0.0065*14
Speed (rpm)	[0 1200 2000 3000 4000 5000 6000 6500 10000]
Torque (N-m)	[400 400 225 150 100 80 70 0 0]
Time Constant (sec)	0.02*2/1.5
Shaft Inertia	0.2
Resistance (Ω)	0.01
Inductance (H)	[0.0015979 0.00205]
Efficiency (%)	91
Generator	
Stator Resistance (Ω)	0.05*0.095
Inductance (H)	[0.000635 0.000635]
Speed (rpm)	[0 1200 2000 3000 4000 10000 15000]
Torque (N-m)	[400 400 250 150 110 0 0]
Time Constant (sec)	0.02*2
Shaft Inertia	0.2
Resistance ((Ω)	0.01
Controller	
Engine Start rpm	800
Engine Stop rpm	790
ICE Kp	0.02
ICE Ki	0.01
ICE Kd	0.01
Generator Kp	10
Generator Ki	3
Generator Kd	5
Motor Kp	500
Motor Ki	300
Motor Kd	200
Vehicle Kp	0.02
Vehicle Ki	0.04
Vehicle Kd	0.02
Vehicle Parameters	
Vehicle Mass (Kg)	600*2
Vehcile Tire Radius(m)	0.3
Vehicle Wheel Inertia ($Kg\text{-}m^2$)	0.1
Engine Vehicle Gear Ratio	1.3
CG Front Axle	1.35
Frontal Area	2.16
Shaft Inertia	0.25
Max Power (W) Speed at Max Power (rpm)	57000+57000 and 5000

Table 1: Design Parameters for HEV

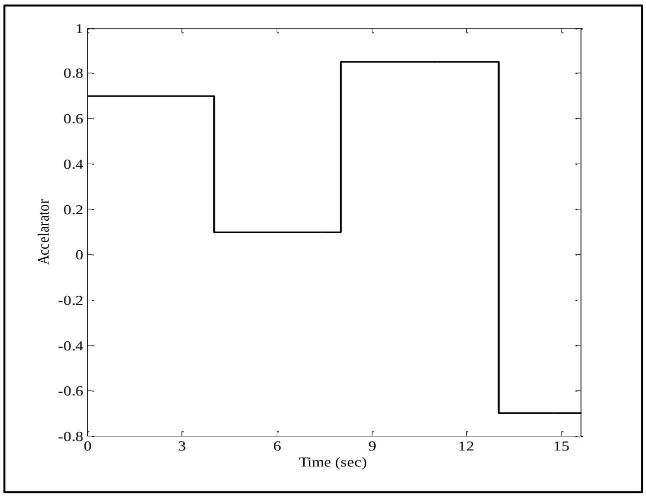
VI. Simulation Results

The simulation shows totally different operating modes of the SPHEV over one complete cycle.

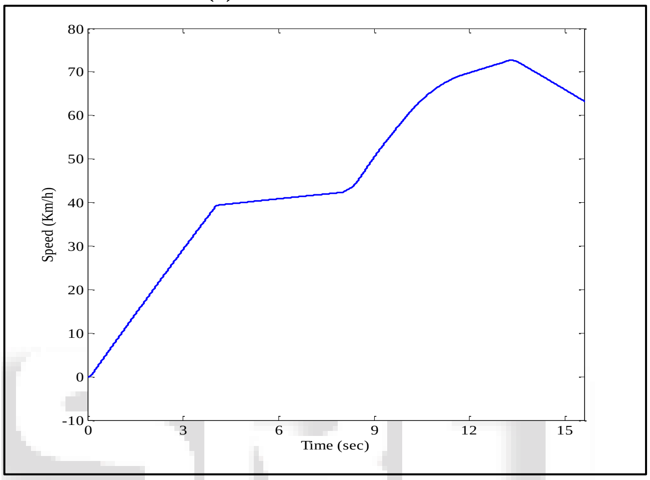
Accelerating 2 Cruising 3. Recharging the battery whereas fast and 4. Regenerative braking.

The HEV speed starts from 0 km/h and reaches 73 km/h at 14 s and eventually decreases to 61 km/h at 16 s. This result is obtained by maintaining the accelerator pedal constant to 70% for the first 4 s and to 10% for the next 4 s when the pedal is released then to 85% when the pedal is pushed again for 5 s and finally sets to -70% (braking) until the end of the simulation. The subsequent steps can justify explain operation of the HEV.

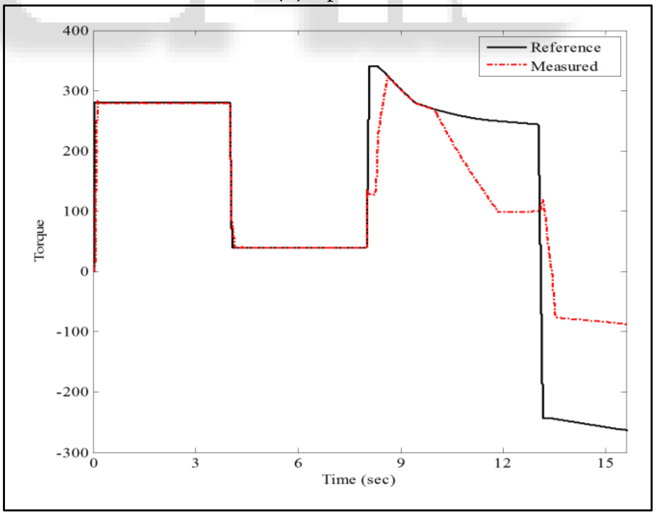
1) At t = 0 sec the HEV is stopped and also the driver pushes the accelerator pedal to 70%. As long as the required power is lower than 12 kW the HEV moves using only the electric motor power fed by the battery. The generator and the ICE provide no power.
2) At t = 1.4 sec the required power becomes greater than 12 kW triggering the hybrid mode. In this case the HEV power comes from the ICE and the battery (via the motor). The motor is fed by the battery and also by the generator. In the planetary gear the ICE is connected to .the carrier gear the generator to the sun gear and the motor and transmission to the ring gear. The ICE power is split to the sun and the ring. This operating mode corresponds to acceleration.
3) At t = 4 sec the accelerator pedal is released to 10% (cruising mode). The ICE cannot decrease its power instantly therefore the battery absorbs the generator power in order to reduce the required torque.
4) At t = 4.4sec the generator is totally stopped. The required electrical power is only provided by the battery.
5) At t = 8 sec the accelerator pedal is pushed to 85%. The ICE is restarted to provide the extra required power. The total electrical power (generator and battery) cannot reach the required power due to the generator ICE assembly response time. Hence the measured drive torque is not equal to the reference.
6) At t = 8.7 sec the measured torque reaches the reference. The generator provides the maximum power.
7) At t = 10 sec the battery SOC becomes lower than 40% (it was initialized to 41.53 % at the beginning of the simulation) therefore the battery needs to be recharged. The generator shares its power between the battery and the motor. It is observed that the battery power becomes negative. It means that the battery receives power from the generator and recharges while the HEV is accelerating. At this moment the required torque cannot be met anymore because the electric motor reduces its power demand to recharge the battery.
8) At t = 13 sec the accelerator pedal is set to -70% (regenerative braking is simulated). This is done by switching off the generator (the generator power takes 0.5 s to decrease to zero) and by ordering the motor to act as a generator driven by the vehicle's wheels. The kinetic energy of the HEV is transformed as electrical energy which is stored in the battery.



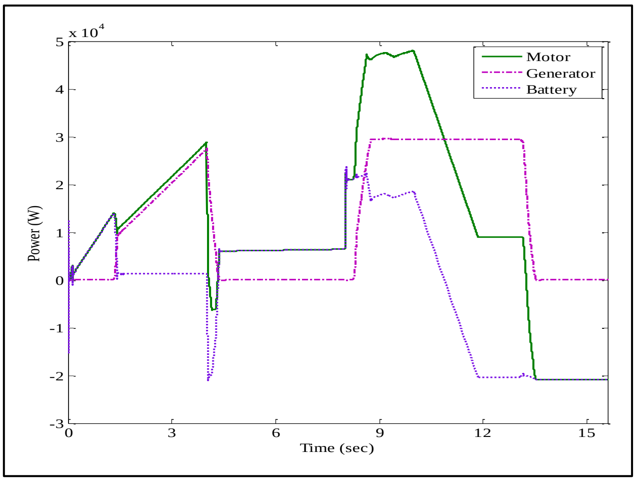
(a) Accelerator Profile



(b) Speed

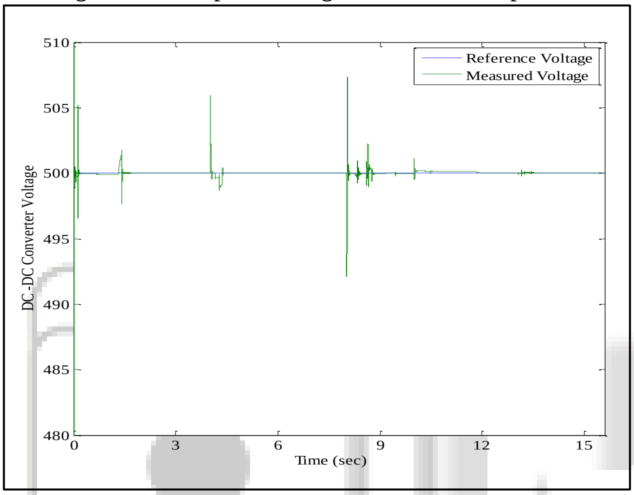


(c) Torque

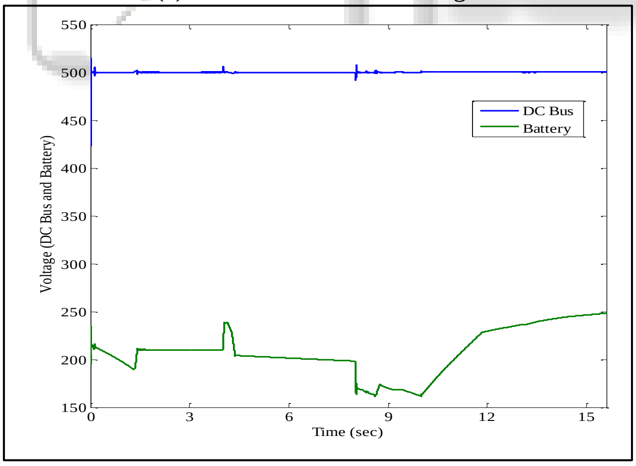


(d) Power

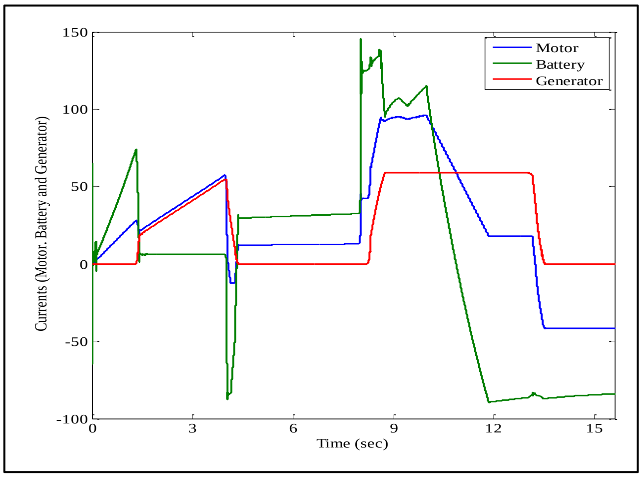
Fig. 2: Car Response for given accelerator profile



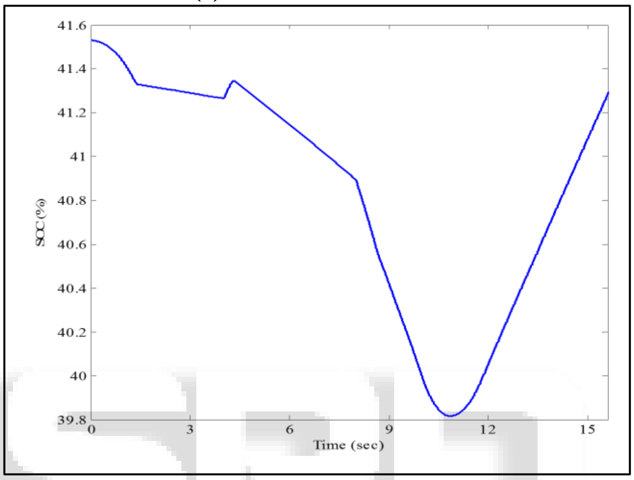
(a) DC-DC Converter Voltage



(b) Voltage wave form

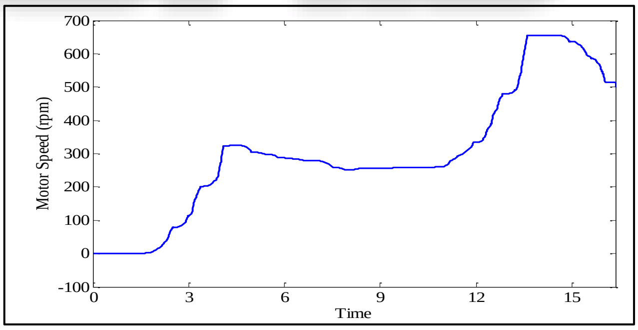


(c) Currents wave form

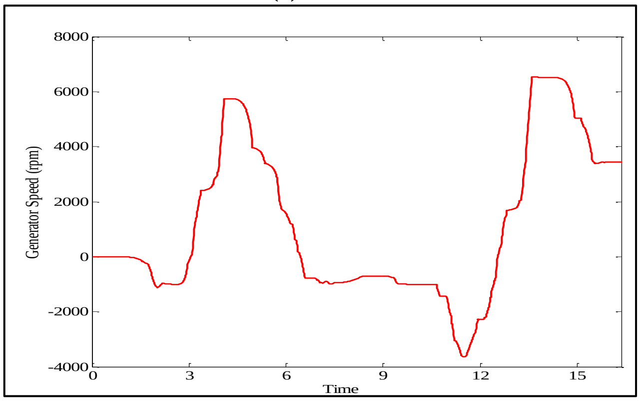


(d) Battery SOC

Fig. 3: Electrical subsystem variations for Battery, Generator and Motor.

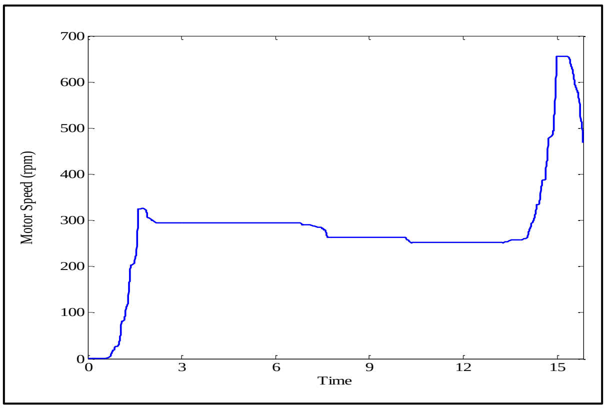


(a) Motor

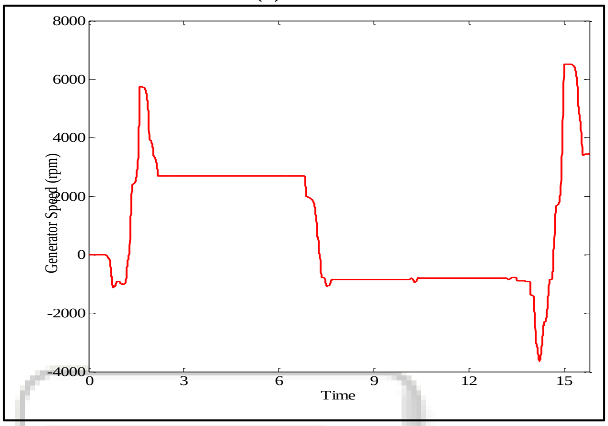


(b) Generator

Fig. 4: Variations of Motor Generator Speed due to PI Controller

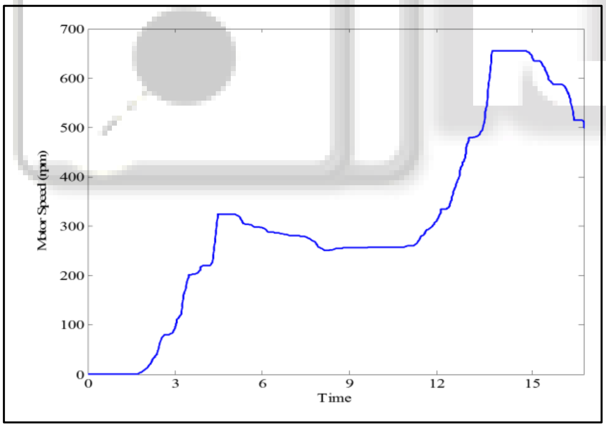


(a) Motor

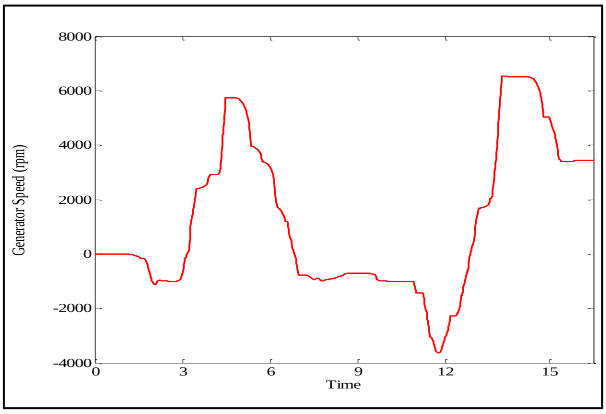


(b) Generator

Fig. 5: Variations of Motor Generator Speed due to PD Controller



Motor



(b) Generator

Fig. 6: Variations of Motor Generator Speed due to PID Controller

Controller	Rise Time (Sec)	Peak Time (Sec)	Peak Overshoot (%)	Settling Time (Sec)
PI	1.5937	2.5937	15.23	5.548
PD	1.5917	2.5917	21	5.5567
PID	3.3467	4.3467	21	9.2627

Table 2: The performance of HEV using PI /PD/PID Controller

In this paper we have described simplified model of SPHEV during which we have focused on different parts such as vehicle dynamics electrical subsystem and energy management system. In this chapter we have also enlightened controllers such as PI, PD and PID in brief used for speed control of SPHEV. It can be noted that modelling and simulation will play important roles in the success of HEV design and development [10].

In this paper PI, PD, PID control for engine has been investigated. The main aspect is maximizing the vehicle's energy capture during the braking process. Finally sustaining the SOC of the battery is adopted by a robust controller of the ICE. The controllers have been designed by considering speed of vehicle as main constraint. The vehicle's performances have been analyzed for given accelerator profile. The simulation results show that world control system is effective to regulate the engine operating points within the highest efficiency region, exploiting of machines for capturing most braking energy as well as to sustain the SOC of the battery while satisfy the drive ability. The proposed management strategy for the studied HEVs sounds interesting than the conventional strategies PI, PD and PID controller and is possible as supported by a large amount of simulation results.

VII. CONCLUSIONS

Following conclusions can be drawn from this thesis.

1) The MATLAB®/SIMULINK SPHEV model provides modular flexible and easily modifiable platform so that different kind of HEV can be modeled and simulate to virtually investigate their performance prior to the actual manufacturing of the HEV.
2) We discussed how the complications arise from the complex interaction between various mechanical and electrical components i.e. engine battery electric machines controllers and vehicle mechanics and complications get removed by using HEV.
3) We can conclude that the efficiency, fuel consumption and pollution is reduced by using HEV.

VIII. SCOPE OF FUTURE WORK

Future work that could build off this dissertation work would include the implementation of the hybrid vehicle design and collecting real world data to compare results against what was modeled using FLC. While the basic strategy is in place more considerations need to be made. While the hardware in the loop testing has been used to improve shift quality on road testing may show more improvement is still needed. Following points should be focused as future work.

1) The current strategy is only optimized for speed control of motor based on FLC and therefore limits

engine torque and restrains the engine speed so a performance mode could be added that further open the engine operation range using other advanced technologies such as neural network, genetic algorithms etc.

2) The other interesting thing is to add a super capacitor in the HEV in connection to the battery. The super capacitor has higher specific energy and can deliver higher power than an ordinary battery. It is an electrolytic capacitor device and the energy is stored as electrostatic charge. The current from the battery is sometimes smaller than required. Therefore we can add a super capacitor that can deliver a higher current during a certain time, when it is required and be a backup and give extra power to the battery.
3) Another idea is to have different strategies when charging the battery. It is better to charge the battery only when it has reached the lower limit or should it be charge continuously when a good opportunity appears. It is also important to investigate how components and models in MATLAB® toolboxes can be combined with other libraries

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