STUDY AND ANALYSIS OF SERIES PARALLEL HYBRID ELECTRIC VEHICLE

A Dissertation submitted in partial fulfillment of the requirements for the award of degree

Of

MASTER OF ENGINEERING

In

Power Systems

Submitted by

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DECALARATION

I hereby certify that the work which is presented in dissertation entitled, **"STUDY AND ANALYSIS OF SERIES PARALLEL HYBRID ELECTRIC VEHICLE"**, in partial fulfillment of the requirements for the award of the degree of Master of Engineering in Power Systems, submitted to Electrical & Instrumentation Engineering Department of Thapar University, Patiala is as authentic record of my own work carried under the supervision of Dr. Santosh Sonar. It refers others researcher's work which are duly listed in the reference section. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other degree to any other university or institute except as reported in text and references.

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This is to certify that the above statement made by the candidate is true to best of my knowledge and believe.

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DEDICATED TO MY PARENTS

TEACHERS AND FRIENDS

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ABREVIATION

1: SPHEV	**SERIES PARALLEL HYBRID ELECTRIC VEHICLE**
2: Nm	**NEWTON METER.**
3: T_R	**TORQUE CONSTANT.**
4: T_C	**TIME CONSTANT.**
5: ICE	**INTERNAL COMBUTION ENGINE.**
6: PI	**PROPORTIONAL INTEGRATION.**
7. OEM	**ORIGINAL EQUIPMENT MANUFACTURE.**

ABSTRACT

With growing oil prices and escalating environment worries, cleaner and supportable energy solutions is demanded. Present transportation contributes large amount of energy consumption and emission of pollutants. In this work, hybrid vehicle technology has been analyzed, with Power split configuration having internal combustion engine and battery as the power source. Initially the analysis of SPHEV performance is done with battery of higher amp-hr capacity .In advanced state the converter circuit is implemented to reduce the battery rating. Different cases has been observed with different charging and discharging circuitry of battery. To improve modeling accuracy, MATLAB (Simscape/Simdriveline/Simulink) tool is used for simulation, discovering the possibilities of advanced hybrid powertrain architectures and energy storage system designs. The study forms the foundation of the proposed work. Hybrid electric vehicles are admired because of their ability to achieve related performance to a standard automobile while prominently improving fuel efficiency and tailpipe emissions. SPHEV is combination of the series and parallel Hybrid electric vehicle configuration. Though having complex architecture SPHEV are preferred over simple power trains because of its advances and advantages. The work can be analyzed with different sources like Fuel cell, as the energy source to the vehicle, making the less use of fossil fuel.

CHAPTER 1

INTRODUCTION

Renewable energy technologies like fuel cell and solar are gaining popularity for vehicle application. These energy sources reduces harmful gases, and reduce dependability on the fossil energy. An increasing ecological awareness and the shortage of fossil-fuel resources leads to develop more efficient vehicle, with lower fuel consumption. The hybrid electric vehicle, combining power conventional internal combustion engines (ICE), batteries, ultra-capacitors, or hydrogen fuel cells (FC) is a hopeful concept. In addition, the development of powerful batteries with large capacities allows the electric vehicle to be alternative for the vehicle application[2]. Representing an innovative change in vehicle design philosophy, hybrid vehicles raised in many different ways. HEV with onboard energy storage devices and electric drives allows braking power to recover and ensures the ICE to operate in the most efficient way, thus improving fuel economy and reducing pollutants. Because of advanced design philosophy and technology, the development and commercialization of HEV technologies demanded extensive research and study. This research aims to address number of problems in the development of HEV[2]

1.1 LITERATURE SURVEY

[1] In the paper fractional order control of three level boost DC-DCconverter used in HEV is discussed.Power electronics is wildely used in medical,transportation and aeronautic. In HEV the DC-DC converter is used to control the power flow between battery and motor/generator set.a FOPID controller for control of storage system through DCDC converter. Simulation results are verified using the MATLAB Simulink. Comparison with the classical PID controller is done and also the future use of these convereter to make the performance of power electronic circuitry better.

[2] Overview of the hybrid electric vehicle is discussed with future scope of vehicle technology. Different configuration are discussed with benefits of the each series parallele and seies-parallel configuration .different types of motors which can be used in the HEV are discussed in the paper

with advantages , disadvantages. It gives an overview about Hybrid technology how we can use different energy sources together.

[3] As green technology is gaining attention because of the rise in cost of the petroleum products. Battery driven vehicle are not new to the market , now concept of hybrid electric vehicle is gaining attention . power electronics play very important role in connecting these renewable sources like solar cell fuelcell to the vehicle as the energy source.in the paper designing of dual DC-DC converter for hybrid vehicle is discussed . converter perform buck ,boost ,buck-boost operation for the HEV as per requirement .experimental result are verified in the paper.this is useful in study the comparison of converter operation for ideal and actual condition .this paper gives overview of the integration of sources like PV solar wind etc to the vehicle .

[4] In the paper two different control strategy,with two different energy source ,one with battery and fuel cell, other battery and supecapacitor.In the paper new method to calculate the power demand using the hybrid algorithm with wavwlet distribution and neural netwaork is given.MATLAB fuzzy loggic tool box is used.in the paper th study of HEV with different sources on board is discussed and simulation reault are being displayed, signal distribution with wavelwt distribution is implemented using fuzzy which give scope of implementing new methodolgy for distribution of signal thus more control on power distribution is possible.

[5] This paper about the modelling of the DC-DC converter for HEV and EV applications. Basic understanding of the converter circuit is analysed using in this paper. Matlab modelling for buck converter is explained with simulation result for HEV and EV application .The overshoot in the system is distributed by the PID controller. The paper determine the high performance features of DC-DC convereter for the HEVand EV.Thus meeting the future load demand of vehicles also the same time efficiency is increased using the electronic circuitary . Reduction in volume as well as weight of wire harness ,Fuel economy is also improved using the Hybrid technology . Use of advanced power electronic devices for management of fuel from the engine and best utilisation of the battery pack.

[6] Hybrid electric vehicles are in demand because of the rising price of the fuel used in vehicles. Modelling and simulation of Hybrid electric train is being discussed in the paper thoroughly.the speed torque response of the poertrain are also described in the paper.In the model the sysytem is

considered to be loassless, so further efficiency of model can be improved by taking in consideration the losses as well the hybrid PMSM motor .

[7] In the paper co simulation method is implemented using the HEV model in MATLAB simulink and ADAMS is used for electro-mechanical transmission modelling .as the modelling and simulation are very important part of the development process for the vehicle.dynamical analysis of the EV and HEV can be performed using simulation software.Control startegy using the torque control and speed control is discussed in the paper.

[8] In the paper series hybrid electric vehicle design and development using the MATLAB software is done . as the HEV is new technology so specific study how the model is developed and study of various types of parameters helps the development process. Future implementation of this model on hardware gives actual reslut under different condition .

[9] In the paper approach to identify state of art and trends in electrical mobility is discussed using the survey report of coprising data of more than 200 electrified vehicle. Parameters are being selected on which the performance of these vehicle depends i.e Batteries(technology(LiOn ,NiCd), nominal energy ,nominal power,specific energy and power), Electric machines(technology(synchronous machine ,induction machine),effective power KWH,power density KW/Kg,nominal torque. HEV power train archictecture are defined taking in consideration the new trends in tecnological advancement of parts of vehicle.In the paper vehicle comparison on basis of carbon dioxide and other gases emission is examined .

[10] In the paper DC-DC coverter for electric vehicle as been simulated using the MATLAB as well the implementation with PMDC motor is decribed. Using the power electronis circuitry efficiency of vehicle can be improved . less space more efficient behaviour of the power electroniv device make them feasible to be implemented in cars . study of converter circuit can make possiblity of reduction in the battery size .

[11] In the paper knowledge about the renewable sources which are gaining popularity in the vehicle application are discussed . Overview of the solar cell technology, fuelcell technology, super capacitor technology,battery model technology,is explained with regard to the contribution as energy source for HEV. Various problems which are faced during development of the HEV model are discussed in the paper. In the paper characterstics and factors affecting the different

energy sources used for HEV described. This paper is helpful in uderstanding the renewable sources available for use in vehicle sd energy sources.

[12] In the paper driving cycles for hybrid locomotives desing are explained which is useful in conditioning the size and performance of the vehicle. Systemic approach for integration of driving cycles is defined .Power flow model for engine and battery using simulation technique for analysis is explained. Designing of indicaters corelated to sizing and efficiency of the hybrid architecture which is directly related to driving cycles such as max Power ,average power, specific energy also the cummulative distribution function associated with load power.

[13] In the paper different configuration of HEV are discussed , and elaborated with block dagram. The HEV is good option to make the vehicles we are using more suitable with enviorment by reducing the gases which our vehicles through in enviorment. In the paper phsical imlementaion usinf the ICE and battery pack is done, helpful in study the practicle problems which are to be faced in development of these HEV . using two sources redusces the stress on engine motor thus making its functioning more batter . overall performance depends on number of factors which are discussed in the paper and other simlation done by authors .

[14] Battery is very essential part of the electric vehicle system and HEV , so its modelling plays very crucial role in perfrmance of the vehicle. Litium ion battery is very well known kind of battery compatible with most of electronic devices. In the paper features governing the battery performance are discussed i.e charge control ,battery capacity,run time information, charge cycle. Co,pare to other batteriies the lithium ion batery has highest power density snd heslthy life.using software MATLAB the modelling is done and simulation result of battery performance are presented in the paper, which is very usefull in making the battery selection and study very easy. In the paper temperature effect, SOC effect and charging discharging characterstics are analysed.

[15] In the paper hybrid vehicle architecture for series hybrid, parallel hybrid , series parallel hybrid are defined with the block diagram representation. Modelling of these architecture and role of various parts in the powertrain are discussed. These papers can help in the study of latest trends in technology as well the the new advancement in field of engineering. Study and use of HEV in

future is quite impressive so study of this paper helps in getting what this technology is and how it is benificial.

[16] In the paper overview of the electric vehicle , HEV , SHEV ,PHEV , mild hybrid , is presented. Basic methodolgy for different vehicle s is defined well in paper . two different drive cycle HWFED, UDDS are choosen two study behaviour of different vehicles under diving conditions . highway, and urban drive cycles these are.this paper briefly explain the benefit of using series-parallel hybrid over the SHEV and PHEV thus making aspect of choosing different energy sources for best use on the vehicle. Complication of the SPHEV are discussed , control startegy is complex but results are benificial so more relevant work in the field is useful and authors are developing softwares , and othe methods to make this hybrid energy more beneficial

[17] In the paper basics for HEV are described. Different types of fuel which can be used in colabration with the internal combution engine.Ethanol , fuel cell, batteries different sources are discussed in the paper. Electrical machine like PMDC , BLDC are defined which are used as motor/generator in the HEV configuration . full Hbrid , mild hybrid configuation are also presentred in the paper. Letting the reader to get knowledge about the HEV so as to make more use of the matters discussed in the paper.

[18] This paper summaries a number of electrical machine technologies, comprising brushless permanent magnet(BLDC), induction(IM), switched reluctance(SRM), and brushless reluctance machines, taking in cosideration Hybrid elecrtric vehicle technology, and compares advantages/disadvantages, in terms of power density and torque, effective speed range, load capability, and efficiency.

[19] Hybrid electric vehicle concept is very dedicated and good concept for urban areas . thid type of technology not only reduce the pollution but increase the fuel ecocnomy of drive vehicles. Power split hybrid is combination of both the series as well the parallel hybrid . Planetary gear set in heart for thus SPHEV . In the paper this configuration of the SHEV is presented . use of fuzzy logic is done in the paper . using this power split control strategy we can make best use of power sources in HEV.

[20] This paper gives overview of different power train methodology i.e series HEV,parallel HEV Performance under different drive cycle. Which train is efficient for particular drive cycle is explained Structure and control strategy analysis of PHEV and SHEV explained using the drive cycle related to highway and within city that helps in understanding the requirement for which train to be select. Emission of CO for drive cycle chosen as the parameter for the comparison that is helpful in understanding the requirement of HEV technology optimization

[21] In the paper HEV, architecture has discussed with various cons and pros regarding the series and parallel HEV architecture .in comparison to the series-parallel architecture using the Power Split device. Power split series parallel HEV having strength of both series and parallel HEV architecture are explained. Working of power split device and various modes in which HEV can operate using this methodology described. Introduction about the energy storage devices and electric motor is also included in this paper.

[22] In the paper Ansoft Simplorer siftware is used for modelling of multipurpose wheeled vehicle using the hybrid vehicle topology. Series hybrid vehicle modelling for high mobility application is simulated using the software. Different vehicle operating modes being discussed in paper which are very usefull in understanding the working of the SHEV and its application for use in high mobility apllication . army and defence services need these HMMWV so developing its simulation result in getting advancement in topology used for development of thest vehicle.

[23] In the paper electrical throttle is used in place of the mechanical throttle. Method for the development of the ideal control system based on the electric throttle is used. Presently the need of such control is very important so as to make the use of the fuel to the best value. More precision is to be developed about which overview is gien in the paper.

[24] Conventional vehicle gain popularity because of the cheap fuel, in early stages but now the scenario is changed and vehcile not only causing harm to enviorment but the fuel cost is alarmingly high . in the paper new technology of Hybrid vehicle is explained . in the paper selection of battery on various factors is explained, choice among different batteries like lithium ion, NIMH battery is discussed. Different configurations for the HEV are elaborated in the paper. It is helpful in making choices of better energy sources for future vehicle.

[25] In the paper Power split configuration of HEV is explained and analysed using ADVISOR and MATLAB-SIMULINK software . modelling of the engine system ,battery system thus control methods for driving HEV are explained.Dynamic models for motor /generator are explained in the paper. Mathematical derivation for development of the dynamic model for various parts of HEV train Model architecture for HEV subsystem engine motor generator battery are explained. This paper explained model which is effective tool for development of control system for Power-Split HEV.

[26] In the paper application of the batteries,super capacitor and fuel-cell in hybrid and single electric vehicle configuration application is explained.simulation models of energy sources like battery and fuel cell are presented and used to investigate the design consideration for vehicle either electric or hybrid. Use of these sources at present is no cost effective at start but has great reduction is pollution and also increase the fuel economy of vehicle. Under different drive cycle result of simulation are examined .Study is done taking into cosideration lead acid battery ,PEM fuel cell and super capacitor comparison anmong them on the basis of certain parameters like mass ,volume energy density is dicussed in the paper.This paper is helpful in making best choice as per drive cycle among the energy sources available for development of hybrid model.

[27] In the paper developent of battery system for PHEV is described.Different battery system i.e nicklemetal hydride battery system and lithium ion battery system are analysed.Dynamic simulation of vehicle result using these battery system is compared .charge depletion/charge sustaining mode proporting taken into consideration along with test cycle for battery system is defined in this paper. This paper helps in understanding the battery system and parameters to choose the battery pack for PHEV.

[28] In the paper simulation and test of Axial Flux Motor characterstics for the HEV are explained using vehicle simulator. Torque speed curve for different air gap and inout voltages are developed using simulator are used for studying the characterstic of motor.Four quadrant operation of the motor is explained in the paper. This paper gives in depth knowledge of the axial motor for HEV
. helpful in understanding various characterstics of the motor.

[29] It is survey report of new technology emerging in the field of trasnportation . Comparison between the Electric vehicle and Hybrid vehicle is presented in the paper . how th HEV is beneficial over normal EV and vehicles running on petrol diesel etc. component and fuels which are used for HEV are discussed in the paper . comparison of different batteies performance is also defined in the paper. Power electronic devices are being used in HEV so use of these and effect on performance is discussed.

[30] In the paper package for electric and hybrid vehicle is discussed in details.V.ELPH 2.01 version is used which is written in MATLAB/simulink graphical simulation language and is comprises of 4 main component motor, battery ,engine ,and supported component of HEV.for different drive cycle the simulation result are analysed in the paper. Series HEV,parallel

HEV,conventional ICE drive train methodology is explained briefly in the paper.the new method of visual graphics is being discussed in the paper which is usefull in study the HEV and its different architecture

1.**2 OVERVIEW OF HYBRID ELECTRIC VEHICLE**

Hybrid electric vehicle architecture gives the insight of the HEV technology. Classification of the HEV based on configuration of the vehicle drivetrain. There are three hybrid vehicle architectures discussed which are series, parallel and series-parallel. Lately, many HEV in production are either series or parallel. In terms of automated structure, these two are primeval and comparatively simple. The series-parallel powertrain supplement more degrees of freedom to vehicle engine operation with system complexity.

1.2.1 Series Hybrid

Series hybrid is simple configuration, shown in figure below. The ICE used to generate electricity in a generator. Electric power produced by the generator goes to either the motor or the energy storage systems (ESS). The hybrid power summed at an electrical node, the motor. The latest replenishment of the hybrid vehicle, several automotive OEMs revealed the chance of development of SHEV. Some of the most known are the Mitsubishi ESR, Volvo ECC, and BMW 3 Series. The series hybrid configuration have an affinity for high efficiency to engine operation. The regenerative braking assistances from the full size motor. The cost and weight of the vehicle is more because of large size of the engine and need of two electric machine. The series architecture presumed to be more appropriate for vehicles used in city/towns with quickly varying requirements of speed (and power). SHEV can also implemented in large vehicles, where the lower efficiency of both ICE and the mechanical transmission make it much convenient for the electric propulsion.

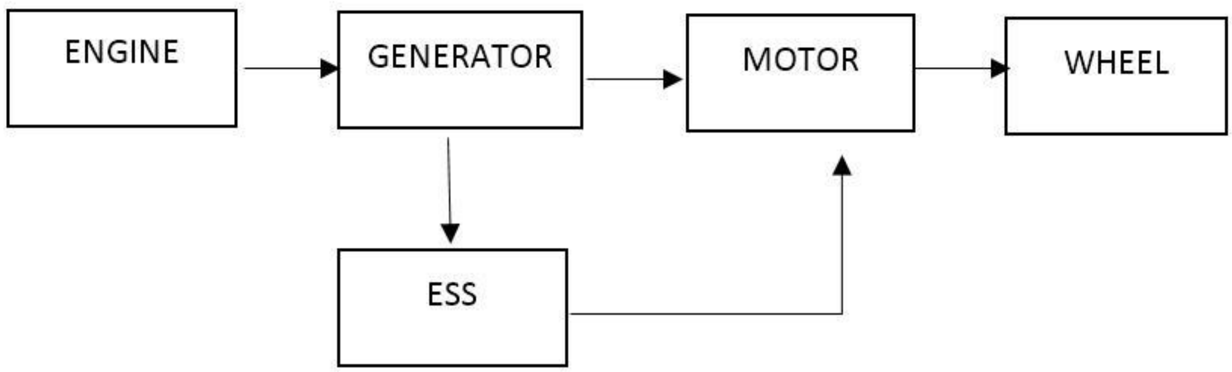

Fig 1: Series Hybrid Electric vehicle

1.2.2 Parallel Hybrid Electric Vehicle

Parallel hybrid systems link the electrical and ICE to the mechanical transmission. Classification for PHEV based on the ratio, contribution of drive power of different component. In some cases, the internal combustion engine is the governing component and used to supply power primarily with the battery supplying power for a boost. In this arrangement, both the engine and the motor deliver traction power to the wheels, which refer that hybrid power summed at a mechanical node to power the vehicle. The engine and the motors can be downscaled, because impact on both is reduced, making the parallel architecture more feasible with more efficiency and lower costs.

Earlier development by OEM’s of PHEV are the BMW 518, Citroen Xzara Dynactive and Saxo Dynavolt, Daimler-Chrysler ESX 3, Fiat Multipla, and the Ford Multiplia and P2000 Prodigy[24]

.The PHEV usually use same gearboxes which is castoff in conventional vehicles, whichever in automatic or manual transmissions. Based on location of gearbox in the powertrain, there are two different parallel HEV architectures that are pre-transmission parallel and post-transmission parallel, as shown in Figure 2

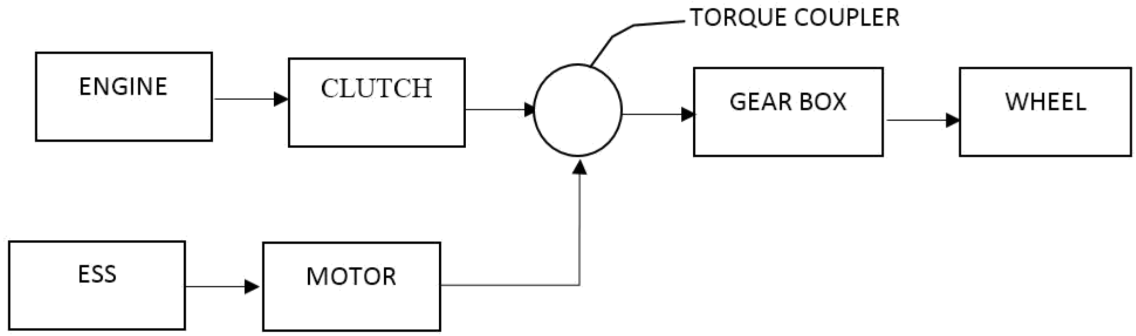

Fig 2: Pre Transmission PHEV

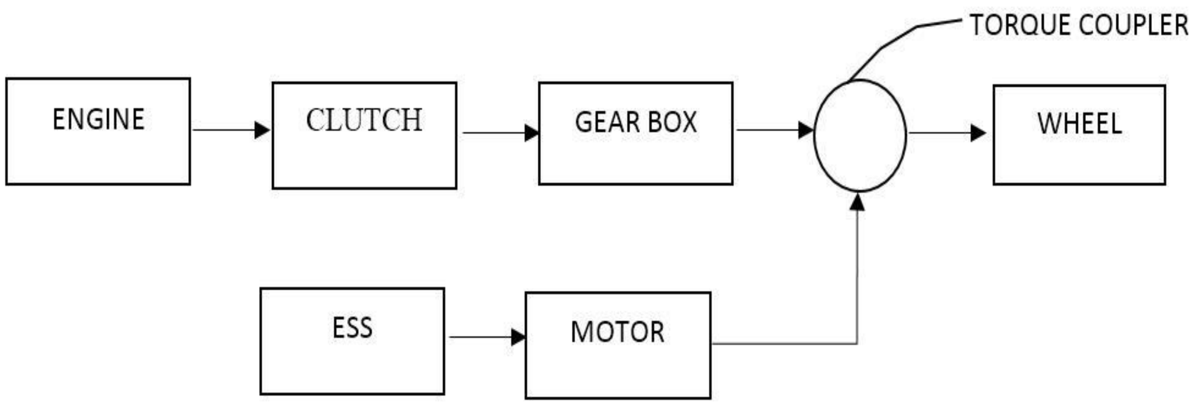

Fig 3: Post Transmission PHEV

Pre-transmission parallel HEV, the gearbox placed on the main drive shaft next to the torque coupler. Thus, gear speed ratios applied to both the engine and the electric motor. The power summed at the gearbox. However, in a post-transmission parallel hybrid, the gearbox is located on the engine shaft prior to the torque coupler. The gearbox speed ratios apply to the engine. A continuous variable transmission (CVT) can be used as an alternative of conventional gearbox to improve engine efficiency. Pre-transmission configuration, torque from the motor summed up with torque from the engine at the gearbox. Post-transmission, the torque from the motor added with the torque from the engine conveyed to output shaft of the gearbox. Device such as a clutch can used to unlock the gearbox while motor is freely. Post-transmission electric hybrids used for hybrid vehicles with a greater grade of hybridization. Hydraulic power implemented to heavy-duty trucks and commercial vehicles. Honda Insight is perfect car available in the market with PHEV configuration.

1.2.3 Series-Parallel Configurations

Series-parallel architecture, the vehicle can function as a SHEV, PHEV or a combination of both. Architecture governed by two motors/generators and the relations between them, which may be both electrical and mechanical. The mechanical connection between engine and electric machines can be accomplished by use of planetary gears known as power splitting devices (PSDs). Main advantage of a series-parallel configuration is that, engine speed can decoupled from the vehicle speed. Which gives partial offset for the losses in the conversion between mechanical power from engine and electrical energy.

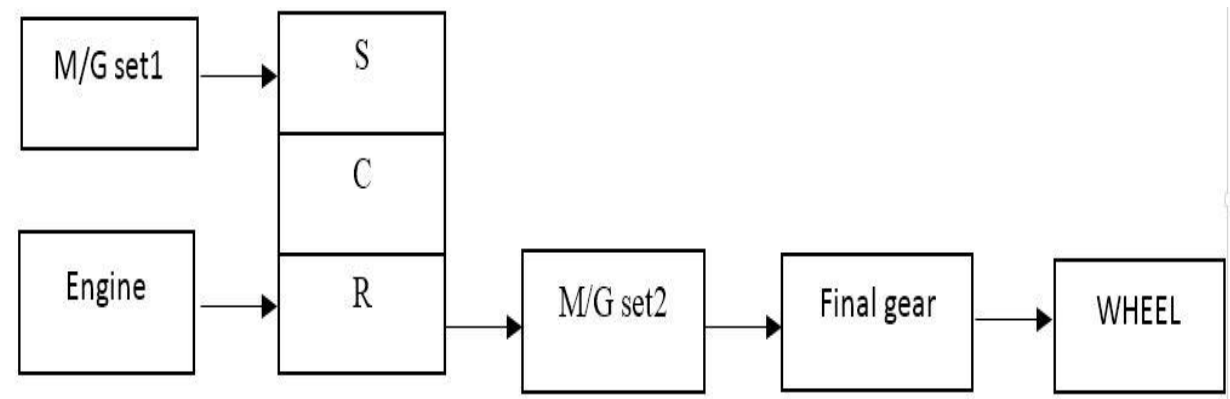

Fig 4: Series Parallel Hybrid Electric Vehicle

The series-parallel design has key feature: the propulsion supplies are decoupled from the ICE operation and the overall losses are lesser since a fraction of the power generated by ICE is delivered to wheel without any transitional energy conversion. This feature makes the management of the power flow very flexible, making ICE to work in wide range of driving condition. SPHEV can operate in different modes.

1.3 The Need of Hybrid Electric Vehicles

Renewable energy technologies like fuel cell and solar are gaining popularity for vehicle application. These energy sources reduces harmful gases, and reduce dependability on the fossil energy. An increasing ecological awareness and the shortage of fossil-fuel resources leads to develop more efficient vehicle, with lower fuel consumption. The hybrid electric vehicle, combining power conventional internal combustion engines (ICE), batteries, ultra-capacitors, or hydrogen fuel cells (FC) is a hopeful concept. In addition, the development of powerful batteries with large capacities allows the electric vehicle to be alternative for the vehicle application[2]. Representing an innovative change in vehicle design philosophy, hybrid vehicles raised in many different ways. HEV with onboard energy storage devices and electric drives allows braking power to recover and ensures the ICE to operate in the most efficient way, thus improving fuel economy and reducing pollutants. Because of advanced design philosophy and technology, the development and commercialization of HEV technologies demanded extensive research and study. This research aims to address number of problems in the development of HEV[2].

1.4 Environmental concern

In 2013, transportation contributed more than half of the carbon monoxide and nitrogen oxides, and almost a 4^{th} part of the hydrocarbons emitted into our air. Air pollution from vehicle divided into primary and secondary pollution. Primary pollution released directly into the atmosphere; secondary pollution results from chemical reactions between pollutants in the atmosphere. Major pollutants from vehicles are: Particulate matter(PM), Hydrocarbons(HC), Nitrogen oxide(NOx), Carbon monoxide(CO),Sulfur dioxide(SO_2),Greenhouse gases[11]. This air pollution brings risks for human health and the environment. By use of clean vehicle and fuel technologies, we can considerably reduce air pollution from our vehicles. Hybrid electric vehicles have the capability to reduce greenhouse gas (GHG) emission and other gas pollution. ICE based hybrids can improve the fuel economy and reduce tailpipe emission by more efficient engine operation. The development come from regenerative braking, shutting down the ICE while it is stationary and allowing a smaller, much efficient engine, which is not required to follow the power at the wheel as closely as the engine in a conventional vehicle. The Corolla is one of most efficient conventional vehicles on the market. Hybrid electric vehicles (HEVs) can help to accomplish goals – improving fuel economy between 5% and 40% and lowering emissions by 10% to 50% below Comparable vehicles with only internal combustion engines (ICEs) burning petroleum based fuels (gasoline and diesel)[24]. Globally, we are facing an upward trend in oil demand and tight supply. Maintaining a vulnerable energy supply becomes important concern. The transport energy consumption worldwide are also continue to rise rapidly. In 2000, it was 25% higher than in 1990 and it projected to grow by 90% between 2000 and 2030. Fig1 shows the Global Energy consumption acc. to Economic forum 2011. It is clear from the chart that light duty vehicle covers more than 50 % of the part of energy consumption. So targeting this area for fuel economy improvement will reduce the stress on oil consumption, which is increasing rapidly. Many HEV projects reported fuel economy improvement from 20% to 40% thus; HEV provides a promising solution for the energy shortage.

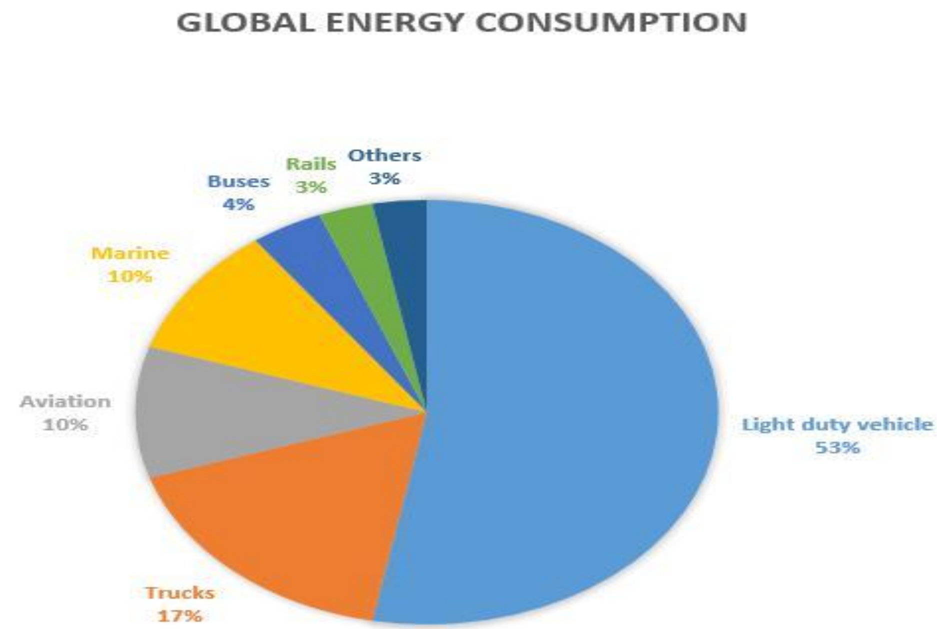

Fig 5: Global Energy Consumption of fuel

1.5 Current HEV Market

In 1970s, many automakers such as GM, Ford, and Toyota started to develop electric vehicles powered by batteries due to the oil shortage .Light-duty HEVs launched in 1999 by Honda, followed closely by Toyota. Since that Time, the Toyota Prius has become the leading HEV worldwide. Prius the Bestselling vehicle in Japan, and also includes nearly one-half of all HEVs sold in the United States. Within the last two years, the number of available HEV models has grown substantially. At present companies like Audi, BMW, Daihatsu, Ford, GM, Honda, Hyundai, Mercedes, Nissan, and Toyota have HEV models available in the market. However, these electric vehicles powered solely by battery power did not go far enough. The interest in hydrogen fuel cell cars increased, because of the problems with the battery driven HEV. However, with more than 15 years of strenuous development, there are not any fuel cell hybrid cars on market because of high manufacturing cost. During the time, automotive manufacturers have progressed in another direction of ICE based HEV. In 1997, Toyota launched the Prius, the first ICE based HEV to the Japanese market. Ever since, HEV number is increasing with good pace. The sales of different HEV up to 2015 is quite promising fact that HEV is new interest of people. The figure below shows the various HEV sales, which is rising[9].

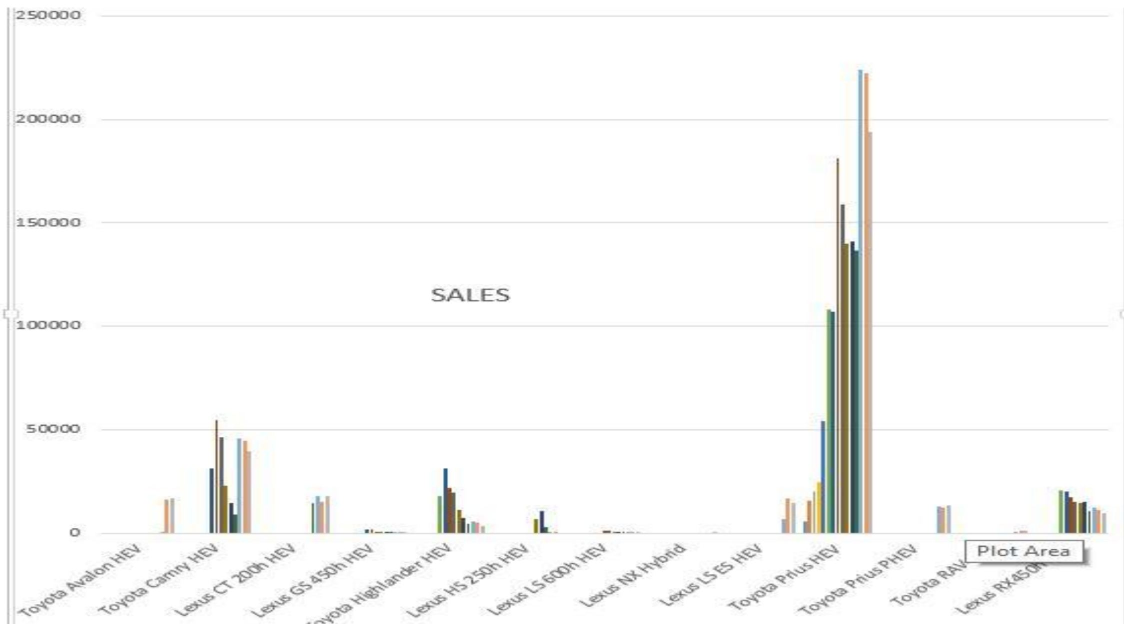

Fig 6: Sales of Hybrid Electric Vehicle

1.6 Thesis outline with material and method used

1. SPHEV is new study combining the benefits of both series as well parallel configuration. Model of the SPHEV developed using the MATLAB (Simulink/Simdriveline/Simscape) and under the drive, cycle test performed. Drive cycle is simple with acceleration at start then constant drive region then de acceleration region

2. This report includes the Series Parallel Hybrid Electric Vehicle simulation and results using the MATLAB software. Complete simulation and analysis of the SPHEV. This gives the idea how the HEV system works and what are problems faced in its development.

3. Mathematical modelling powertrain for SPHEV. This gives over all force requirement which in return gives the rating of motor generator engine to be selected

3. Modelling of the boost converter. Boost converter inclusion to the SPHEV for reduction of the battery size requirement .To get the dc output boosted from the battery to match the desired value.

4. SPHEV performance without converter studied using the simulation software. Battery and ICE two power sources work to drive the vehicle. Simulation results verified with mathematical calculation for the drivetrain.

5. Control strategies used, are explained in other chapter. Simulation result presented in thesis report. Focus on the strategy to the battery size reduction using the boost converter done.

CHAPTER: 2

THEORY AND CALCULATIONS

In the chapter various aspect regarding the modelling of Series Parallel Hybrid Electric Vehicle are discussed. Block diagram representation. Parts like Engine, batteries, motor/generator set are explained in context to the model of SPHEV in MATLAB. Derivation with respect to DC converter and tractive force are explained.

2.1 Block diagram of Power Split HEV

Block diagram representation for the power split HEV is better way to get the development process of the HEV for study purpose. As Power split, HEV has advantages of both the series as well as parallel HEV, thus working on this architecture cover the study of others two types as well. This block diagram shows the various parts of the HEV i.e. Engine, battery, converter, Motor, generator, power split device. Various control strategies are involved which are discussed in other chapters.

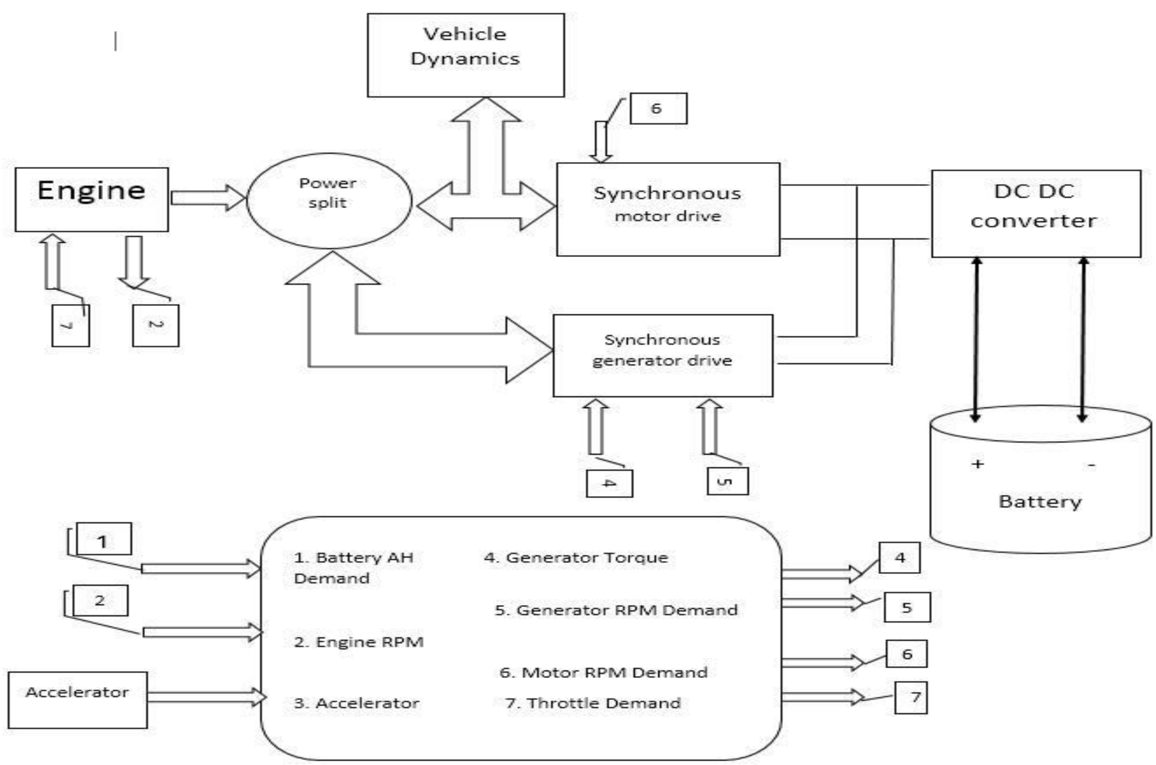

Fig 7: Block Diagram for SPHEV

2.2 Tractive force requirement for drive cycle

Development of the drivetrain for HEV is very important part as it gives the overall tractive force requirement for driving vehicle. By using the simple drive cycle, the approximate calculations for the power requirement to drive the vehicle calculated. Using the speed time curve for the drive, tractive force calculated with the vehicle dynamics known. This force is useful to make the motor rating for vehicle as well as approximation of power needed to drive vehicle throughout the drive cycle .Tractive effort is the calculation of force obligatory by the drive to overcome the resistance as well as to accelerate the drive train. The tractive force has to perform following functions

1. Accelerate the drive train mass horizontally.

2. Accelerate rotating part of the train like wheels, gears etc.

3. Overcome force due to gravity.

4. Overcome train resistance.

Equations for the tractive effort calculation

(a) Tractive effort to accelerate train mass (newton)

$$F_{a1} = (1000M) \times \frac{\alpha \times 1000}{3600} = 277.8M\alpha, N \quad (1)$$

Where,

M=mass in tones.

=acceleration in kmphps.

(b) Tractive effort required to accelerate rotating part

$$F_{a2} = (J_1 + J_2) \times \frac{\alpha \times 1000}{3600R} \quad (2)$$

Where,

=moment of inertia of wheels.

=moment of inertia of motor referred to wheels.

R=radius of wheel.

Net tractive force equation is

$$F_a = F_{a1} + F_{a2} \quad (3)$$

(c) Tractive effort to overcome gravity

$$F_g = 1000M \times \frac{G \times g}{1000} \quad (4)$$

G=gradient in meters.

g=gravity constant ($9.81 m/s^2$)

(d) Tractive effort required to overcome train

resistance It consists of three basic components:

1. Coulomb friction, which is independent of speed.

2. Viscous friction, which is proportional to speed.

3. Air friction which proportional to speed square.

Thus,

$$= \quad + \quad + \quad ^2$$

Where V=velocity of car in kmph

A, B, C are the constants. (5)

Since its value is very small as compare to the so it is neglected

Total tractive force

$$F_{ta} = F_a + F_g + F_r \quad (6)$$

(e) Torque calculated as

$$T_u = F_t \times 2\pi R \tag{7}$$

(f) Energy requirement also calculated using the speed time plot.

$$E_u = \frac{F_u \times D_u \times 1000}{3600} \tag{8}$$

Where, =energy in Wh.

=distance in km.

2.3 Designing of the boost converter for HEV

Because of the rising petroleum prices and the harmful emissions the automobiles sector has been looking out for the alternative propulsion systems. Which lead to rise the development of the Electric Vehicle (EV) and Hybrid Electric Vehicle (HEV) technologies. EV only depends on ICE engine for the traction power, consumes electrical energy from the electrical storage system (ESS) for generation of traction power. On the contrary, an HEV depends on an ICE as well as an ESS both. Hence in an EV/HEV energy conversion productivity advances and thus it increases the efficiency and reduces the harmful emissions. Individually each energy source delivers power to the cargo through the DC-DC converter in EV/HEV. Thus, part count, size, cost, and overall weight of the DC-DC converters is important. [5][3]

Circuit configuration for buck/boost configuration is different; however, one circuit topology can operate both as step up as well as step down converter as its duty cycle varied continuously from zero to unity.

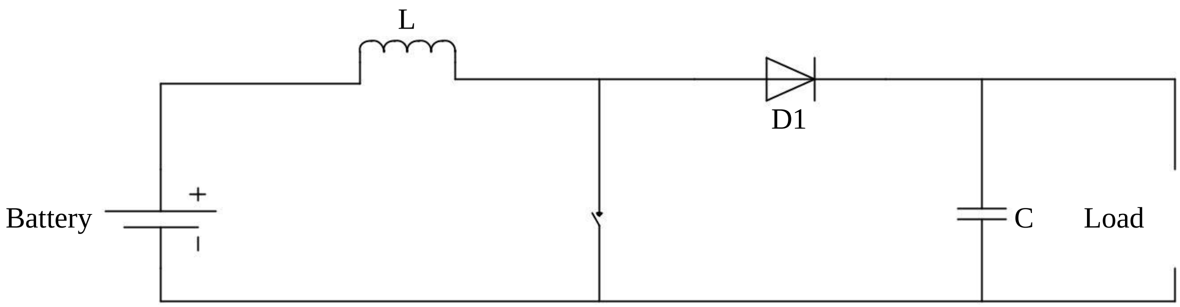

Fig 8: DC DC converter

Figure 13 shows the DC DC boost converter topology with inductor in series switch and capacitor in parallel.

= ((+))
= ((+)

Energy stored in inductor is (9)

Energy released by inductor during (10)

Assuming system to be lossless, energy balance equation is
Energy input, =energy output,

(+) = (+

=( ) or =( ) (11)

Where, ∝= duty cycle =output voltage. =input voltage.

The above derivation shows the duty cycle relation with the input and output voltages.

2.4 Synchronous Motor/Generator drives

[18]Motor/generator are crucial for HEV. Electrical machines and drives are a key enabling technology for hybrid electric (HEV). The basic characteristics that are required for electrical machine for traction applications include:

(a) High torque density and power density

(b) High torque for starting, at low speeds and hill climbing, and high power for high speed cruising

(c) Wide operating speed range

(d) High efficiency over wide speed and torque ranges, particularly at low torque operation

(e) Intermittent overload capability for short durations.

Commonly used motors: Various motors are present in the market but mostly used are Induction machine, SRM, BLDC motor, basic features discussed below for these motor describing the benefits of each machine with regard to electric and Hybrid electric vehicle.

A. Induction Machines

The major advantages of IMs include:

(a) Mature technology

(b) Robust structure

(c) Relatively low cost

(d) High starting torque

(e) High overall efficiency

(f) Excellent flux-weakening performance (constant power operation).

The major design parameters for IMs are number of poles, the number of stator and rotor slots, the shape of the stator and rotor slots, and the winding disposition, which determines the IM topologies. With an inverter fed IM, constant torque and constant power, characteristics that are required for traction applications can be easily satisfied. Both a high starting torque and a low starting current can achieved[18]. The envelope of the torque/power-speed characteristic, encompassing both constant torque and constant power operating modes, the copper loss varies slightly with speed. In contrast, initially the iron loss increases with speed and is a maximum at the base speed, after which it gradually reduces as the degree of flux weakening is increased. It has well known that when the iron loss and copper loss are similar the efficiency will maximized. Therefore, an IM for traction applications should designed such that the iron loss is higher than the copper loss around the base-speed, and vice-versa at low and high speeds.

B. Switched Reluctance Machines (SRM)

SRM termed as doubly salient machine. In SRM, both the stator and the rotor are made of irons, which magnetized by the current through coil on the stator. Because the rotor is out of line with the magnet field, a torque produced to minimize the air gap and make the magnetic field symmetrical. Dissimilar the BLDC, the current in the coil does not need to alternate. The main trouble with SR motor is that the timing for turning on and off the stator currents must controlled more carefully.[6], [18]

The major features of SRMs summarized as follows:

(a) Simple, tough rotor structure, without magnets or windings, which is suitable for high Temperature environment and high-speed operation;

(b) Potentially low cost, although relatively high manufacturing tolerances are required due to the need for a small air gap

(c) Smooth operation at low rotational speeds needs comparatively complex outlining of phase current waveforms and precise measurement of rotor position

(d) Unipolar operation requires unusual power electronic modules, but SR drives have an intrinsic amount of fault tolerance.

(e) since their operating is based on the consecutive excitation of diametrically opposite stator coils in machines having the basic 6/4 and 8/6 stator/rotor pole number combinations, the acoustic noise, vibration and torque ripple tend to be relatively high

(f) Unsure short-duration, peak torque capability as the magnetic circuit tends comparatively saturated. In direction to get high peak torque, it is necessary to employ a dense stator back iron, which is also beneficial for reduction of the acoustic noise and vibration.

C. Brushless Direct Current Motor (BLDC)

This is an AC motor. Other names given to it are permanent magnet synchronous motor, electronically commutated motor, self – synchronous motor etc. It is called brushless because Armature has no brushes connected to it. The rotor consists of a permanent magnet. The stator coil takes alternative supply from a dc source, which generate magnetic field. The interaction of this magnetic field with the permanent magnet conveys the movement of the rotor. Due to back emf generated in stator coil, the torque reduces as the speed increases. The advantage of this motor is that currents need not to be induced in the rotor (like in induction motor), making them somewhat more efficient and giving slightly greater specific power. The disadvantage is that it is costlier because of the existence of permanent magnet.

2.5 Batteries

Batteries are handy sources of electrical energy, which converted to the mechanical energy in the electric motor for momentum. There are many types of batteries in actuality for hybrid electric vehicle application. They are Lead Acid, Nickel Iron, Nickel Cadmium, Nickel Metal Hydride, Lithium Polymer, Lithium Iron, Sodium Sulphur, and Sodium Metal Chloride. Examples of metal air battery which are instinctively refueled are: Aluminum – Air and Zinc – Air Battery Performance Criteria are Specific Energy, Energy Density, Specific Power, Typical Voltages, Amp Hour Efficiency, Energy Efficiency, Commercial Availability, Cost Operating Temperature, Self – Discharge Rates, Number of Life Cycles and Recharge Rates. The designers must be aware how the battery performance varied with temperature, charge and discharge rates, battery geometry, optimum temperature, charging methods and cooling needs. For modelling equivalent circuit of the battery used to study behavior vehicle under ideal condition as well.[27], [31]

2.6 Engine

Hybrid-electric vehicles (HEVs) summed up the advantages of gasoline engines and electric motors and can organized to obtain other objectives, like improved fuel economy, increased power, or additional auxiliary power for electronic devices. ICE is power source as per necessity work as primary and secondary in HEV. Along with batteries, it works in combination thus making the HEV working more efficient. Use of two sources results in overall stress, which is earlier high on ICE, reduced. Hybrid Electric Vehicles use electric throttle as an alternative to mechanical throttle, thus dispensing power and optimize engine performance. Presently, in direction to keep oil pump and compressor working normally, idle speed control needed for HEV. Closed loop control as mentioned above in the block diagram made to control the throttle demand as per the HEV accelerator cycle. With new technology and scientist and researcher working to make the engine more efficient, advancement in both petrol and diesel engine is observed. Engine load when reduced by use of the battery as the other source. Efficiency capability will improve.

2.7 Power split device (PSD)

PSD is the heart of the series parallel HEV. It is the mechanical device with gear system which comprises of the sun, ring, planetary. Generator RPM demand calculated using the power split basic gear ratio figure 12 shows the Power split device which is most important part of the SPHEV it plays crucial role , mechanical connection between Motor Generator, Engine and shaft to drive axes is through this[19] . Gear system is shown in figure 12

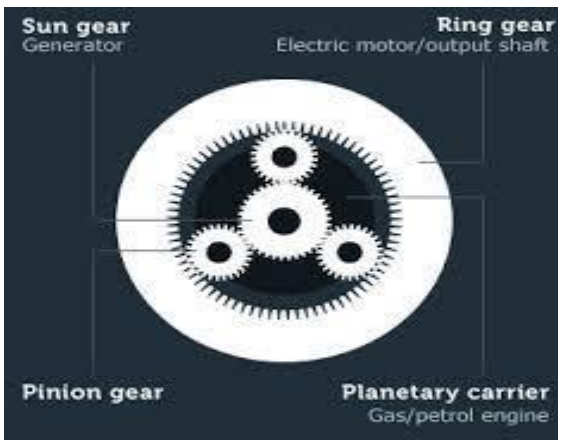

Fig 9: Power Split Device

$$\frac{(\ -\ )}{(\ -\ )} = - \frac{}{} = -K \qquad (12)$$

$$+ - (\ +\ ) = \qquad (13)$$

For power split ratio of ring to sun must be greater the 1, for our simulation we have selected the ratio as 2 which gives the equation governing the generator speed demand as per the motor and engine speed demand as follow.

$$= - + \qquad (14)$$

. Denotes angular velocity. Sun connected to generator, ring to motor, carrier (planet) to the engine

CHAPTER 3

CONTROL STRATEGIES FOR SPHEV

This chapter gives an overview of various controls that are to be used while construction of the HEV. Operation of the vehicle according to demand can managed to use vehicle in different conditions making it reliable and adjustable as per the cycle.

3.1 Engine speed demand (Throttle demand)

Gasoline engine is very important part of the HEV. Its control method is thus form the base for HEV (Power split) architecture. Engine ignition is initiated at what deflection of pedal is decide as per the drive cycle , what is requirement of engine to start for is decided so that generator ignite the engine to start up as per taking the power from battery source. Block diagram representation of the Throttle demand for HEV shown in figure. Throttle value for engine depend on engine rpm , engine rpm demand, also the condition that engine is on or not .for simulation the throttle value must be b/w 0 and 1 which mean that 0 is equivalent to engine is off and 1 means engine giving full power to the HEV. Engine RPM and demand is compare using the comparator, which further given to PI controller, then using the electronic circuitry signal for throttle demand is fed to the gasoline engine so as to give Power and torque as per the throttle value. Engine ignition is initiated at what deflection of pedal is decide as per the drive cycle , what is requirement of engine to start for is decided so that generator ignite the engine to start up as per taking the power from battery source . For simulation in our HEV model, this speed fixed to 800 rpm until this speed not reached the signal not generated which makes the generator to start the engine. Throttle value for engine depend on engine rpm , engine rpm demand, also the condition that engine is on or not .for simulation the throttle value must be b/w 0 and 1 which mean that 0 is equivalent to engine is off and 1 means engine giving full power to the HEV . Using PI controller the error signal, from engine rpm demand and actual rpm converted into throttle signal, which drives engine model in simulation.

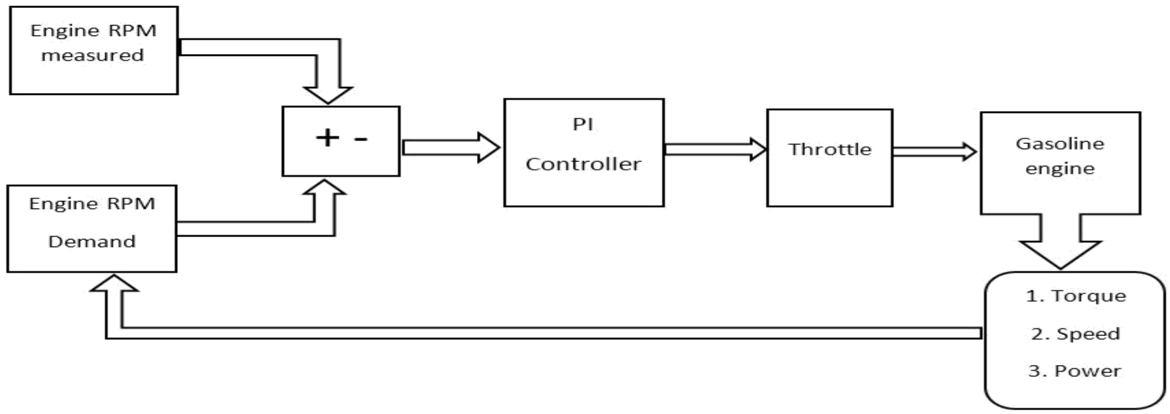

Fig 10: Engine Speed Control

3.2 Motor control

Motor output as per the accelerator cycle is adjusted by close loop methodology of comparing RPM demand and measured value and adjusting the motor mechanical output as per the Speed-Torque curve of the motor . Use of the power electronics is very important part in management of the Motor power/speed control. Block diagram representation for the same is give in figure. RPM measured from motor using the Hall Effect sensor converted into equivalent voltage, which compared to RPM demand as per accelerator cycle. Compared voltages then converted and fed back for comparison as torque speed curve maintain the motor mechanical output. Input to motor is from the battery shown by +- terminals. Block diagram for the motor control is

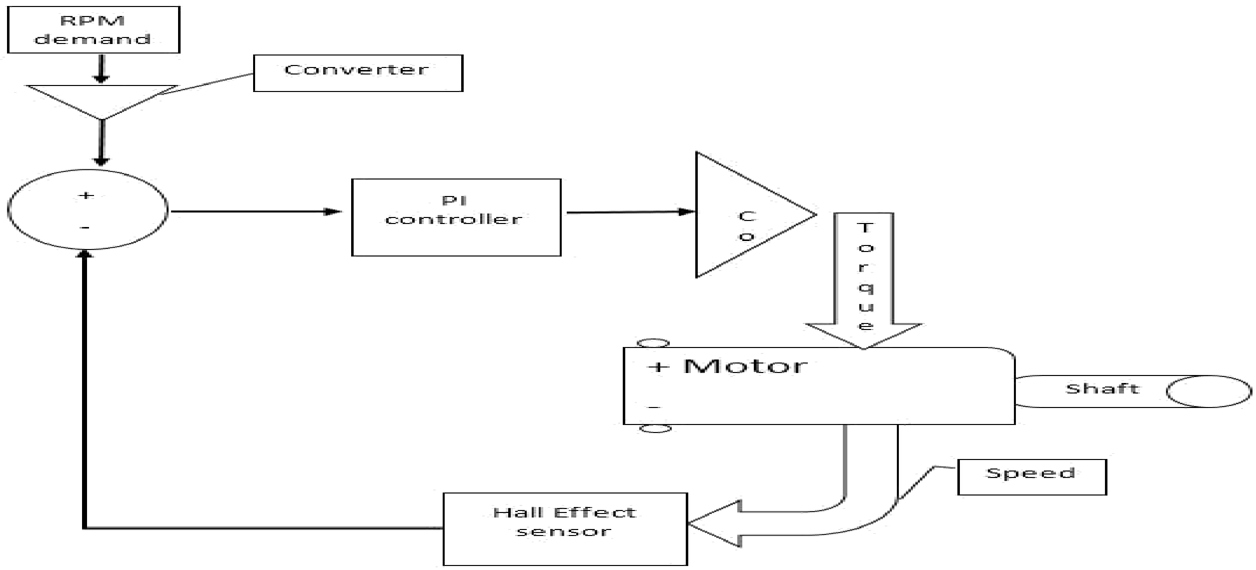

Fig 11: Block Diagram for Synchronous motor drive

3.2.1 Synchronous motor drive

Using servo motor block in MATLAB Simulink model synchronous drive for the HEV achieved. Servomotor block represents a servomotor and drive electronics operating in torque-control mode or current-control mode. The motor's permissible range of torques and speeds is defined by a torque-speed envelope, and the output torque is assumed to track the torque reference demand Tr with time constant Tc. The servomotor block connected to a DC supply (Battery).The block produces positive torque acting from the mechanical C to R ports. By comparing the RPM, demand of the motor and actual RPM of the motor using PI controller toque to the motor is control.

Torque and speed envelop is defined for the motor drive as follow

Vector of rotational speeds: [0 1200 2000 3000 4000 6000 6500 10000] RPM

Vector of maximum torque values: [400 400 250 150 110 90 0 0] Nm, Time constant=0.02s

From this power rating of motor designed as per requirement

3.2.2 Motor Drive Specification

Speed output from the motor drive converted into equivalent voltage (5/65000) volt/rpm, which compared to the rpm demand converted to equivalent volts. The voltage signal from comparison using PI controller is the given to torque reference after converting the volts to Nm. this close loop will give the torque speed curve governing the motor mechanical output. The amount of power drawn from source depends upon this torque speed curve.

Hall Effect sensor conversion factors used =5/65000 volt/rpm. Volt to Nm conversion =400/5 volt/Nm

3.3 Generator control

Generator in HEV used to start the engine and to assist engine power to feed back to the battery to recharge it during the constant drive a braking. Generator works as connection between battery and engine. Using servo motor block in MATLAB Simulink model synchronous drive for the HEV achieved. Servomotor block represents a servomotor and drive electronics operating in torque-control mode or current-control mode. The motor's permissible range of torques and speeds is defined by a torque-speed envelope, and the output torque is assumed to track the torque reference demand Tr with time constant Tc. The servomotor block connected to a DC supply (Battery).The block produces positive torque acting from the mechanical C to R ports. Block diagram representation shown below. RPM demand, measured and torque demand are the parameters to be compared to control the mechanical output of the generator. Block diagram for generator control shown in figure 12

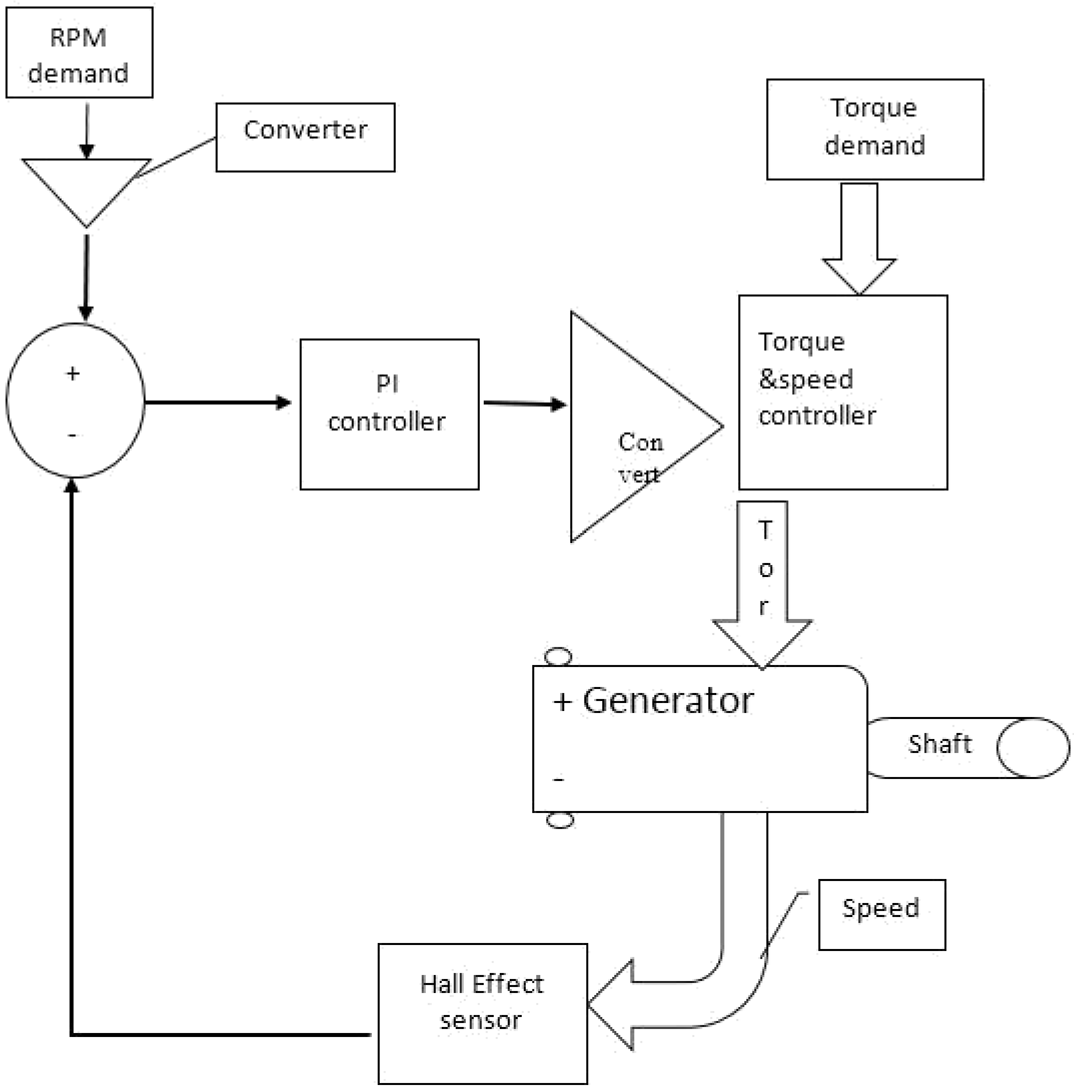

Fig 12: Block diagram for generator drive

3.3.1 Synchronous generator and drive

Similar to the motor drive servo motor block is used as generator has to work as a starter to Engine also used to charge battery during the cycle so using control strategy torque demand of generator is compared to the speed of the generator thus adjustment of generator speed in response to requirement is done . Torque to the drive controlled, resulting in proper functioning of the drive. Rating of generator drive

Vector of rotational speeds [0 1200 2000 3000 4000 10000 15000] RPM

Vector of maximum torque values: [400 400 250 150 110 0 0] Nm

Time constant=0.02s

3.3.2 Generator Drive specification

Its working is very much similar to motor drive. The difference is the loop controlling the speed torque curve. The output speed from motor is coveted to equivalent voltage using Hall Effect sensor compared to RPM demand of generator, with use of PI controller and comparator the error voltage is given to switch which makes the selection according to pre specified topology when to turn on engine and change in torque as per the need of HEV. The speed torque curve will decide the output of generator. Hall Effect sensor conversion factors used =5/10000 volt/rpm. Volt to Nm conversion =400/5 volt/Nm.

3.4 Battery Power supply control (AH)

Battery is very important part of HEV; it is the energy source for driving the vehicle. Battery not only drive the vehicle during the operation but also act as the starter for the engine as per torque and speed demand. Power split device helps the electronic circuit to work in coordination with the engine. Control of the battery for the better fuel economy is very necessary, in our model we used AH of the battery as the control strategy for battery operation. Block diagram representation for control method shown in figure13. Battery is source driving the vehicle in summation to gasoline engine. Ideal battery model for which the output voltage given by

$$= - \qquad (1)$$

Where, is the rated voltage, I is the output current and R is the internal resistance. Parameters for battery are:

Rated voltage=500V
Ampere-hour rating=200Ah
Initial charge=10Ah
Internal resistance=0.05ohm

As battery has to drive the vehicle initially to accelerate it to required rating Engine is ignite by the generator when RPM demand is increased , then Engine take over to drive the vehicle also it charge the battery

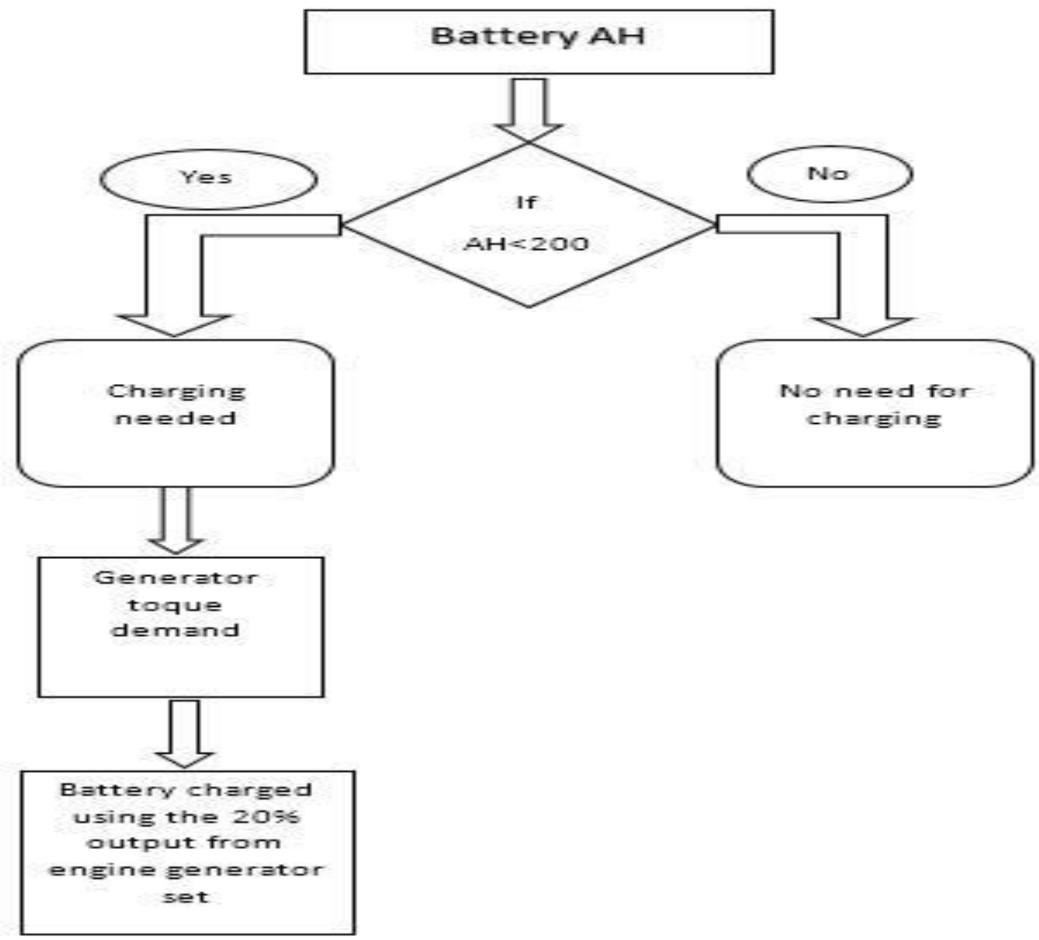

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Fig 13 Battery AH control

Battery Ah compared to the engine speed so that result of it is to decide the generator toque demand which is charging the battery. Only 20 % of allowable torque used to charge the battery.

3.5 Speed management

Speed control is very important part of the HEV, as it results how our ICE and Battery will work together to get most out of this new hybrid technology. Speed demand are set according to the accelerator cycle, which vary where our hybrid vehicle has to be driven either in city or on the highway. Block diagram for the setting up the speed demands as per the power split configuration shown in. Using the look up table in simulation the accelerator input is converted to speed , which is further decide requirement of generator/motor speed demand also the engine speed as well as when engine is ignited to work in coordination with battery to drive the vehicle can be controlled

. For simulation acc. demand is divided into two parts such that engine speed and motor rpm is decided , by using the power split the operation of generator is decided as per the gear ratio of power split device.

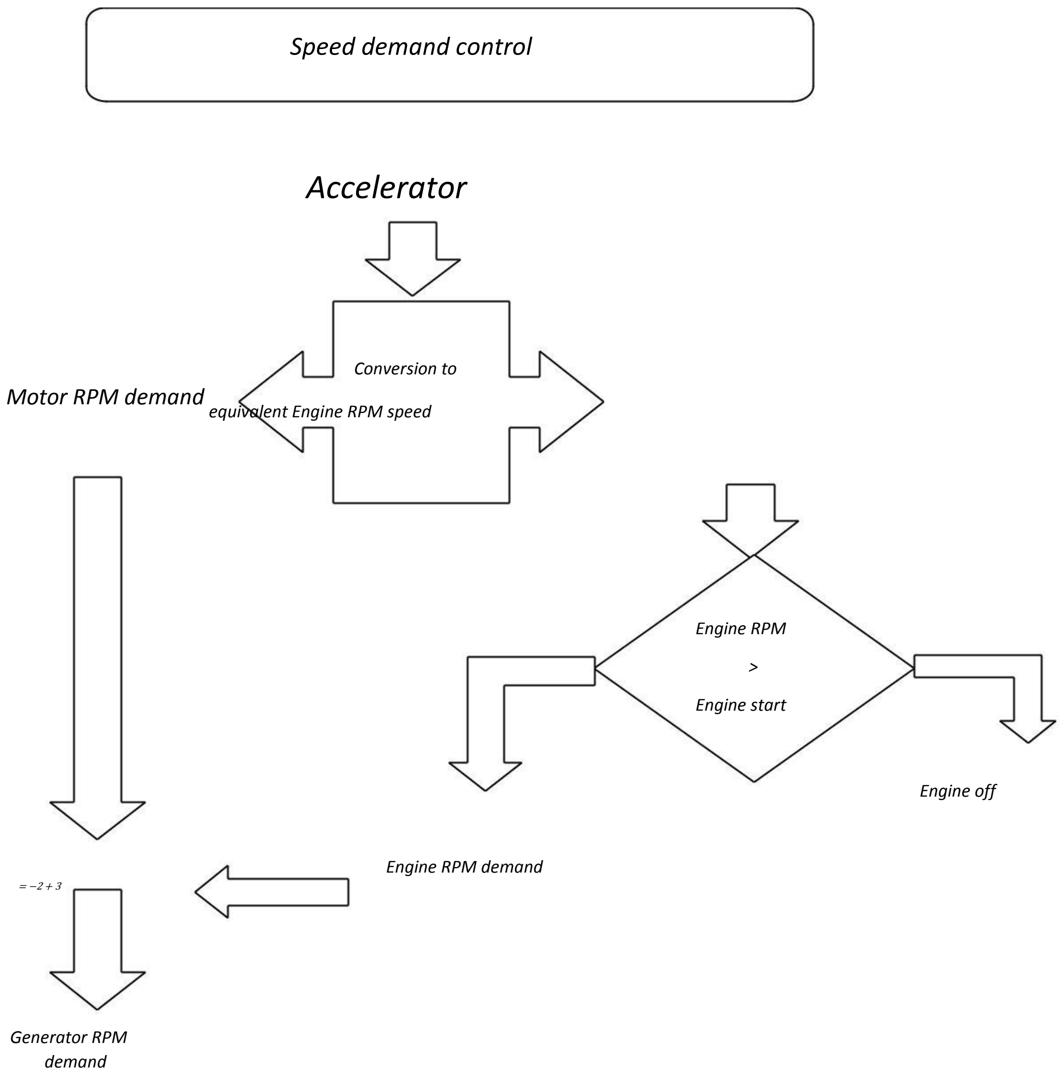

Fig 14: Speed management for the SPHEV

Fig 14 shows the speed management of the SPHEV as per the accelerator cycle and time to start the engine or speed at which engine starts. According to the gear ratio of Power Split Device the generator speed varies so as to manage the engine and motor speed at constant value.

CHAPTER 4

RESULTS AND DISCUSSION

In the chapter simulation results using the MATLAB(Simulink,Simdriveline,Simscape) are discussed . also the mathematical result for PSD , tractive force , presented in the chapter.

4.1 Simulation parameters and Results

There are no. of parameters to be considered for study of Hybrid Electric Vehicle of which some for our simulation study are:

Vehicle mass =600kg

Tire radius =0.3 m

Total wheel inertia =0.1kgm^2

Aerodynamic drag coefficient =0.02 N/kmh^2

Engine to vehicle gear ratio =1.3

Using the accelerator cycle given below tractive force and torque requirement for driving vehicle is calculated, thus motor\generator\engine speed demand, and torque demand can be derived.

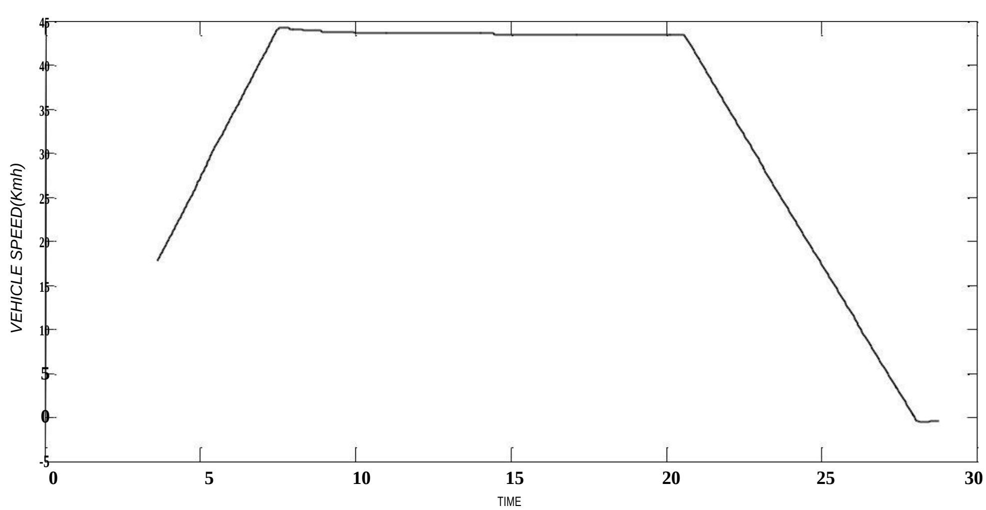

Fig 15 : Drive cycle

Figure 15 shows the acceleration cycle for the study we can modify this cycle as per requirement, acceleration period of up to 7.5 the constant drive till 20.5 sec then deceleration period.

Using this plot and vehicle dynamics tractive force calculated from which required torque for drive is calculated for acceleration period, constant period and de acceleration period.

From this plot

$$= \quad .= \ .=$$

During acceleration all three forces are to be considered thus resulting in the torque requirement of nearly 365 Nm during acceleration, when constant drive period is considered is neglected thus result in requirement of 10.95Nm, during deceleration -365Nm is required.

Table 1: Average results from simulation and calculated values

Cycle	Average results from simulation	Calculated result
Acceleration	271.25Nm	300.53Nm
Constant drive	9.20Nm	10.23Nm
DE acceleration	273.22Nm	280.878Nm

Table 1 shows the tractive power required for the power train calculated using the mathematical expression defined in chapter 2 and results which are obtained from the simulation. These are nearly matching.

A. Power (Motor/Generator/Engine/Battery)

Power management in HEV is very important. Battery and engine are working in collaboration with each other. At starting, the battery with motor runs the vehicle. Battery work as the starter for the engine as per the speed demand, battery with generator start the engine, and Power split device is heart of the SPHEV, which helps in starting. Sun/ring/planet gears were connected to the generator/motor/engine, which as per the gear ration sets the speed demands. The Power plot shows the variation of the Motor/Generator/Engine during the accelerator cycle. Other figure represent the battery power during the cycle.

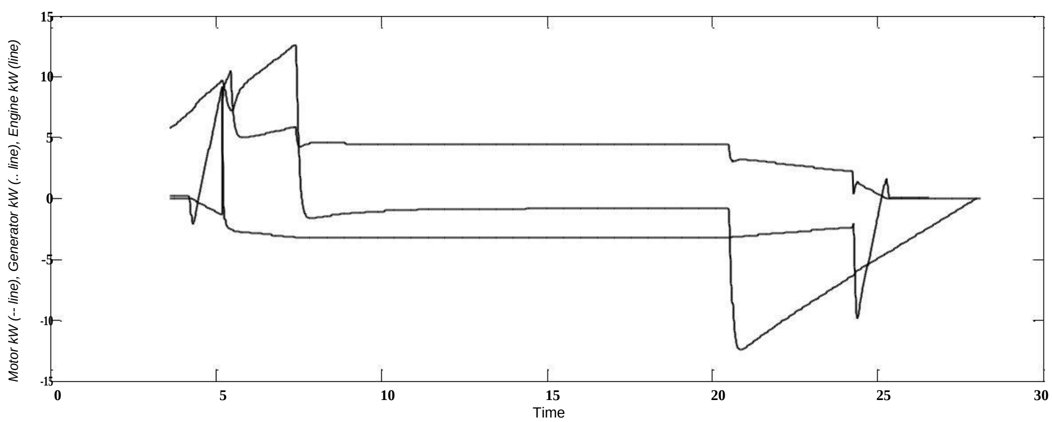

Fig 16: Motor kW (-- line), Generator kW (... line), Engine kW (line)

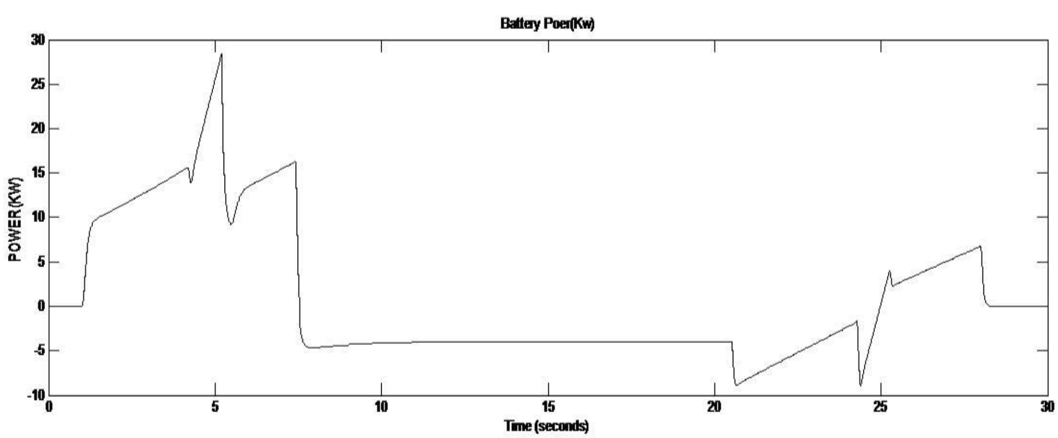

Fig 17: Battery Power

Figure 16 illustrate the Power in KW as shown by Motor kW (-----), Generator kW (.....), Engine kW (line). Engine in running the vehicle as well charging the battery through generator can be seen from the plot. Engine power is sum of motor generator and vehicle drive power. Thus engine during the constant drive is playing role of main source of power. At start battery is running motor and generator to run vehicle as well to start the engine. At end engine power decreased slowly. Figure 17 shows the battery power during the cycle, at start its contribution is high because it has to start engine as well to drive vehicle. During constant period it is being charged and during deceleration change in power as engine stops and make the vehicle to stop smoothly so power variation is there.

B. Speed

Using the look up table in simulation the accelerator input is converted to speed , which is further decide requirement of generator/motor speed demand also the engine speed as well as when engine is ignited to work in coordination with battery to drive the vehicle can be controlled .

Figure shows the motor rpm demand and measurment as per the drive cycle , generator speed is varied so as ti maintain engine speed and motor speed remain constant ,results in smooth operation of the vehicle drive.

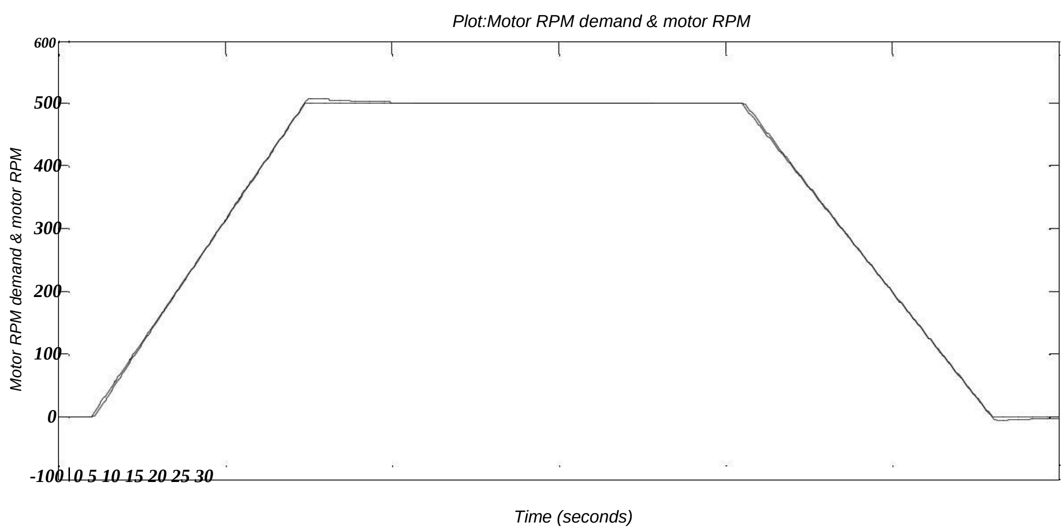

Fig 18: Motor RPM demand and actual value

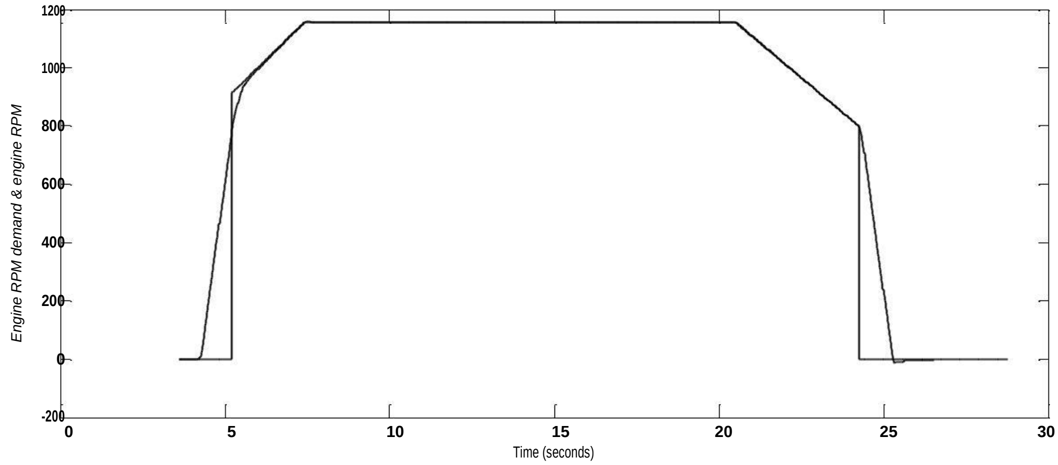

Fig 19: Engine RPM demand (----) and Actual (line)

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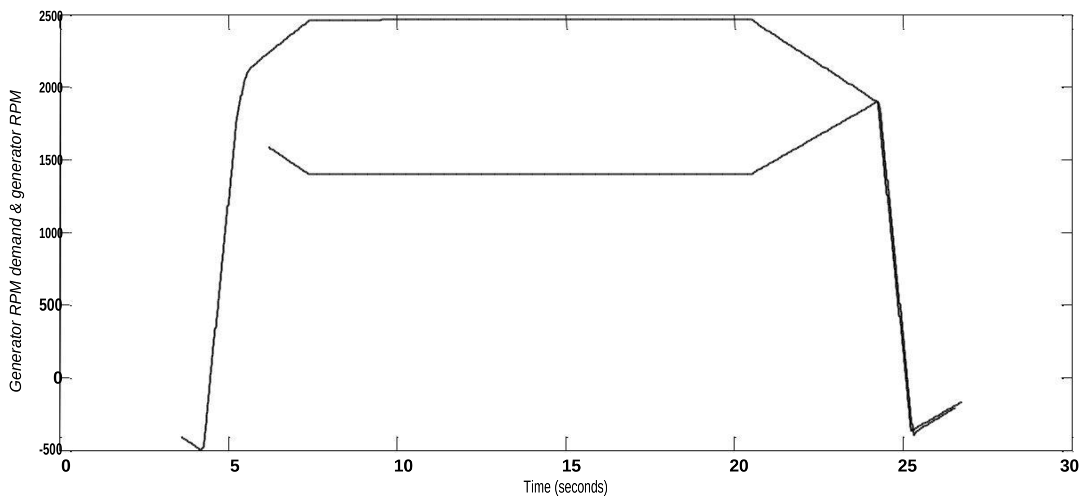

Fig 20: Generator RPM demand (---) and Actual value (line)

Figure18 shows the Engine rpm demand(line) and measurment(dotted line) plot during the drive cycle. Both are nearly matched this is reslut of power split device which make generator to vary its output as per demand

Figure 20 illustrate the generator RPM measured (line) and demanded (dotted line) clearly shows the difference in generator RPM to manage the Engine and motor RPM constant.

Figure 19 shows the engine RPM demand(dotted line) and RPM measured (line) at start and end the variation because of the more power given by generator to start the engine . and at end it shuts slowly.Generator plot for RPM demand and measurment is below which shows the working of the power split according to demands the generator speed is varied to maintain the motor and engine speed.

Results for drive cycle

The values of power from different sources Engine, generator, motor, battery, vehicle torque demand with time. this data shows clearly working of the SPHEV with no converter, that when engine in on the at 5 sec the power from sources changes .as the battery start charging when drive is in constant period , observed from the table. Similarly the generator operation when it start giving power to battery from engine the change in power is observed.

Table 2: POWER (Motor, Engine, and Generator)

Drive Cycle Time Period (sec)	Vehicle torque(Nm)	Power battery(Kw)	Power engine(Kw)	Power demand(Kw)	Power generator(Kw)	Power motor(Kw)
0.5	312.6340584	7.437524	-0.00038	0.7120397	0.02464431	0.71052
1	308.5485342	8.182085	-0.00017	1.5833938	0.05001594	1.58258
1.5	305.4198466	8.936533	-6.27E-05	2.4280088	0.07308648	2.42986
2	303.3277523	9.716683	-1.41E-05	3.2580621	0.09472298	3.26376
2.5	302.0153825	10.51969	6.89E-06	4.0811432	0.11549356	4.09139
3	301.2965018	11.34336	1.46E-05	4.902383	0.13577773	4.91754
3.5	301.0362049	12.18602	1.62E-05	5.7253164	0.15582805	5.74553
4	301.3223732	14.58994	-0.36082	6.5477422	0.38691993	6.90806
4.5	302.3030612	22.01113	-1.08378	7.3980707	6.86886839	7.80392
5	273.1955372	6.828143	5.944518	7.4775849	-2.5812026	6.03963
5.5	300.8768017	9.867795	4.751653	9.0277861	-2.73462733	7.86009
6	302.7198933	10.58957	4.990027	9.9039238	-2.85533224	8.63303
6.5	304.2379148	11.29503	5.236316	10.779465	-2.97419608	9.40248
7	305.7952383	12.01179	5.484284	11.665279	-3.09179101	10.1811
7.5	119.2452668	0.994727	4.323844	4.8542275	-3.19263456	3.62337
8	-3.879687824	-4.561244	4.536623	-0.158002	-3.18733174	-1.48382
8.5	0.127342772	-4.413067	4.5277	0.0051704	-3.1903394	-1.31326

9	3.226723591	-4.296708	4.517544	0.1307214	-3.19248941	-1.18126
9.5	5.470989975	-4.211912	4.510312	0.2212859	-3.19397151	-1.08609
10	7.095408327	-4.150252	4.505184	0.2866552	-3.19498701	-1.01744
10.5	8.271176688	-4.105468	4.501554	0.3338749	-3.19567799	-0.96788
11	9.122213884	-4.072971	4.498989	0.3680031	-3.19614424	-0.93209
11.5	9.738211872	-4.049403	4.497181	0.3926797	-3.19645564	-0.90623
12	10.18408872	-4.032319	4.495909	0.4105276	-3.19666098	-0.88754
12.5	10.50683126	-4.019938	4.495016	0.4234393	-3.19679418	-0.87404
13	10.74044795	-4.010968	4.494392	0.4327817	-3.19687871	-0.86427
13.5	10.90955374	-4.004469	4.493957	0.4395424	-3.19693077	-0.85721
14	11.03196483	-3.999762	4.493656	0.4444352	-3.19696141	-0.85211
14.5	11.12057657	-3.996352	4.493447	0.4479764	-3.19697819	-0.84842
15	11.18472272	-3.993882	4.493304	0.4505397	-3.19698617	-0.84576
15.5	11.23115921	-3.992093	4.493206	0.4523951	-3.19698874	-0.84383
16	11.26477616	-3.990797	4.49314	0.4537383	-3.19698814	-0.84243
16.5	11.28911321	-3.989858	4.493095	0.4547106	-3.19698581	-0.84143
17	11.30673253	-3.989178	4.493065	0.4554145	-3.19698266	-0.8407
17.5	11.31948876	-3.988686	4.493046	0.4559241	-3.19697926	-0.84017
18	11.32872444	-3.988329	4.493034	0.4562931	-3.19697593	-0.83979
18.5	11.33541141	-3.98807	4.493026	0.4565602	-3.19697286	-0.83952
19	11.34025317	-3.987883	4.493021	0.4567536	-3.19697013	-0.83932
19.5	11.34375903	-3.987747	4.493019	0.4568937	-3.19696775	-0.83918
20	11.34629767	-3.987649	4.493017	0.4569951	-3.19696573	-0.83907
20.5	11.34813601	-3.987577	4.493017	0.4570685	-3.19696404	-0.839
21	-297.5264642	-8.162363	3.201341	-11.31258	-3.08435179	-12.292
21.5	-295.3153616	-7.164384	3.050985	-10.39797	-2.97412348	-11.301
22	-293.3846049	-6.18745	2.890248	-9.51483	-2.86393101	-10.3399
22.5	-292.2284465	-5.218768	2.732511	-8.672852	-2.75360395	-9.42199
23	-291.6090411	-4.254288	2.577283	-7.857089	-2.64342436	-8.53201
23.5	-291.3504203	-3.291757	2.424245	-7.057353	-2.53359853	-7.65949
24	-291.3252744	-2.330077	2.273163	-6.266871	-2.42424132	-6.79747
24.5	-290.4901109	-7.062311	1.133943	-5.459021	-8.12935374	-5.77233
25	-291.2348199	0.337143	0.401905	-4.688248	-1.57E+00	-4.95457
25.5	-292.5113494	2.591267	-0.01523	-3.92E+00	0.12550983	-4.15885
26	-291.7674674	3.413935	-0.0136	-3.127172	0.10541946	-3.32703
26.5	-292.0480987	4.26308	-0.01172	-2.344941	0.0861438	-2.50015
27	-292.2431902	5.104933	-0.01002	-1.560915	0.06208557	-1.66719
27.5	-292.3488665	5.939657	-0.00852	-0.775738	0.03440145	-0.82979
28	-292.3625976	6.767245	-0.00721	0.0098957	0.00398143	0.0106
28.5	16.1258964	0.012735	-0.01001	-0.007636	-3.31E-04	0.00266
29	12.00478003	0.01744	-0.00735	-0.004126	-7.19E-05	0.00327
29.5	8.705345446	0.02211	-0.00542	-0.002169	8.65E-05	0.00315

30	6.312361537	0.025965	-0.00402	-0.00114	1.76E-04	0.00269

C. Speed

This table below shows the speed demanded and measured value satisfying the operation of the SPHEV as per the speed demand fixed by the accelerator cycle in accordance to the gear ratio of the power split device.

Table 3 Speed demand and actual value

Speed engine demand(RPM)	speed engine actual(RPM)	speed generator demand(RPM)	speed generator actual(RPM)	speed motor Actual(RPM)	Speed motor demand(RPM)	vehicle speed out(Kmph)
0	-1.19939547	-67.56756757	-60.14558455	28.27369907	33.78378378	21.74899928
0	-0.664899518	-135.1351351	-129.4066571	63.70597925	67.56756757	49.00459943
0	-0.311999665	-202.7027027	-198.3135389	98.68876994	101.3513514	75.91443841
0	-0.08663483	-270.2702703	-266.9408246	133.34046	135.1351351	102.5695846
0	0.051365631	-337.8378378	-335.3497488	167.7519228	168.9189189	129.0399407
0	0.130248737	-405.4054054	-403.5874044	201.9890753	202.7027027	155.3762118
0	0.169767781	-472.972973	-471.6901634	236.0997334	236.4864865	181.6151795
0	202.7294174	179.4594595	68.6715178	269.7583673	270.2702703	207.5064364
0	608.8512958	1311.891892	1218.949831	303.802028	304.0540541	233.6938677
924.9249249	907.6800676	1724.324324	2043.472893	339.7836549	337.8378378	261.3720423
972.972973	965.0954058	1656.756757	2150.318783	372.4837174	371.6216216	286.5259364

1021.021021	1015.18609	1589.189189	2233.268358	406.1449559	405.4054054	312.4191968
1069.069069	1064.781075	1521.621622	2314.655381	439.8439216	439.1891892	338.3414782
1117.117117	1114.016581	1454.054054	2394.920733	473.5645059	472.972973	364.2803891
1155.555556	1157.880398	1400	2462.93784	505.3516768	500	388.7320591
1155.555556	1156.710503	1400	2458.994402	505.5685529	500	388.8988869
1155.555556	1156.478307	1400	2461.364913	504.0350041	500	387.7192339
1155.555556	1156.30088	1400	2463.061199	502.9207209	500	386.862093
1155.555556	1156.15467	1400	2464.235669	502.1141707	500	386.2416698
1155.555556	1156.035101	1400	2465.044556	501.5303737	500	385.7925952
1155.555556	1155.937981	1400	2465.598335	501.1078041	500	385.4675416
1155.555556	1155.859546	1400	2465.974776	500.8019311	500	385.2322547
1155.555556	1155.796511	1400	2466.228484	500.5805241	500	385.0619417
1155.555556	1155.746065	1400	2466.397683	500.4202554	500	384.938658
1155.555556	1155.705841	1400	2466.509043	500.3042404	500	384.8494157
1155.555556	1155.673872	1400	2466.581101	500.2202579	500	384.7848137
1155.555556	1155.648535	1400	2466.626681	500.1594622	500	384.7380479
1155.555556	1155.628505	1400	2466.654614	500.1154508	500	384.7041929
1155.555556	1155.612705	1400	2466.670938	500.083589	500	384.6796838
1155.555556	1155.600268	1400	2466.679759	500.0605223	500	384.6619403
1155.555556	1155.590494	1400	2466.683838	500.0438225	500	384.6490942
1155.555556	1155.582827	1400	2466.685017	500.0317318	500	384.6397937
1155.555556	1155.576821	1400	2466.684506	500.0229779	500	384.6330599

1155.555556	1155.572122	1400	2466.683086	500.0166396	500	384.6281843
1155.555556	1155.56845	1400	2466.681249	500.0120502	500	384.624654
1155.555556	1155.565584	1400	2466.679299	500.008727	500	384.6220977
1155.555556	1155.56335	1400	2466.677408	500.0063206	500	384.6202466
1155.555556	1155.561609	1400	2466.675671	500.004578	500	384.6189062
1155.555556	1155.560254	1400	2466.674131	500.003316	500	384.6179354
1155.555556	1155.559201	1400	2466.672798	500.0024021	500	384.6172324
1155.555556	1155.558382	1400	2466.671665	500.0017401	500	384.6167232
1108.148148	1110.994137	1466.666667	2388.963329	472.0095406	466.6666667	363.084262
1060.740741	1062.784845	1533.333333	2314.16135	437.0965929	433.3333333	336.2281484
1013.333333	1014.789493	1600	2239.159831	402.6043239	400	309.6956338
965.9259259	966.9211301	1666.666667	2163.904791	368.4292997	366.6666667	283.4071536
918.5185185	919.1528832	1733.333333	2088.490539	334.4840552	333.3333333	257.2954271
871.1111111	871.463711	1800	2012.980759	300.7051868	300	231.3116821
823.7037037	823.8368935	1866.666667	1937.417123	267.0467789	266.6666667	205.4205992
0	631.8860927	1321.333333	1429.076124	233.2910772	233.3333333	179.4546748
0	225.9128785	188	278.0590014	199.839817	200	153.7229362
0	-7.965690059	-333.3333333	-356.8103437	166.4566368	166.6666667	128.0435667
0	-6.686949174	-266.6666667	-286.1698792	133.0545159	133.3333333	102.3496276
0	-5.53882393	-200	-215.9691977	99.67636296	100	76.67412536

0	-4.588047929	-133.3333333	-146.3751315	66.30549387	66.66666667	51.00422605
0	-3.800858231	-66.66666667	-77.28332196	32.94037363	33.33333333	25.33874895
0	-3.149244857	0	-8.607363739	-0.420185416	0	-0.323219551
0	-3.793863706	0	0.375378679	-5.878484899	0	-4.521911461
0	-2.817196085	0	0.082616022	-4.267102139	0	-3.28238626
0	-2.095899025	0	-0.100321424	-3.093687825	0	-2.379759865
0	-1.563703825	0	-0.205465981	-2.242822746	0	-1.725248266

Torque

Torque from engine, generator, motor is compared for the time period giving the working of SPHEV as per the demanded speed. To keep the motor and engine speed constant hoe generator is working by changing the value.

Table 4 Engine, generator, motor torque

Engine torque(Nm)	Generator torque(Nm)	Motor torque(Nm)
3.012552552	-3.912770405	239.9734023
2.392915402	-3.690823065	237.223549
1.917998685	-3.519298095	235.117291
1.556614875	-3.388533185	233.7371663
1.281467459	-3.288752196	232.9025615
1.072156217	-3.212641909	232.4829338
0.913389717	-3.154715468	232.3840624
-16.99585708	53.80415766	244.541362
-16.99816748	53.81096073	245.2977267
62.53961896	-12.06214637	169.7379897
47.01602083	-12.14413771	201.5075805

46.93843426	-12.20919749	202.980188
46.96095564	-12.2702847	204.1339503
47.01101965	-12.32793592	205.2992734
35.6597035	-12.37847493	68.46848661
37.45238139	-12.37773296	-28.02664797
37.38622109	-12.37748089	-24.88072259
37.30808119	-12.37729224	-22.42943348
37.25306982	-12.37713651	-20.65549827
37.21456288	-12.37700896	-19.37238346
37.18770017	-12.37690522	-18.44432635
37.16903289	-12.37682135	-17.77310353
37.15611847	-12.37675388	-17.28765708
37.14723028	-12.37669984	-16.93658358
37.14115034	-12.37665673	-16.68269907
37.13702152	-12.37662243	-16.4991066
37.13424222	-12.37659524	-16.36635092
37.13239148	-12.37657373	-16.27036011
37.13117572	-12.37655676	-16.2009563
37.13039102	-12.3765434	-16.15077839
37.12989635	-12.37653289	-16.11450267
37.1295947	-12.37652464	-16.08827908
37.12941976	-12.37651818	-16.06932343
37.12932654	-12.37651313	-16.05562238
37.12928475	-12.37650918	-16.04572007
37.12927428	-12.37650609	-16.03856386
37.12928192	-12.37650369	-16.03339265
37.12929915	-12.37650181	-16.02965618
37.12932064	-12.37650035	-16.02695666
37.12934312	-12.37649922	-16.02500651
37.12936473	-12.37649833	-16.02359788
27.51639546	-12.32894188	-248.6811315
27.41360398	-12.27260457	-246.8942991
27.19759422	-12.21374475	-245.249581
26.98622976	-12.15163483	-244.2080739
26.77599766	-12.08664477	-243.5833143
26.56430812	-12.01903382	-243.237356
26.34878793	-11.94879463	-243.0700651

17.13657134	-54.32153585	-236.2784967
16.9884707	-53.82703787	-236.7530306
18.25889449	-3.359012911	-238.5853726
19.41768837	-3.517776621	-238.7799583
20.20759263	-3.808935064	-239.5220865
20.86270484	-4.050370722	-240.1086287
21.40645707	-4.25071853	-240.5522059
21.85825124	-4.417128241	-240.8637946
25.19989241	-8.413891107	-4.318312781
24.89846859	-8.309230606	-7.307153144
24.68337406	-8.233592859	-9.717554625
24.53352235	-8.181001047	-11.46984838

4.2 SPHEV performance with boost converter

In the section SPHEV configuration with boost converter results are given. Boost converter makes the reduction in battery size. Unidirectional boost converter, thus battery is not charged from the engine. Battery assist the engine during the acceleration period, reducing the stress on the engine.

A. Power: Hybrid vehicle is implementation of the two power sources for fuel economy. SPHEV or Power split HYBRID performance with the boost converter is different from the above-mentioned HEV. Battery in this assist the vehicle acceleration during the starting period. Battery used is of 12 v, which is very small as compare to the battery pack applied for the SPHEV. The battery pack of rating 500v is big as compared to the 12v battery. Drawback of this model is battery is to be charged separately. Boost converter is simple electronic circuit to boost the voltage applied to the required value.

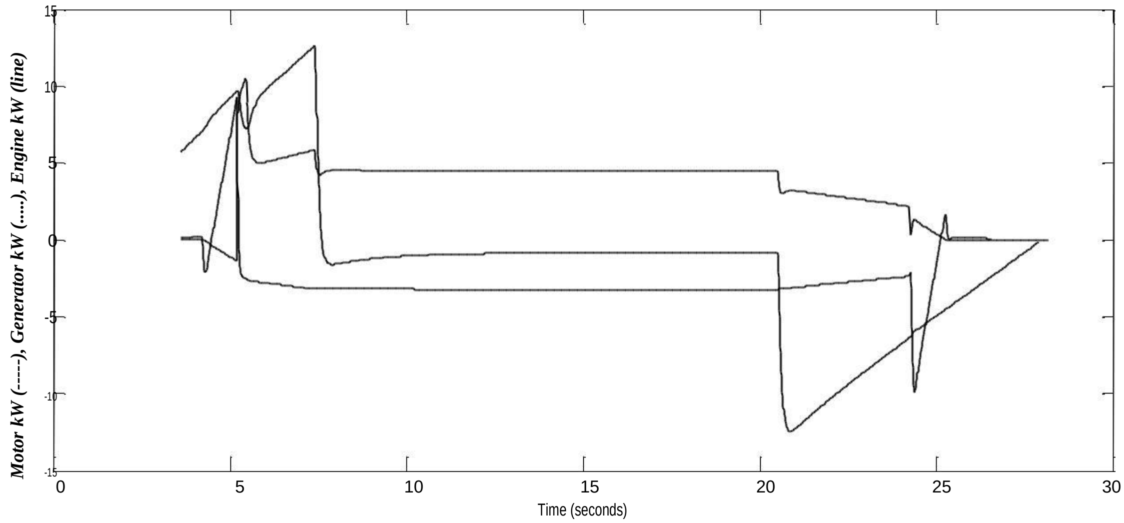

Fig 21: Motor kW (-----), Generator kW (.....), Engine kW (line)

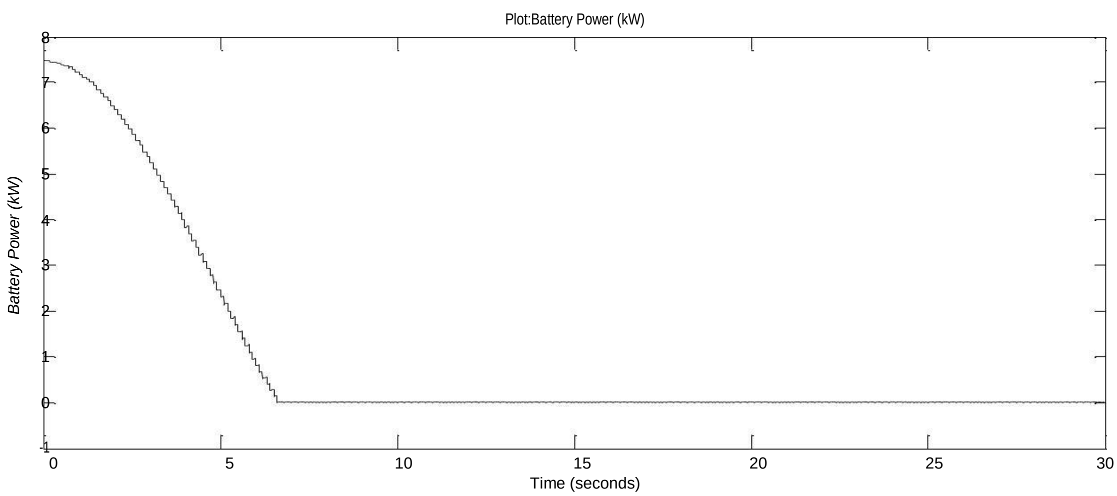

Fig 22: Power Battery

Figure 21 demonstrate the Power in KW as shown by Motor kW (-----), Generator kW (.....), Engine kW (line). Engine is running while driving the motor generator set through the power split device thus driving the vehicle connected to motor shaft. Power from generator converted to electrical is fed to motor .thus engine is driving vehicle alone as battery is not charged.

Figure 22 illustrate the battery power for SPHEV with boost converter, as battery support the engine during the acceleration period only the value is zero show the contribution during the peak demand of the battery to the SPHEV drive. It’s nor re charged as converter is not bi directional so it is to be charged separately

B. Speeds (motor/generator/engine)

Speeds of all motor generator engine play important role in the Hybrid vehicle. The speed control and torque control methodology used in the SPHEV for the performance of the vehicle to be good. RPM demand and measured values are given in the plots, which gives overview that how motor and engine RPM are maintained to the desired results by variation the generator speed cause for this is generator is to act as starter with battery for the engine.

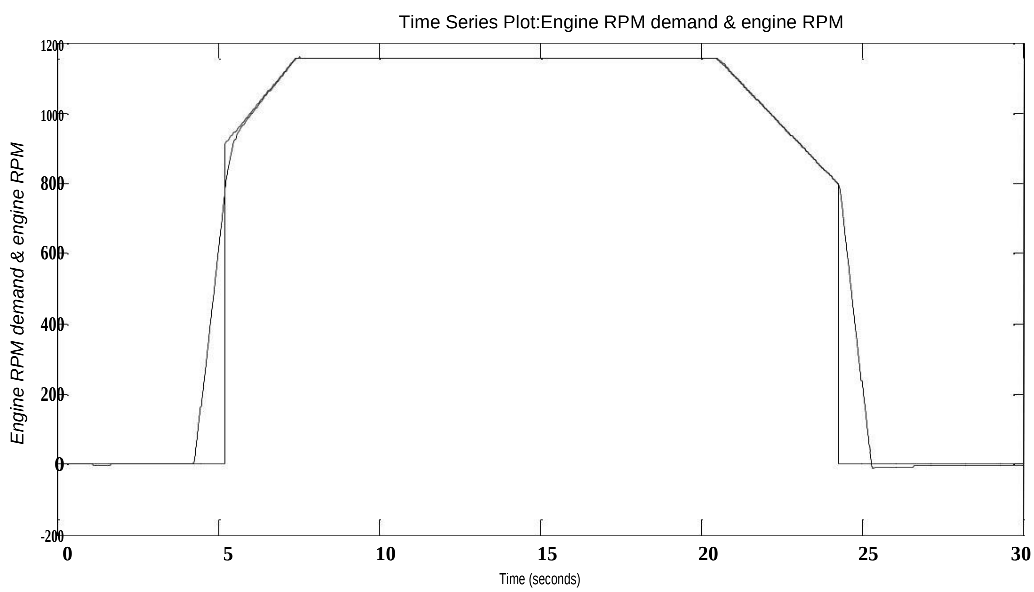

Fig 23: Engine RPM demand (---) and actual (line)

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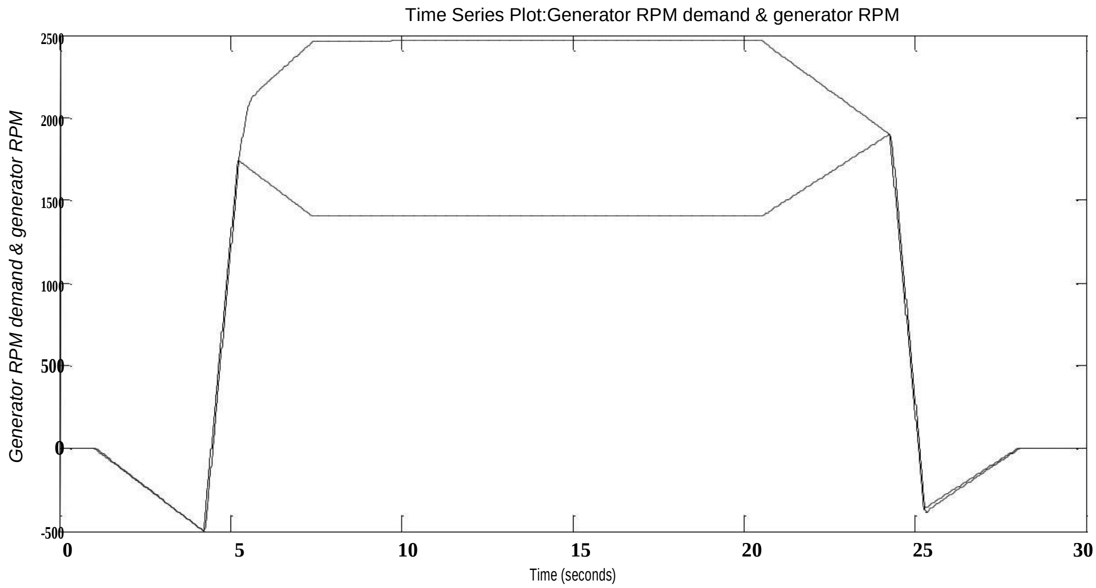

Fig 24: generator RPM demand (---) and Actual (line)

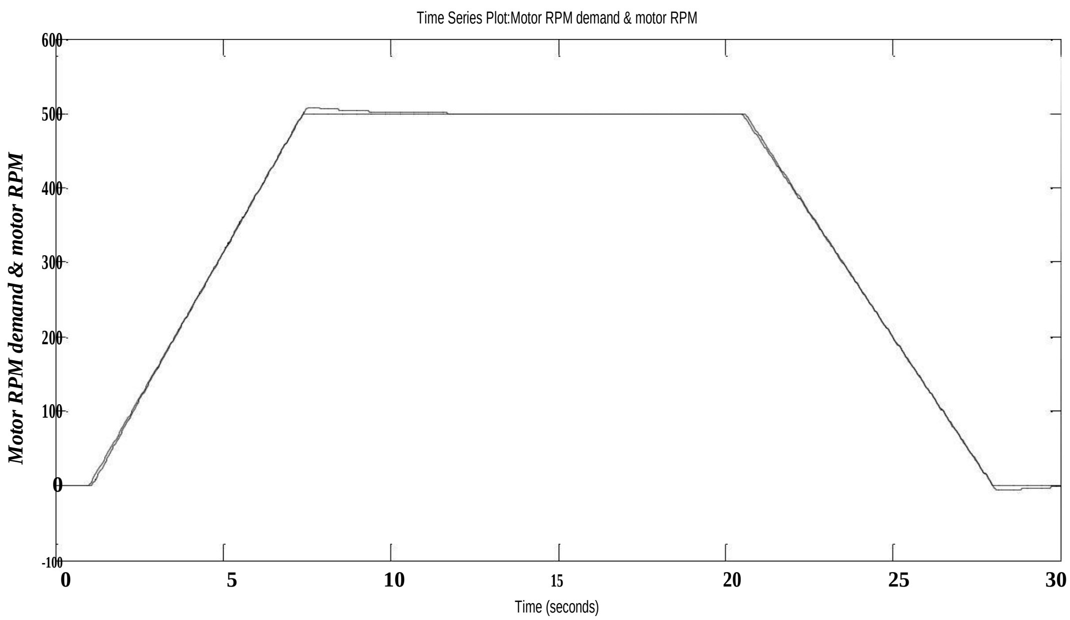

Fig 25: Motor RPM Actual (line) and demand (---)

Figure 23 shows the engine RPM demand(dotted line) and RPM measured (line) at start and end the variation because of the more power given by generator to start the engine . and at end it shuts slowly

Figure 24 illustrate the generator RPM measured (line) and demanded (dotted line) clearly shows the difference in generator RPM to manage the Engine and motor RPM constant.

Figure25 shows the Engine rpm demand(line) and measurment(dotted line) plot during the drive cycle. Both are nearly matched this is result of power split device which make generator to vary its output as per demand.

C. Torque

The torque plays crucial role in the vehicle performance the generator toque to start the vehicle developed when engine is on thus resulting the demand to start the engine as per the control loop, which includes min value of speed to be attained at which engine start. When vehicle is becomes at stand still the torque in opposite direction as such shown in the plot to stop the engine. The torque control in very crucial for the vehicle performance so closed loop control with battery is done to get most output as per the battery power.

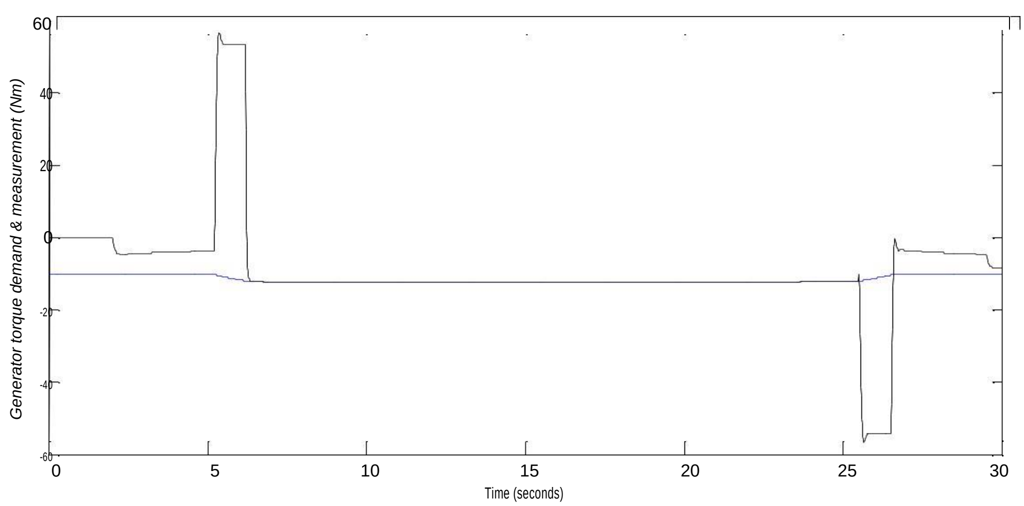

Fig 26: Torque Generator

Figure 26 shows the torque of generator which is more at start and end so as to start the engine and make shut down operation of engine easy

CHAPTER 5

CASE STUDIES

6.1 CASE 1: Battery as the main source

For hybrid electric vehicle, we are using two energy sources for driving the vehicle. A case is to be focused it is possible to drive the vehicle only by the battery if AH capacity of the battery is increased to the very high value of 5000AH say. Simulation on the model we used when such case is studied only battery is driving the vehicle, ICE has no role to play. Therefore, this is the possibility to use such battery and use of ICE in the constant drive period to charge the battery to certain amount. Implementation of battery with this large size is not possible right now, but in future nanotechnology is field in which work to reduce size is done so possible future of cars.

6.2 CASE: 2 Solar cell as the extra source

As the model developed for SPHEV with boost converter is having drawback of not charging the battery from the vehicle drive , thus use of other sources like solar cells on the roof of cars can work as best option for charging the battery . Charging the battery by use of solar energy work efficiently as it can store the energy also handling the other equipment which require the energy like bulbs, horns can also use this energy.

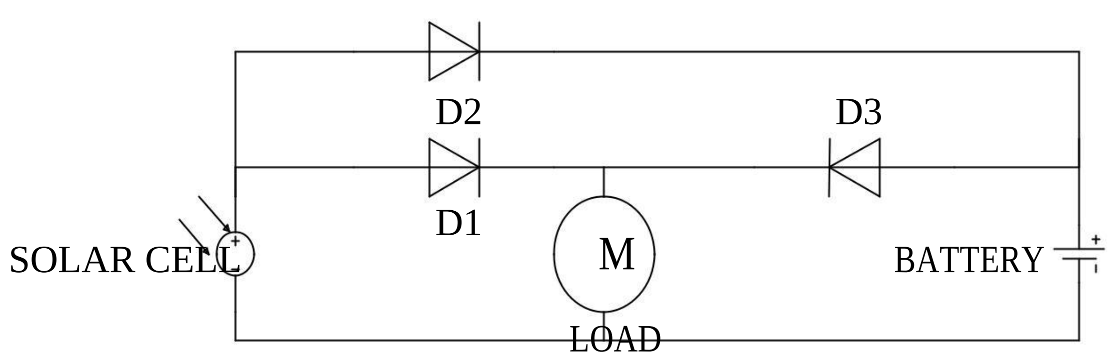

Fig 27: Schematic diagram of solar cell for load as well battery

As shown in figure 28 solar cell connected to load as well the battery. Use of the diode is to make sure the unidirectional current. Charging battery using solar energy, this not only save the electricity we use to charge the battery by plug in method, but also make best use of renewable source. Thus the battery charging possible while driving the vehicle. The simple methodology shown in figure 27, studied with load motor, battery of 12 V, solar panel with voltage of 12 V. This method can be implemented to the HEV drive [32], [33]

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

7.1 Conclusion

In the thesis report study and analysis of the Series parallel hybrid electric vehicle is done. Boost converter is implemented for the reduction of battery voltage requirement from 500 V to 12 V, this makes the low voltage battery to use for the HEV as source for acceleration region. Possibility of using solar energy or some other source to charge the battery while driving the vehicle is possible. Plug in charging is very much popular in exciting vehicle. The Simscape model used to represent HEV mostly use transformer as the converter circuit which is not possible practically thus boost converter in implemented as such giving the scope of using electronic circuits for making SPHEV more efficient. Use of the Power split device in the HEV makes the connection of the motor generator set with the engine, also this device is helpful in attaining the speed of the of HEV. Gear ratio between the engine and M/G set, also between the motor and drive shaft can be managed as per the Power split device. Closed loop control methods for speed and torque control of HEV as per the drive cycle are explored. Engine RPM and motor Rpm by change in generator RPM are maintained constant thus showing the efficient use of the Power Split Device. Motor generator output control by using the Speed torque curve as the reference method, making the efficient working of the Drive. Accelerator cycle study make things easy to develop model thus development of model to work in under different cycle. Engine Electrical control of the throttle demand is implemented in the SPHEV using the control strategies , when throttle value is 0 fuel flow is not there as battery is running the vehicle and max value of Fuel flow when throttle value is 1. Engine RPM required for drive cycle is achieved by using a control loop controller. Making the use of the renewable energy sources not only reduce pollution but make reduction in the utilization of petroleum product thus making efficient use of energy we have. Hybrid Electric vehicle is the future of transportation sector, with use of sources available making best Vehicle to match the demands.

7.2 Future scope

The research forms the foundation for further studies on the modeling and analysis of advanced hybrid vehicle powertrain configurations using advanced modeling and simulation tools.

The preliminary studies on SPHEV system for vehicle; the introduction of boost converter to model, power split configuration basics provide promising research directions that deserve further study.

Implementation of the bi directional DC DC converter is possible for the HEV. Circuit diagram for the converter is given in figure 29. Another topologies of converter circuit can also be implemented.

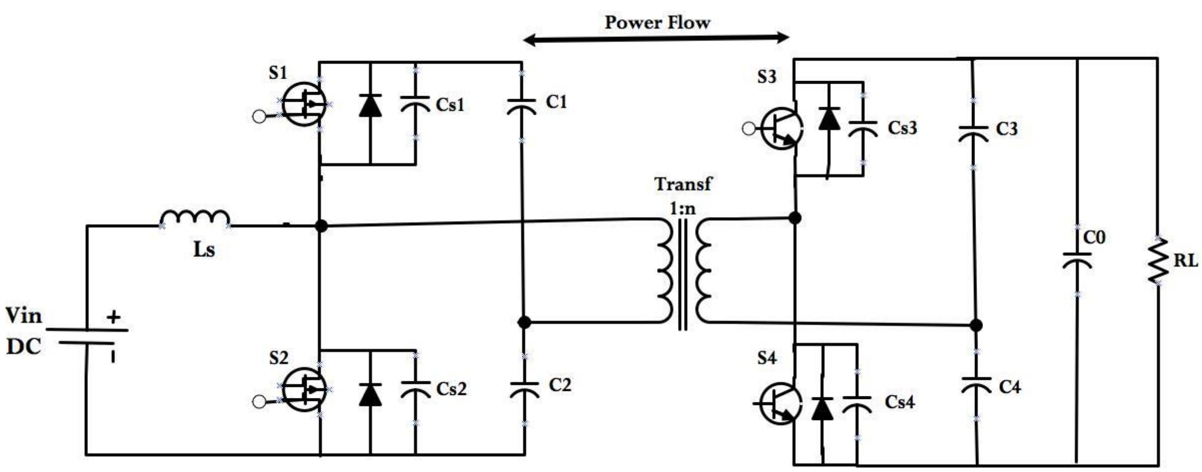

Fig 28 Bi directional DC DC converter

Power electronics making the huge difference in the performance of the vehicle, thus use and study of development of the HEV with help of Power electronics is good area to explore.

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