# HYBRID ELECTRIC VEHICLE WITH EFFICIEFUEL CONSUMPTION MECHANISM

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**ABSTRACT—As we all know that in today's world, there is a huge demand of fuel and in order to meet the demand of fuel we are introducing a hybrid electric vehicle. This paper examines the requirement for demonstrating and reproduction of electric and hybrid vehicles. Distinctive displaying strategies, for example, material science based resistive Companion Form procedure and Bond Graph strategy are given to powertrain segment and framework demonstrating models. The displaying and reproduction abilities of existing devices, for example, Powertrain System Analysis Toolkit (PSAT), ADvanced VehIcle SimulatOR (ADVISOR), PSIM, and Virtual Test Bed are exhibited through application models. Since power hardware is crucial in hybrid vehicles, the issue of numerical motions in dynamic simulations including power electronics is quickly tended to. A hybrid electric vehicle is generally a combination of an internal combustion engine (ICE) and electrical drive system. The accuracy and the efficiency of the electrical system of the vehicle is directly proportional to the performance of the vehicle. Hybrid electric vehicle is powered by fuel cell, battery and PV panel and also, we are trying to generate power when the system is powered by the IC engine. This paper consists of a Simulink model which is simulated successfully and results are more efficient than existing model. For Simulink model we have used synchronous motor. The simulation results are discussed and compared with the state-of-the-art methods like rotor speed, electromagnetic torque, current, DC-DC converter current, voltage, state of charging, grid charger performance, photovoltaic panel performance and mechanical torque. With the reference frequently used in the electrical system of the HEV the research compares the performance of the energy stored system.**

**Keywords- hybrid electric vehicle; power system of vehicle; fuel cell vehicle; solar vehicle, electric vehicle; parameter design; optimum algorithm; powertrain system, Runna, Sedan Vehicle, Control Strategy, Power Converter, ADVISOR; bond graph; hybrid vehicles; modeling and simulation; physics-based modeling; Powertrain System Analysis Toolkit (PSAT); PSIM; saber; simplorer; Virtual Test Bed (VTB)**

## INTRODUCTION

Based on the facts released by centre of solar energy and hydrogen research the total number of new hybrid vehicles registered till 2015 are 550,000. The electric vehicle according to the use of energy storage can be classified into battery electric vehicle, hybrid electric vehicle and plug-in

hybrid electric vehicle. The improved performance of power electronics and motor drives are the key
factor behind the revolutionary thought of hybrid electric vehicle. The performance of motor drives is directly proportional to the performance of the electric drive train of HEV. Due to the immense improvement in the performance of various power electronics devices like converter, switches and motor drives, the demand of hybrid electric vehicle is increasing day by day. Except the development in the hardware of the hybrid electric vehicle a silent revolution in the field of software of HEV also happened.

A hybrid electric vehicle generally consists of an ICE and motor for propulsion. Mostly each and every vehicle manufacturer are emphasizing on hybrid electric vehicle due to the safety of environment. Hydrogen was introduced as a fuel source of the vehicle to keep the environment safe. To utilize the hydrogen as major fuel source of the vehicle fuel cell technology specifically proton exchange membrane fuel cell (PEMC). Vital choice for the manufacturer in case of electric vehicle is an environmentally safe and efficient fuel hydrogen. The reduction of carbon-di-oxide emission is the main advantage of hybrid electric vehicle beside the improved fuel economy. By May 2016 the carbon dioxide rate was near 407.70 ppm and it is rapidly increasing with time. HEV (hybrid electric vehicle) technology, has many efficient systems like fuel cell, regenerative breaking and many more, which will reduce the consumption of fossil fuels which will further lead to the great reduction of emission hazardous elements responsible for ecological imbalance by polluting the environment. In HEV the system consists of efficient power electronic circuits and the all-electric system will effectively enhance the overall performance of the hybrid electric vehicles. The powertrains in electric vehicles are taken to next level where the advanced energy storage devices and energy converters are used like fuel cells, Li ion batteries, ultracapacitors and etc. The designing of hybrid electric vehicle is a bit complicated, as hybrid electric vehicle consists of a combined mechanism of all hydraulic equipments and also linked with internal combustion engine and also the electrified components. This system is a multidisciplinary system. Considering all the parameters the design specifications are chosen particularly for the better performance and efficient fuel consumption and overall dynamic performance maintaining the price acceptable by consumer market.

Creating a prototype and performing tests for each and every design combination is highly costly, time taking process. Simulation and modelling are the key for idea assessment, prototyping, examination, analysis on results for HEVs. Besides, the multifaceted nature of new powertrain structures and reliance on installed programming is a reason for worry to car innovative work endeavours. For instance, running an installed power device model and contrasting the genuine energy unit working factors with those acquired from the model can help blame determination of power devices

## BASICS OF VEHICLE SYSTEMS MODELLING

Before going into the modelling and design we need to understand some technical terms. The following explanations are based on publication by Dr. P. Fritzson from the Linko ping University, Sweden and are related to HEV modelling.

SYSTEM: The article or items we wish to think about. With regards to this paper, the framework will be an electric or HEV.

EXPERIMENT: The demonstration of acquiring data from a controllable and perceptible framework by astutely changing framework inputs and watching framework yields.

MODEL: A surrogate for a genuine framework whereupon tests [ can be directed to pick up understanding about the genuine framework. The kinds of investigations that can be truly connected to a given model are commonly restricted. In this way, extraordinary models are commonly required for a similar target framework to direct the majority of the tests one wishes to lead. In spite of the fact that there are different kinds of models (e.g., scale models utilized in wind burrows), in this paper, we will principally talk about material science based scientific models.

SIMULATION: An experiment performed on a software prototype to demonstrate or understand the outcomes.

MODELLING: The demonstration of making a model that adequately speaks to an objective framework to simulate that show with explicit foreordained analyses.

SIMULATOR: A PC program fit for playing out a recreation. These projects frequently incorporate usefulness for the development of models and can regularly be utilized related to cutting edge factual motors to run exchange contemplates, structure of examinations, Monte Carlo schedules, and different schedules for hearty plan.

There are different kinds of numerical models and test systems accessible to perform vehicle framework simulations. Generally, any vehicle system design consists of mix of an empirical data like engineering assumptions and applied physics based statistical procedures. Great test systems give an expansive assortment of vehicle segments alongside informational indexes to populate those segments. The parts would then be able to be associated together as the client wants to make a working vehicle powertrain, body, and suspension. Associations between segments scientifically transmit exertion and stream (e.g., torque and speed or voltage and current) amid a reproduction.

## MATHEMATICAL MODELLING

The mathematical modelling of permanent magnet synchronous machine are briefly discussed in [8]-[10].During the modelling of Permanent magnet synchronous machine the modelling is done in rotor d-q frame. Park transformation is used to transform the frame abc to frame d-q. From park transformation we can write for stator current,

Here,

$V_q$, is the quadrature axis voltage

$V_d$, is the direct axis voltage

$I_d$, is the direct axis current

$I_q$, is the quadrature axis current

$L_q$, is the quadrature axis inductance

$$\frac{d}{dt}(i_d) = \frac{1}{L_d}(V_d - R_s i_d + L_q i_q \omega_r)$$

$$\frac{d}{dt}(i_q) = \frac{1}{L_q}(V_q - R_s i_q - L_d i_d \omega_r - \lambda_{pm} \omega_r)$$

$L_d$, is the direct axis inductance

$R_s$, is the stator resistance

pm, is the permanent magnet flux linkage

$\omega_r$, is the rotor speed

For d-q frame electromagnetic torque will be,

Here P is the number of poles. Relation between electromagnetic torque and the load torque can be defined as below,

## III. SIMULATION STUDIES AND RESULT

### *A. Permanent Magnet Synchronous Machine*

A salient pole permanent magnet synchronous machine is used in the Simulink model where back emf waveform will be Sinusoidal. According to Figure 2 when the simulation is done electromagnetic torque of the permanent magnet synchronous motor is varied from -100 Nm to 300 Nm at t=16 sec. Rotor speed is simultaneously increasing and increase till the speed goes to 7000 rpm and tends to follow the expected. The mechanical power is varied according to the reference within the range 0 W to $15*10^4$ W. There are some distortion found

$$T_e = 0.75P * (\lambda_{pm} i_q + L_d i_d i_q - L_q i_d i_q)$$

$$T_e = 0.75P * (\lambda_{pm} i_q + (L_d - L_q) i_d i_q)$$

$$\frac{d}{dt}(\omega_r) = \frac{1}{J}(T_e - T_L + B\omega_r)$$

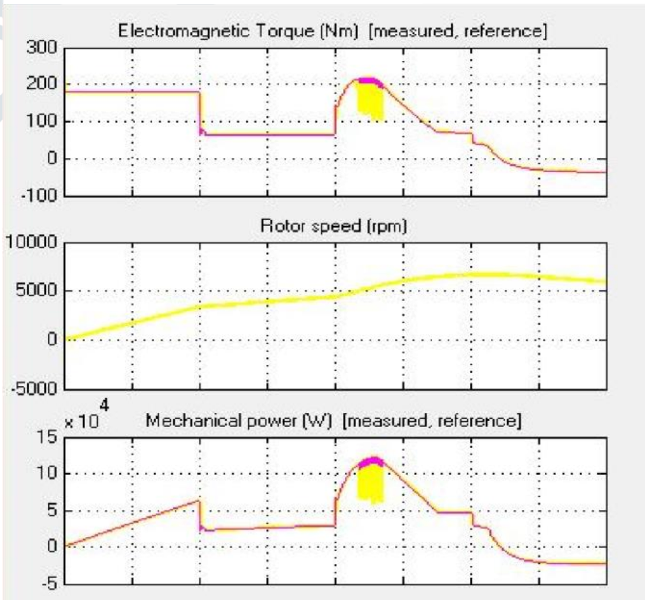



Figure 2. Performance Variation of PMSM

in case of electro-magnetic torque and mechanical power with the reference output. However this performance fluctuation is for a small period of time and can be neglected as overall rotor speed is continuously increasing. The stable output of rotor speed ensures that this two slightly fluctuated value has a very low impact on the overall stability of the entire system. According to Fig. 3 quadrature current varies within the range 0 A to 500 A and the waveform also tends to follow the expected. Similarly the reference voltage, quadrature voltage varies within the range of 0 V to 200 V and direct voltage varies within the range of 0 V to -200 V at t=16 sec.

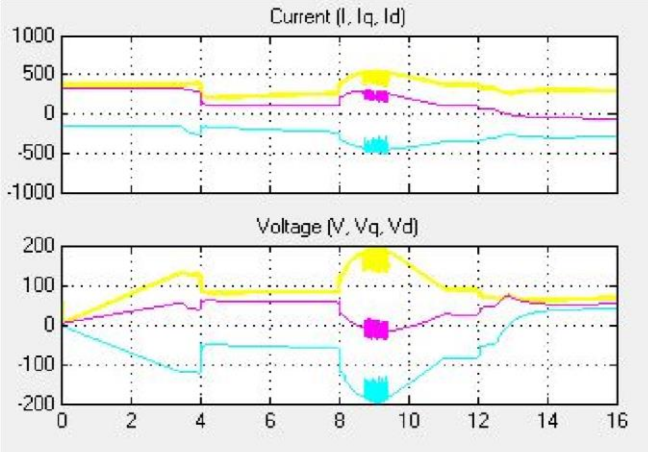
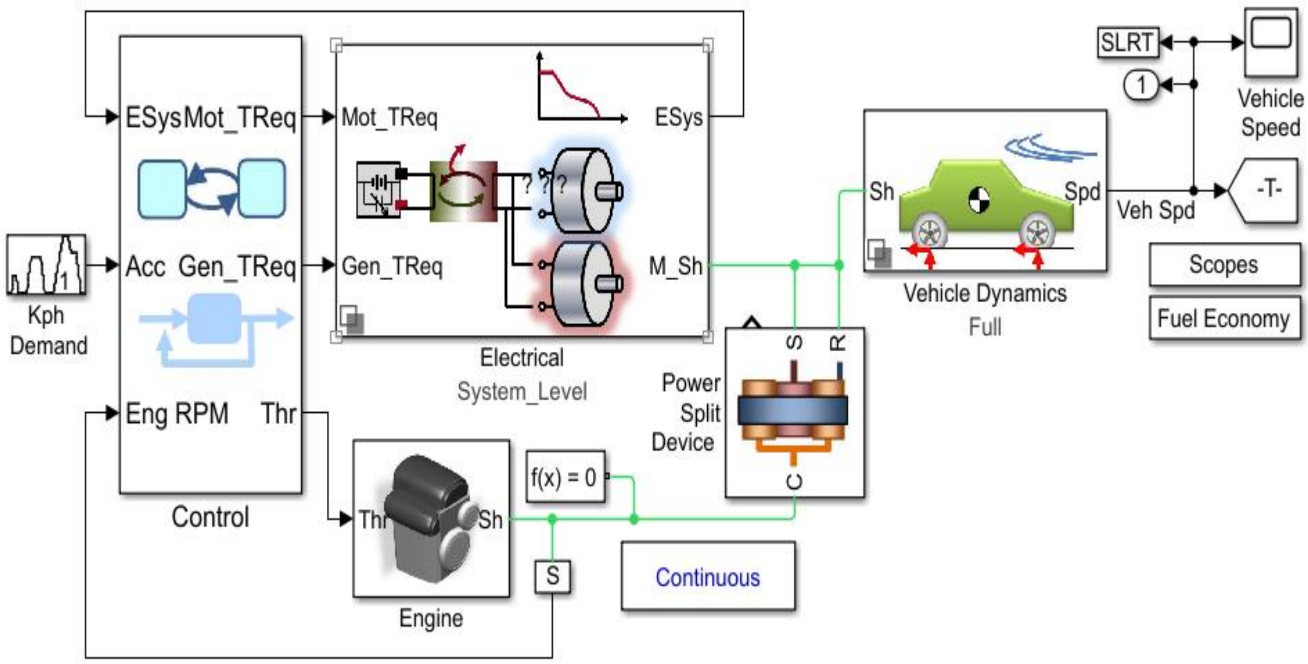



Figure 3. Current and Voltage response of PMSM

### *B. Grid Charger*

A grid charger is an electronic device that can charge the battery pack of hybrid electric vehicle at a very low current. In near future vehicle to grid charge concept can be seen where electric vehicles can be charged directly from the gird [11][12].Its name

implying that it will use AC power for charging. During parking electric vehicle can be recharged and by vehicle to grid technology a vehicle can recharge its battery pack anywhere. This will be a great improvement as battery electric vehicles are
Figure. Simulink model for Hybrid Electric Vehicle
struggling with their battery packs. Widespread implementation




of vehicle to grid technology will remove the driving range limitations of electric vehicle. Detail specification of grid charger used in the Simulink model are given below.

TABLE I. GRID CHARGER SPECIFICATION

| Parameter | Value |
|---|---|
| Peak amplitude | 312 V |
| Frequency | 50 Hz |
| Phase | 0° |
| Transformer Primary | 312 V |
| Transformer Secondary | 280 V |
| **Diode Parameters** | |
| Snubber resistance | 500 ohm |
| Forward voltage | 0.8 V |
| Resistance Ron | .001 ohm |

The Simulink model of grid charger which is prepared to combine with the Simulink model of HEV power system are visualized below. The model is consisting of a transformer, four diodes and other RLC elements.

According to Figure 5 the output voltage of the grid charger varies within the 255 V to 280 V at t=16 sec which meets the desired system requirement of 280 V.

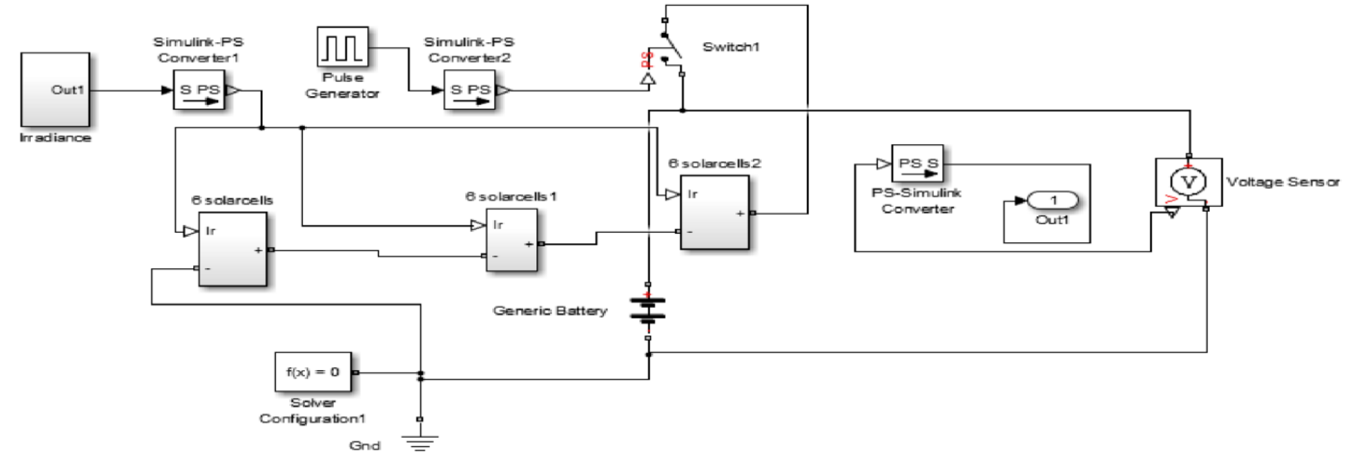



Figure. Simulink Model for Grid Charger

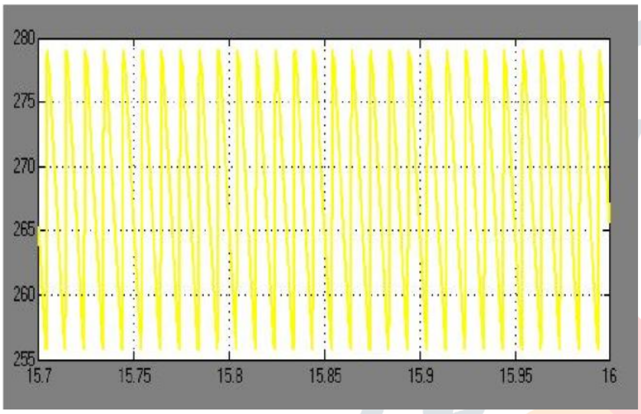



Figure 5. Response curve of Grid Charger

### C. Photovoltaic Panel

Commercial photovoltaic panels cannot provide equal performance due to average thermal conductivity of substrate material [13]. Here eighteen photovoltaic cell are used to complete the model of photovoltaic panel. According to Figure 6 the Simulink model of photovoltaic panel used in the HEV power system to support the battery is shown.

According to the Fig. 7 the output response of the photovoltaic panel is shown. It is mentioned earlier that photovoltaic panel will support the auxiliary battery of the vehicle which is typically contains the rating of 12 V. From the simulation result it is seen that initially the panel generating 11.929 V however the generation is slightly reduced in course of time which remains till 15.95s.In 16th second and onwards a constant supply of 11.928 V is achieved which is very close to recharge a 12 V battery. That means photovoltaic panel successfully meets the

Figure. Simulink model for Solar Cells

system requirements.

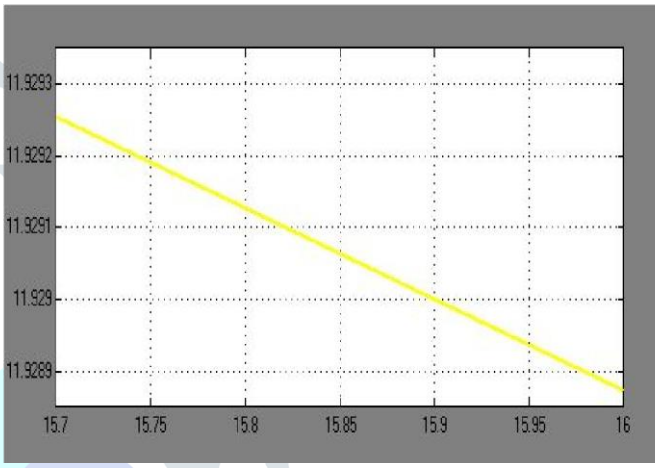



Figure 7. Solar panel response curve

### D. Fuel Cell

Fuel cell is an integral part of the proposed hybrid electric vehicle power system. The use of fuel cell was initiated by NASA as supporting power source to meet the power demand of their space shuttle. Overall performance of the vehicle specifically the fuel economy of the vehicle depends on the vehicle energy management system where the power distribution between fuel cell and battery is done. That means to improve the fuel economy of the vehicle it is equally important to improve energy management system. To measure the performance of the fuel cell system generally the initial state of charging and final state of charging are considered. Specification of fuel cell used in the Simulink model are given below.

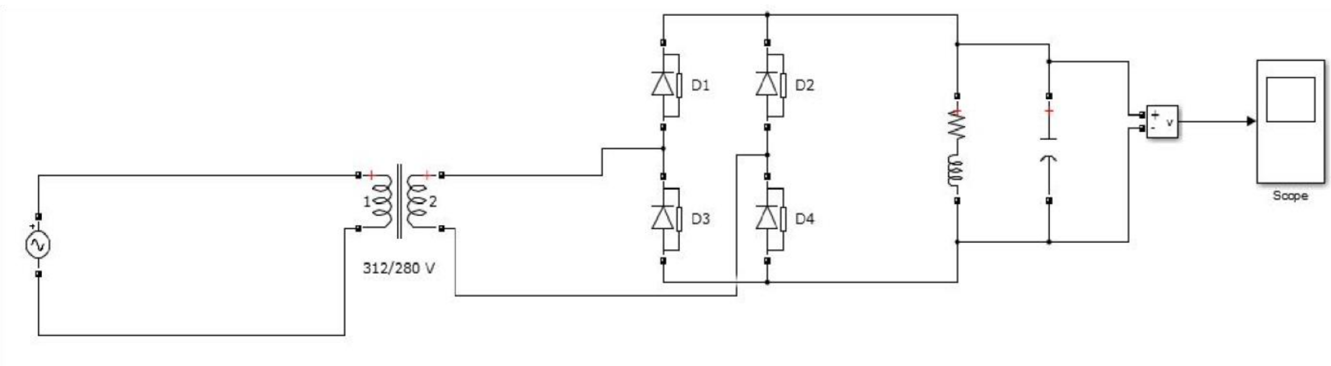


TABLE II. FUEL CELL SPECIFICATION

| Parameter | Value |
|---|---|
| Number of cell | 400 |
| Stack efficiency | 57% |
| Operating temperature | 95˚ |
| Nominal air flow rate | 1698 Ipm |

Total number of fuel cell stack used in this Simulink model is 400 where stack efficiency is 57%. Operating temperature plays important role in case of fuel cell. In this system the system temperature kept 95˚C. Vehicle fuel cell system can be classified into four sub-system and the air flow sub-system plays important role with having greater impact on fuel cell overall performance [15]. Air flow system is generally consisting of cooler, compressor, valve and pipes etc. To maintain the stable and reliable performance air flow control is an impressive method for fuel cell system. Here nominal air flow rate is 1698 Ipm.

According to Figure 8 it is shown that 400 fuel cell stacks are sufficient to produce the expected voltage of 280 V and the power produced by the stacks is 85.5 kW when the current is 280 A and produced power is 100.02 kW when the current is 350A. As auxiliary loads are supported by the photovoltaic panel so power produced from the fuel cell will be used completely for the propulsion of the vehicle. The relation between stack voltage vs. current and stack power vs. stack current reflects the accurate power production from fuel cell.

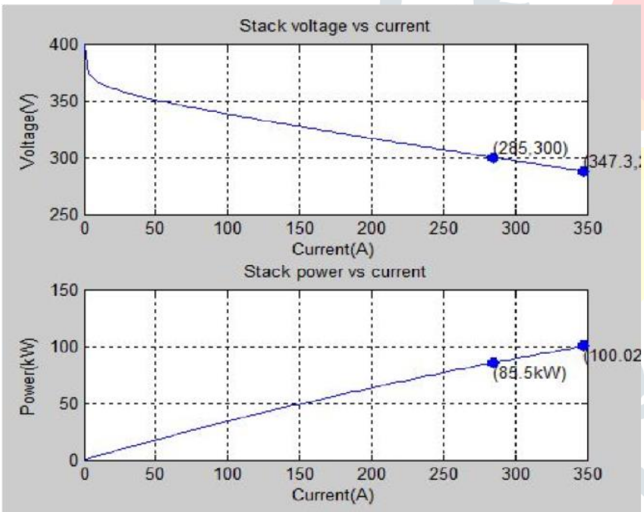
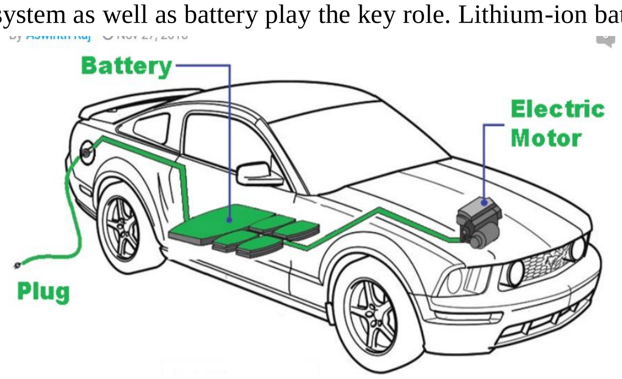



Figure 8. Fuel cell response curve

***E. Battery***

In any energy management system (EMS), energy storage system as well as battery play the key role. Lithium-ion battery




is used in this Simulink model. Detail specification of the battery used in the Simulink model are visualized below.

TABLE III. BATTERY SPECIFICATION

| Parameter | Value |
|---|---|
| Battery type | Lithium-ion |
| Nominal voltage | 288 V |
| Rated capacity | 13.9 Ah |
| Initial state of charge | 40.32% |
| Fully charged voltage | 335.2283 V |
| Battery response time | 30 sec |

## ADVANCEMENTS IN EXISTING SYSTEM

The existing system has a motor as well as generator in it which increases the weight of the system and also it reduces the place to install more batteries. In this proposed plan there is only one electrical machine which acts both as well as generator and motor based on working of the system. This machine acts as motor in initial stage where the vehicle runs on the batteries but as the battery percentage reduces to 12%-10%, the transmission network or the drive train shifts from motor to the IC engine now this engine runs the vehicle as well as the gives the mechanical input to the machine which now acts as the generator for charging the batteries. And also, one more improvement which is done in the system is batteries are easily removable and replaceable by the owner of vehicle. This is included in the system as main disadvantage of electric vehicles now a days is the range of the vehicle, but by this the customer does not need to wait until the batteries gets charged, he can just remove the drained-out batteries and replace them with charged ones while the discharged batteries are put to charge.

## OVERALL PERFORMANCE MEASUREMENT

Figure represents an overall electrical measurement of the HEV power system. Here the voltage through DC-DC converter varies within 0 V to 400 V. From output response it is seen that the converter output failed to follow the reference waveform accurately though conversion in different time period are done successfully. If the focus can be given on the battery and fuel cell voltage, some distortion in the battery performance can be found though fluctuation for a very small period of time so this fluctuation can be neglected. Though optimum voltage for the propulsion is 288V but the voltage production from fuel cell varies within the range of 300-450 V which is quite satisfactory for the smooth operation of the system. Current production of fuel cell is varying within the range 0 A to 400 A which is within the desired range of the system. According to the figure the state of charge (SOC) lies between the range 39.8% to 40.8% where system requirement is 40.32% so the output response of state of charge (SOC) clearly satisfies the demand.

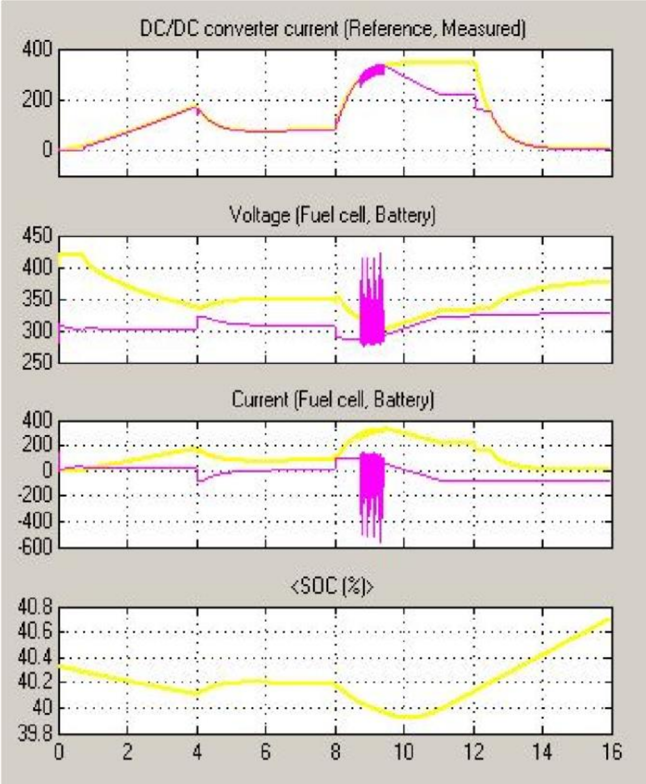



Figure 9. Performance overview of HEV power system

TECHNIQUES TO ENHANCE HYBRID PERFORMANCE

As a summary to the hybridness discussion, various techniques to enhance hybrid performance are arrayed with hybridness in Figure 2.

**Start–Stop**

Engine-off during stops in traffic affords a saving in fuel. The usual 12 V starter does not have the power to restart the engine without delay, noise, and vibration. With the more powerful electrical motors, even in mild hybrid, the engine rpm can be quickly increased. Once smoothly and quickly up to starting rpm, the fuel injection can be activated.

**Damping Driveline Oscillations**

Another way that fuel consumption can be reduced is to shut off fuel flow whenever brakes are applied. Abrupt turn off of fuel can cause shudder and unpleasant oscillations of the engine and of driveline. Damping by the electrical motor can decrease the unpleasantness to an acceptable level. For a hybrid that uses an automatic transmission, some losses in the torque converter can be reduced by locking the torque converter eliminating slippage. Under some conditions, when the torque converter is locked, driveline oscillations are excited; these oscillations are disagreeable to the customer. Once again, damping by the electrical motor can decrease the unpleasantness to an acceptable level.

**Vehicle Launch**

An engine at low rpm has little torque. At launch, torque is essential. An electric motor, even a small one, has high torque at low rpm. The motor fills in the torque hole at low rpm. A small motor can contribute significantly to the initial launch.

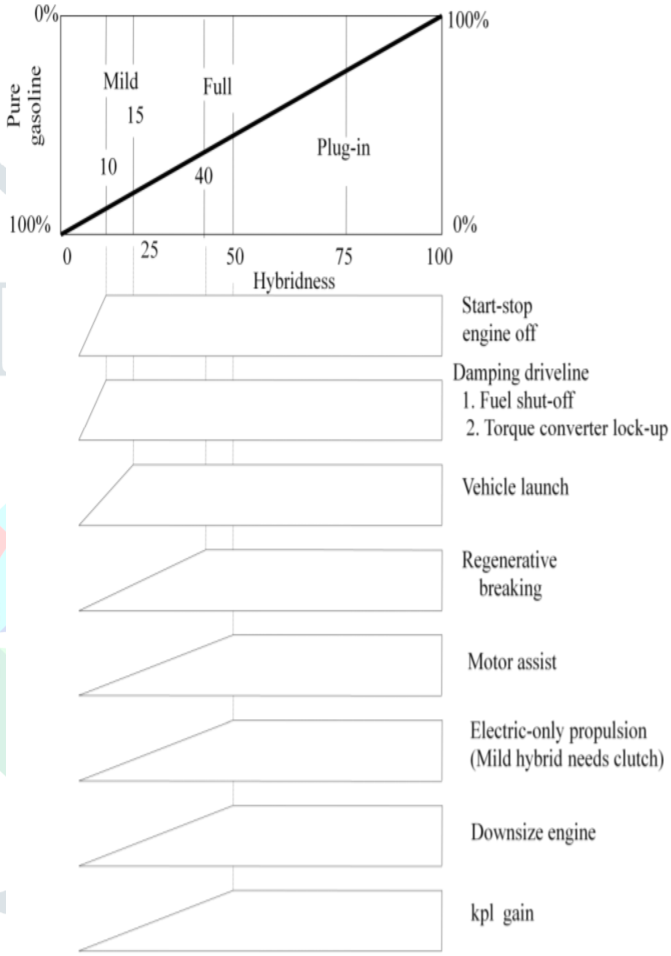
Fig.2. Availability of various techniques to enhance hybrid performance as a function of hybridness and resulting mpg gain. The bar below the hybridness graph has a ramp which extends from H = 0% to a value of H for the particular technology. For start–stop, the ramp ends at H = 10%. The flat bar beyond indicates that for all values of H > 10%, that feature is available to the hybrid designer.

**Regenerative Braking**

For small values of H, which implies small generator, the Motor/Generator (M/G) set cannot absorb the kinetic energy of the vehicles forward motion in a rapid stop. Although modest regenerative braking is possible and is used at low H, regenerative braking can only be fully exploited when H is about 40%.

Motor Assist

Vehicle launch is part of motor assist, but applies to very low speed. Motor assist covers a broader range of speed and vehicle operations such as hill climbing and driving in snow. More power and a larger electric motor are required. Hybridness, H, of 50% yields enough power from the electrical motor to overcome the power deficiencies of the downsized engine.




**Electric-Only Propulsion**

Electric-only propulsion means the gasoline engine is shut down and does not consume fuel. Electric-only operation improves mpg. To achieve performance goals, the motor must have adequate power. At H = 50%, the traction motor is as large as the engine. Alone, the traction motor yields the desired performance. Another reason that electric-only operation is desirable is the fact that emissions are zero or near zero. Stringent emission requirements may be met by electric-only operation. However, cool-down of the catalyst during idle-off is a problem to be solved.

**Kilometre per litre gain**

As hybridness increases, up to about 50%, mpg (1 mile per gallon = 0.425143707 kilometres per litre) also increases. This is a result of a balance between power required and power available. The increase in mpg possible by plug-in is not shown. Plug-in requires energy from charging stations.

**Capacity**

An electric vehicle's battery capacity is measured in kilowatt-hours (kWh), the same unit your home electric meter records to determine your monthly electric bill. In the EV world, kilowatt-hours are to batteries as gallons are to gas tanks. But a full battery can't be completely equated with a full fuel tank. "It's important to understand that the rated capacity of the battery is something you will never be able to use," says Dan Edmunds, director of vehicle testing for Edmunds.com. In order to preserve battery efficiency and battery life, a "state-of-charge" management system never lets the battery become 100 percent full or 100 percent empty. A more relevant measure might be a battery's usable capacity, but that's swathed in mystery, too.

"Usable capacity is not often reported by the manufacturer," Edmunds explains. "That is unfortunate, because the difference is significant. State-of-charge battery management, a very necessary feature of modern electric cars, nevertheless leaves you with about 60-70 percent of the rated capacity to work with."

In other words, don't rely too much on the fact that the Nissan Leaf has a lithium-ion battery rated at 24 kWh, or that the Tesla Roadster's battery is rated at 54 kWh. You'll never be able to tap all of that energy, anyway. Rather than focus on the specific figure describing a given battery capacity, then, consumers should use the rated capacity figure to compare the relative size of batteries. "It's kind of like cargo capacity or any other interior dimension," Edmunds says. "Use the number to approximate which car has 'more,' and by how much."

**Charging**

Charging comes down to two familiar resources: time and money. How long an EV takes to charge depends on its battery size and the voltage of charger that the consumer uses. How much the charging costs depends on when and where the vehicle is charged.

Until recharging stations are reliably available in shopping areas and workplaces in sufficient numbers (a development that might take years), most owners will charge the vehicles at home. And most of them will use the 120-volt "trickle-charging" cord that comes with most EVs. A trickle-charging cord is intended to top off batteries from any standard electrical outlet that can be reached without an extension cord (an extension cord is a big no-no in this process). Unfortunately, it can take more than 20 hours to complete a full charge on 120 volts.

Instead, an EV buyer will likely want to install a 240-volt home charger, which will enable much faster fills. The Nissan Leaf's battery, for instance, takes seven hours to recharge with a 240-volt charger, according to the Environmental Protection Agency. The cost of a 240-volt charger plus installation varies widely due to the differences in home wiring systems, local utility policies and a variety of regional subsidies and tax credits. A reasonable estimate is $2,000.

The cost of charging, meanwhile, depends on where the EV is driven and whether the car is refueling during peak or non-peak hours. There are more than 3,000 electric utility providers in the United States, and rates vary widely. In the Pacific Northwest, hydroelectrically generated power is cheap, and so are average electric rates. In Hawaii, electricity costs are so high that recharging an electric car could rival or exceed the cost of filling up a conventional car. (Edmunds has prepared an article that describes the cost of charging in more detail.)

Basically, cost-conscious EV owners should recharge their vehicles when the cost is the lowest, and allot sufficient time for a full charge. This will usually be at night, when the car is least likely to be needed and when, happily, electric rates are lower. Automakers recognize this is so crucial to the cost of ownership that the latest vehicles (the Leaf and plug-in hybrids such as the 2011 Chevrolet Volt for example) have programmable charge timers built in. These help drivers take full advantage of off-peak rates that might exist in their areas.

At the same time, it's important to remember that the very act of charging carries a hidden cost. Battery charging is inherently inefficient because of the heat that's generated. Fans and cooling systems in the car operate during the process, and they use some more of the electricity that's coming down the charge cord.

"Let's say your charger had a meter — most don't — and it read '12 kWh' after you finished charging," Edmunds says. "Only about 10 kWh of that charging actually made it to the battery. But, of course, you're paying for all of it." Charging losses of 15-20 percent are pretty typical of most electric cars, he says.

Early performance claims from EV manufacturers typically ignored such losses, but the EPA does not. Its official electricity consumption figures are measured at the wall, where your home meter will measure it and add it into your bill. The EPA has accounted for the hidden electricity usage on the vehicle window sticker.

**Range**

Range is the stickiest question facing new EV drivers. That's because it varies much more for an EV than it does for a conventional car, Edmunds says. Nissan says the Leaf's range is 100 miles. EPA testing puts the car's range at 73 miles. Tesla, meanwhile, says its Roadster can go 245 miles. But for all EVs, range will vary.

High and low temperatures affect battery performance and reduce range, which is why some EVs are first being introduced in areas that aren't very hot or very cold. Also, quick acceleration and fast driving discharge the battery faster. Even aggressive braking hurts significantly, because it cheats the EV's regenerative braking system of the chance to recapture some energy and recharge the battery.

Because of all these variables, "if the manufacturer says 100 miles of range, it could be 60 miles or it could be 130 miles," Edmunds says. And if the manufacturer says 100 miles, you're going to want to allow a buffer, he adds.

Further, Edmunds notes, "You can't tempt fate with the low fuel light like you can in a gasoline car, because the only place to fill up may be your own garage. So, if you're wrong, you're walking." And that's why there's so much talk about range anxiety.

While capacity, charging and range might be foreign concepts now, it's because EVs are still in their early days. Hybrids also were mysterious to most car shoppers when Toyota introduced the Prius in the U.S. just over 10 years ago. Now hybrids are a staple in many manufacturers' lineups. In the very near future, EV owners — and maybe even some EV tire-kickers — will quickly get the hang of these new rules of the road.

## CONCLUSION

In this paper mainly discussed modelling and simulation of HEV power system. More specifically performance of various electrical components of HEV power system are closely observed and analyzed. Comparison of the performance of various components of HEV power system with the state of the art methods are done. The growth of market potential of hybrid electric vehicle can be kept up by keeping the uninterrupted supply of power. That means the long lasting success of HEV is largely dependent on the sustainability and flexibility of its power system. Automotive market is currently struggling with the high price of the fuel and the most convenient way to face this is to rely on hybrid electric vehicle. Beside this a major advantage of hybrid electric vehicle is the lower emission of $CO_2$ which ensures the safety of environment. This paper represented a complete Simulink model of hybrid electric vehicle power system which is powered by PEM fuel cell, Lithium-ion battery and photovoltaic panel.

The model represented in this paper ensures the detail and accurate electrical measurement. The simulation is done with MATLAB Simulink. The efficiency of the system met with the expectation which is ensured by comparing resultant output with the state of the art methods but this can be improved by selecting more efficient power electronic equipment's. Hybrid Permanent Magnet Synchronous Machine can play the key role to improve the efficiency of this model.

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