

DESIGN AND DEVELOPMENT OF HYBRID ELECTRIC TWO-WHEELER WITH SOLAR CHARGING METHODOLOGY

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Abstract: *The concern over the environment with respect to pollution, conservation of fuel resources in the world, the automotive industry has entered into a new dimension in production of more fuel efficient, low emission vehicles and new technologies. One of the greatest innovations is Hybrid Electric Vehicle (HEV). The hybrid electric vehicle consists of two or more energy sources for total propulsion of the vehicle. In this paper, two independent propulsions, ICE and electric motor are independently operated for combined effort derivation in total propulsion of the vehicle. The Combined effort of ICE and Electric motor in propelling the vehicle more suitable for country like India is being analyzed in this paper. The ICE will be active in initial pickup and electric motor acts in supportive propulsion. The test area chosen is Mysore City, India in deriving the driving cycle.*

Keywords: *Hybrid Electric Vehicle, Two Wheeler Hybrid Vehicle, Hybrid Electric Scooter.*

I. INTRODUCTION

The invention of internal combustion engine is one of the greatest inventions of mankind. The conventional vehicles with ICE provide a good performance and long operating range. However they have caused and continue to cause serious problems for poor fuel economy, environment pollution and human life. Reducing fuel consumption and emissions is one of the most important goals of modern design. The hybridization of a conventional combustion engine vehicle with an advanced electric motor drive may greatly enhance the overall efficiency and achieve higher fuel with reduced emissions. Considering the urban status in India, a well organized and fuel efficient scooter has to be designed and developed.

II. HYBRID ELECTRIC VEHICLE AT A GLANCE

HEV are the vehicles with more than two energy sources are present. The major challenges for HEV design are managing multiple energy source, highly dependent on driving cycles, battery sizing and battery management. HEV's take the advantages of electric drive to compensate the inherent weakness of ICE, namely avoiding the idling for increasing the fuel efficiency and reduce emission during starting and speeding operations, to use regenerative braking instead of mechanical braking during deceleration and down slope driving.

HEV can meet customer's need and has added value but cost is the major issue. These vehicles are of high cost and certain program should be supported by the specific government for marketing HEVs.

The HEVs are classified into two basic kinds-series and parallel. Recently with introduction of some HEVs offering the features of both series and parallel hybrids, the classification has been extended to three kinds- series, parallel and series-parallel. It is interesting to note that some newly introduced HEVs cannot be classified into these three kinds. Hereby final classification involves series, parallel, series-parallel, complex hybrid.

iii. DEVELOPMENT OF DRIVING CYCLE

The first step in developing a driving cycle is to measure and record real driving behaviors. The obtained data has to be analyzed in forming a representative cycle from real conditions. The obtained data is classified in different sections based on traffic conditions.

iv. SPEED CONDITION AND RECORDING METHODS

The initial need for this work is to measure and record the vehicle speed. The measurement of speed is divided into two groups

1. Using the equipment provided in the vehicle like speedometer.
2. Usage of some additional equipment like GPS system.

v. CLASSIFICATION OF TRAFFIC CONDITIONS

The traffic condition varies with respect to different parts of the city. In classifying the traffic conditions the parameters used to be the average speed and percentage of idle time for each of the trip. The four traffic conditions based on the above criteria are as follows

1. Congested urban conditions: An average speed of 8kmph to 10kmph with low to high idle time.
2. Urban conditions: An average speed of 10kmph to 25kmph with moderate to low idle time.
3. Extra urban conditions: An average speed of 40kmph with low idle time.
4. Highways: An average speed more than 40kmph with very low idle time.

vi. ANYALYSIS OF THE RECORDED DATA

As the primary need for this work is to record the data, the method of recording the speed is done through dynamometer provided in the vehicle. The test vehicle is driven in stock condition through the given test route of Mysore city, India. The propulsion is only through ICE running on petrol fuel. The route chosen in the test area is as shown in the Figure.1.

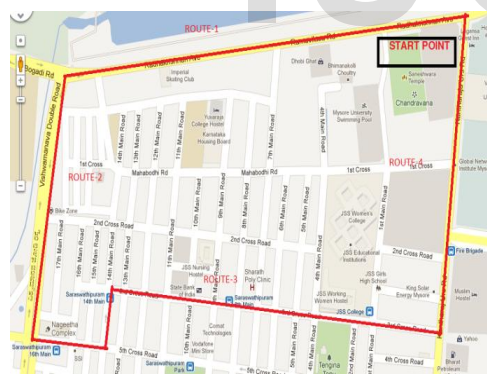


Figure1- Driving Route chosen in the test area (Ref.: GOOGLE MAPS)

The following data are recorded by making the vehicle to travel in the selected route in anticlockwise direction from start point marked on the map. The recorded data is as given in table-1.

The total distance covered in this trip is 3Km. The time taken for covering this distance is 272 seconds under moderate traffic condition. The speed-time curve is plotted for the above readings. The obtained

speed-time curve is analyzed as quadrilateral type as

ROUTE	SPEED (KMPH)	DISTANCE (KM)
ROUTE-1	50	1
ROUTE-2	50	0.5
ROUTE-3	30	0.95
ROUTE-4	40	0.55

shown in Figure.2

Table-1

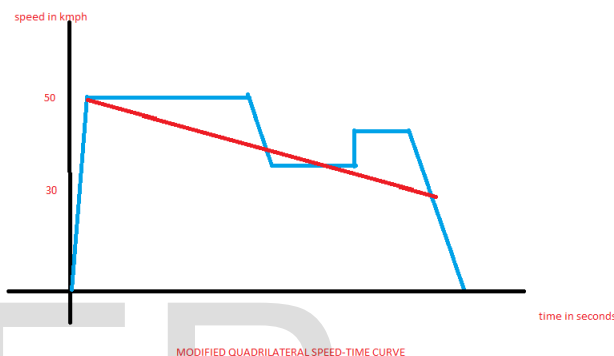


Figure.2-Quadrilateral Speed-Time Curve

The parameters obtained from the curve is as follows in table-2

Table-2

Maximum speed attained at the end of acceleration period	50kmph
Speed at the starting of braking retardation	30kmph
Starting acceleration	6.25kmphps
Braking retardation	7.5kmphps
Coasting retardation	0.07kmphps
Total time of run	280 seconds
Total distance	3km
Average speed	38.5km
Per liter test vehicle mileage	35km (considering the road gradients)

From the obtained average speed, it can be concluded that, the selected test area comes under the category of Extra Urban traffic conditions.

Table-3 shows the comparison between different cycles based on statistical parameters. It can be concluded that the obtained values of the current

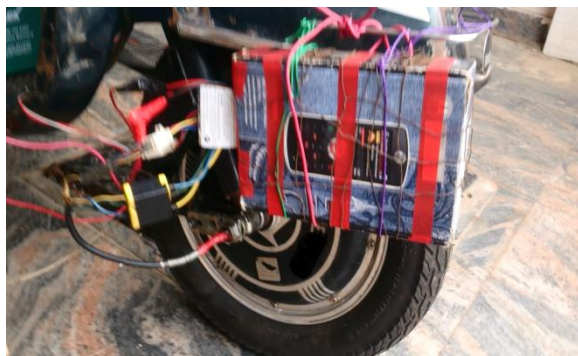
cycle are much superior compared to other in terms of acceleration, average speed and maximum speed.

Table-3

Cycle	Avg. Speed (km/h)	Max. Speed (km/h)	Run Speed ¹ (km/h)	Stop freq. (%)	Avg. Accel. (m/s ²)	Max. Accel. (m/s ²)
DTD4SK	15.42	55	20.56	24.983	1.22	2.83
ECE-15 (UDC)	18.7	50	27.7	26.1	0.75	1.04
FTP-75	25.78	91.2	39	37.95	0.51	1.50
MODE 10-15	22.72	70	33.107	31.375	0.57	0.79
Urb. ARTEMIS	17.68	57.7	23.92	26.7	0.77	2.36

vii. DESIGN AND DEVELOPMENT OF ELECTRIC SCOOTER

The design concept is developed for driving a scooter with individual wheels of the vehicle separately propelled with different sources. The rear wheel will be coupled to the vehicle as in before driven by ICE, whereas the front wheel is replaced with an electric motor in-wheel drive driven by five DC batteries. The chosen test vehicle for the analysis purpose is Kinetic Honda Y2K, made, two-stroke, continuously variable transmission, more suitable for testing purpose. For analysis, the mechanical arrangements with respect to suspension in the front wheel are being altered as per the required design for holding the motor wheel.



The controller for the motor is being interfaced with the motor speed regulation. The speed controlling throttle is being interfaced through the motor controller circuit. The motor used here is 48V, 250W, Ampere made hub motor. The controller for the motor is also Ampere made suitable for controlling the specified motor. The throttle is an ampere made throttle for speed regulation of the specified motor.

The input to the motor is supplied by five Exide made Electra lead-acid batteries each of 12V, 20Ah through controller for testing purpose. Two independent propelling sources are being employed for obtaining total propulsion of the vehicle.

vii. ANALYSIS OF THE DESIGN

The hardware model is developed for the testing purpose as displayed below.



The designed test vehicle is analyzed in the test area route. The area considered for stock vehicle analysis in deriving the above driving cycle is the same route chosen for analyzing the design. The vehicle is driven in the test area with both ICE and motor in running condition for propelling the vehicle. The observed parameters are given below in table 4. The driving

cycle analysis remains the same as describe earlier in this paper.

Table-4

Maximum speed attained at the end of acceleration period	40kmph
Total time of run	350
Total distance	3km
Average speed	30kmph
Per liter test vehicle mileage	52-55kmph (considering the road gradients)

viii. SOLAR PANEL SIMULATION DESIGN AND SIMULATION

The design would not have been completed without implementing hardware or software to the system. During the design process we used various simulation software to check the feasibility of each components that was used in system integration. We used Multisim 11.0, a printed circuit board (PCB) layout and design tool that includes a graphical user interface (GUI) and various simulation interfaces. Multisim has extensive libraries of circuit components. These components are included in the GUI as virtual components. Although, many of the components are already included in component libraries, it was essential that we created the exact number of pins on any virtual components that we added. Moreover, the pin locations and sizes had to match the actual components. This process is known as creating a footprint. The footprints we created in Multisim 11.0 would later have to match those used in Ultiboard, specifically those footprints we added. We later found that it was better to create the footprints in Ultiboard and assign them to a library which could then be accessed by Multisim. Because Multisim 7 and Ultiboard are both made by Electronic Workbench, they share the same component libraries when installed.

The arrangement of components in Ultiboard was a time intensive process. Often times, there does not seem to be a best arrangement and different compromises have to be made throughout the design process. However, as a rule of thumb, placing the components in a way that closely follows the way they were placed in Multisim is desirable as it is easy to identify components and perform troubleshooting. An additional rule is to make the connections as short and straight as possible. When copper traces are really long and distributed, there are more

opportunities for shorts, faulty connections and other circuit problems. By designing the board so that the traces are as short as possible, we conserve space and minimize the overall resistance of the board, thus, conserving power. We tried our best to place the circuit elements used to make external connections on the perimeter of the board. By following this method, it was easier to connect external wires and components to the PCB.

For the Simulation of electric machine and drive systems we used Matlab/SIMULINK 11a software. This package presents computer models of electric machines leading to the assessment of the dynamic performance of open- and closed-loop ac and dc drives. The *Simulink/Matlab* implementation is adopted because of its inherent integration of vectorized system representations in block diagram form, of numerical analysis methods, of graphical portrayal of time evolutions of signals combined with the simple implementation of the functionality of controllers and power electronic excitations. The development of SIMULINK models of drive assemblies is a relatively simple task consisting of combining input output block representation of the various components making up the system. This approach provides a powerful design tool because of the ease of observing the effects of parameter modifications and of changes in system configurations and control strategies.

Three major families of PV cells are monocrystalline technology, polycrystalline technology and thin film technologies. The monocrystalline and polycrystalline technologies are based on microelectronic manufacturing technology and their efficiency is in general between 10% and 15% for monocrystalline and between 9% and 12% for polycrystalline. For thin film cells, the efficiency is 10% for a-Si, 12% for CuInSe₂ and 9% for CdTe. Thus, the monocrystalline cell that has the highest efficiency is the focus of this paper. This paper carried out a Matlab/SIMULINK model of monocrystalline PV cell that made possible the prediction of the PV cell behavior under different varying parameters such as solar radiation, ambient temperature, series resistor, shunt resistor, diode saturation current, etc The solar cell modeling which is discussed presents the effects of the variation of the solar radiation, the influence of temperature on the PV cell outputs are investigated, the effects of the series resistance. Figure 3 shows PV cell Matlab/SIMULINK model.

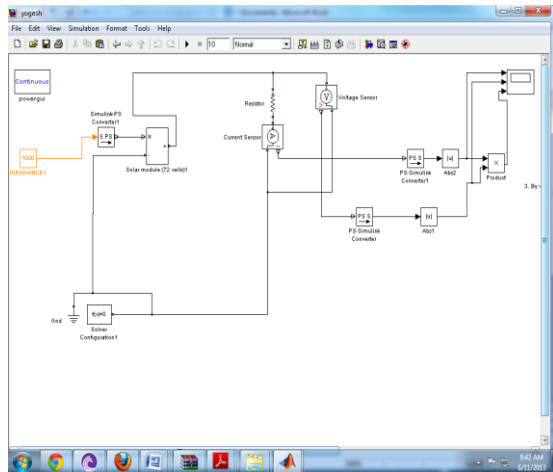


Figure 3 PV Cell Matlab/SIMULINK Model.

Figure 4 below shows the simulation results of the PV cell array model showing current rating (Ampere), voltage rating (Volt), Power Rating (Watts). It is seen that for an arrangement of 72 solar cells in series assuming constant irradiance it is seen to get a current of about 4.5 A with a voltage of about 14.5V together giving approximately 67 Watts of power. The voltage can be varied by varying the resistance and the current rating can be varied by changing the irradiance value thus a precise value can be set by varying irradiance and resistance.

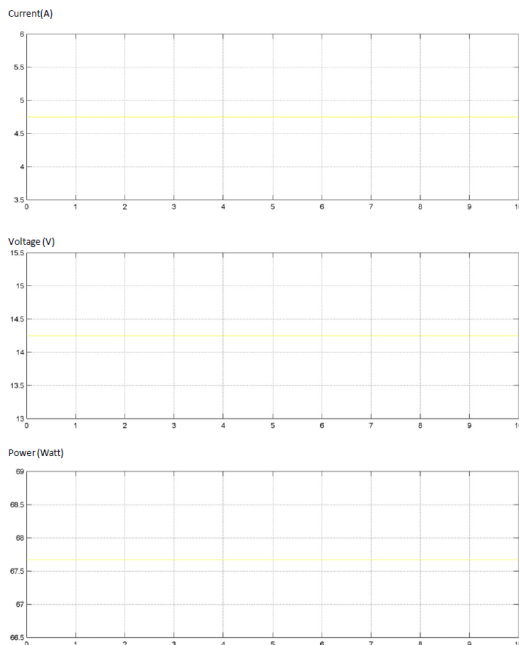


Figure 4 Simulation Results Of A Solar Panel

In order for the Texas Instruments Evaluation Module to be compatible with our battery, it must be able to output about 48V. This can be done by changing the voltage divider between resistors R5 and R7 on the EVM according to equation on the datasheet.

$$R_{BIAS} = \frac{V_{FB} \times R_{FB}}{V_{OUT} - V_{FB}}$$

In the above equation R_{FB} and R_{BIAS} correspond to R7 and R5, respectively. Using an output voltage $V_{OUT} = 48V$ instead of 24V and keeping the error amplifier reference voltage, $V_{FB} = 0.7V$, the ratio of the resistors now become 68:1, instead of 34:1. This seems like a simple adjustment, but making this change to the resistor ratio also causes other changes. It would also require us to compensate for the various other changes, such as an increase in inductor current as well as higher voltages across the capacitors. An alternative idea was to make use of a basic charge pump voltage doubler. This external circuitry doubles the voltage output without changing anything else on the evaluation module. When attempting to change the voltage divider on the EVM during simulations, the inductor current fluctuated quite largely as the voltage changed; the range became anywhere from 1A to 25A. With the charge pump voltage doubler, the output voltage becomes 41.5V (nearly doubles in output) and gives an output current of 1.36A (See Figure 5). The inadvertent change this method creates is that the inductor current at steady state is increased to 8.5A, with minimal peak-to-peak ripple. This presents a problem because the inductor is rated at a maximum of 7.5A, so if we used this EVM, we would have to change the inductor to one which yields a higher current rating in addition to building the voltage doubler. We found this to be the best design for the TI EVM that would double the output voltage because of all the other parameters that weren't affected in the process.

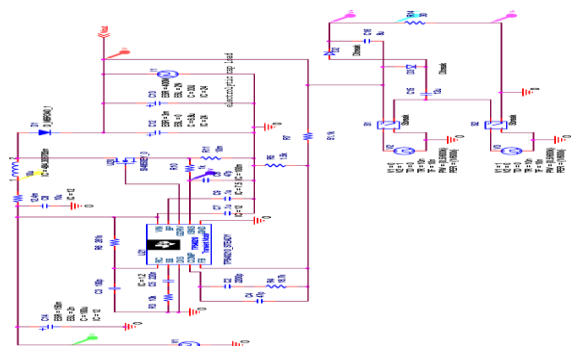


Figure 5 : Texas Instruments EVM Circuit with Voltage Doubler

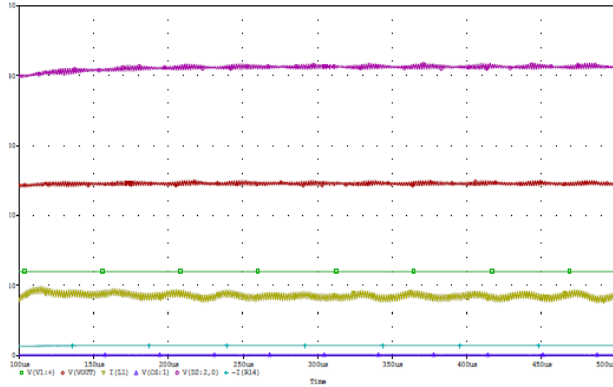


Figure 6: Orcad Pspice Simulation Results for TI EVM with Voltage Doubler

The modifications needed for the Linear Technology Evaluation Module DC1286A-A were simple changes to a few components due to the need for higher voltage and current ratings. The feedback resistor R2 had to be changed from 475k~ to 541k~ according to the equation in the datasheet

$$V_{OUT} = 1.223V \left(1 + \frac{R2}{R1} \right)$$

Where R1 is kept at 12.4k~. According to the LTSpice simulations, after changing this resistor, the voltages across the diodes came within 90% of the breakdown voltage, therefore we were required to get similar diodes which would be compatible with the EVM, but have a higher voltage rating. Also, the five 6.8μF output capacitors in parallel, C10-C14, had to be changed because they also needed a higher voltage rating (See Figure 7). They have a voltage rating of 50V, but the simulations yield a peak voltage of 54.6V across these capacitors. The FETs also had to be changed because the simulations read a peak current of 16.5A through them, where the maximum current rating is 9.6A. For the inductors, the simulations yielded a current of 7.5A, where the saturation current rating is 11A, therefore the inductors that are currently on the EVM were able to handle the increased current and they need not be changed. The output current of this EVM came out to 2.8A which is relatively close to the 3A current that the wall charger provides to the battery. Also, the output voltage is a very nice 54.58V at steady state, which is the optimal voltage required for our battery. It is shown for different cases of input voltage.

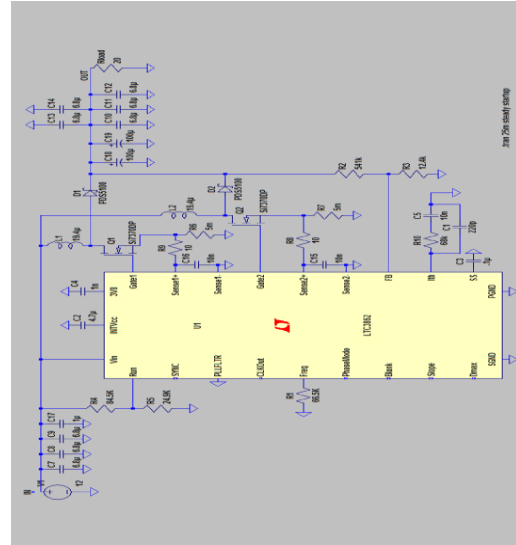


Figure 7: LTSpice Circuit for the Linear Technology EVM

LTC3862(buck boost convertor) RANGE : Vin:5v-36v, Vout:48v,5A

ix. CASE STUDIES

Case 1:

For Vin:15V, Vout: Increases gradually to reach 54V

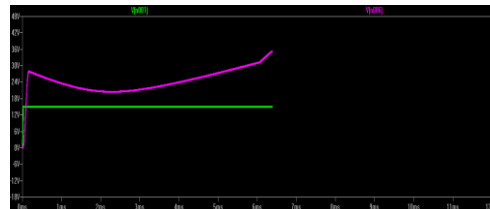


Figure 8: Voltage Increasing (Boosted) Linearly with Respect to Constant Input Voltage

Case 2:

For Vin: 12V , Vout: reaches a constant 54 V after a suitable time.

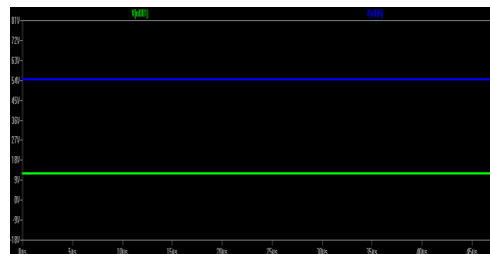


Figure 9: Output Voltage reaching a Constant Value after it reaches 54V

Case 3:

For V_{in} :30V, V_{out} : 54 V

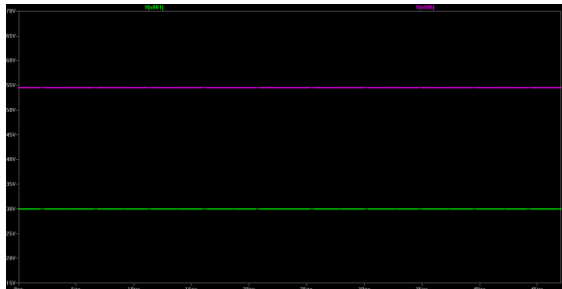


Figure 10: Output voltage remains Constant at 54V for various input Voltages

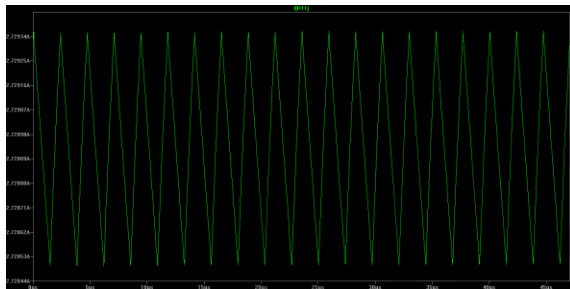


Figure 10: Output Current Waveforms

x. CONCLUSION

It is observed that, the ICE in this built hybrid electric vehicle is utilized for obtaining the propulsion of the vehicle from the rest, as the speed is increased; the electric motor propulsion is combined with the ICE propulsion for total movement of the vehicle. The total torque obtained by both ICE and electric motor are synchronized for respective road gradient by varying suitably the respective controllers utilized. By doing torque distribution accordingly, battery life per total charge can be enhanced in driving the electric motor also minimizing the fuel required for ICE propulsion. For the test route chosen, the vehicle in stock condition, eligible for giving a mileage of 35km (as observed in stock driving), With this type of arrangement, can enhance the mileage performance efficiently by 25%. The throttle with respect to ICE was moderately involved in obtaining the propulsion during the test run. The throttle involved in driving the electric motor was mutually made involved with respect to ICE throttle. Both motor torque and ICE torque were responsible in

propelling the vehicle during the test run. The torque distribution between ICE and electric motor has to be enhanced by designing a suitable torque synchronizer. The short battery life issue related to present electric bikes can be solved implementing this technology. Solar charging scheme which is designed for the proposed vehicle makes it more time efficient. Also low-emission, electric / ICE mode of operations can be further enhanced in this project. **This discussed material is patent pending with application no. 2925/CHE/2014**

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