Architecture and Speed Control of Hybrid Electric Vehicles

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Abstract
Among all the vehicle technologies available today hybrid electric traction has the most advanced vehicular technology. It reduces pollution, increases fuel economy and overall has very smooth performance. Most of the vehicle manufactures today are developing hybrid vehicles as their flagship product. In this paper a detailed study is carried out on types of the hybrid vehicles and speed control of BLDC motor for hybrid electric vehicle through simulation and experimental results.

INDEX TERMS: Hybrid vehicle, BLDC, speed control, Pollution.

1 Introduction
Hybrid vehicles refer to a vehicle which has more than one source of power to drive the wheels. A hybrid-electric vehicle shows that one source of force is given by an electric motor and other source of force can originate from various diverse innovations, however it is ordinarily given by an the internal combustion engine (ICE) intended to keep running on either gas or diesel fuel. Hybrid electric vehicles have smooth driving experience as they have
starting and ICE has high RPM giving vehicle high speed thus giving HEVs good acceleration. Conventional vehicle or a pure electric vehicle have only one source of power which is either a gasoline engine or a electric motor, due to this single power source the vehicle performs very poorly when exposed to changes in road conditions. Induction motors were used as the electric motor in hybrids but now a days BLDC motor has been broadly utilized in light of the fact that the BLDC motor has more straightforward structure and lower cost than the AC motor. As the Brushless DC motor have highest torque and good accelerate they are best the choice for vehicular applications. With no usage of brushes in the motor, temperature rise of the motor is very less and there will be no mechanical wear in the machine. There are two ways in which BLDC motor can be controlled.

1) Sensor technique
2) Sensor-less technique
Sensor technique is similar to the detector which makes the measurement of the appropriate position of the rotor. Hall Effect sensor is most widely used as position detector in BLDC motor.
Sensor-less technique implies that there is no spot detector, however it needs highest execution exhibitor. In the sensor-less strategy of controlling the motor, the cost of the motor is reduced as there are no position sensors but the control strategy is complex which increases the cost of the controller. Despite what might be expected, the price is sidestep for drawbacks.

2 ARCHITECTURE

Based upon the motor and engine driving the vehicle we can recognize the hybrid electric vehicle into different types:

A. SHEV or Series hybrid electric vehicles:

Series drivetrains have the simplest hybrid architecture. Electric motor is the only source which is responsible for vehicle’s moment. Either the battery or the electric generator is used to supply power to the motor’s controller. Vehicle electronics calculates the power from the battery and generator and then determines which source of power should be given to motor controller to drive the motor. Batteries are charged using the generator and regenerative breaking.
Series hybrid electric vehicle perform best when the vehicle has to stop and start frequently, where internal combustion engines are proved inefficient. The vehicle’s electronics allow only battery to power the motor, saving the engine for situations when the battery is low.
The engine in series hybrid is small as its work is only to run a electric generator which is used charge the battery pack. The battery used is of higher capacity than the one used in parallel hybrid as motor is the only source for driving the vehicle. High capacity battery, large electric motor, along with a internal combustion engine and a generator, adds weight and cost to the vehicle. SHEV previously subsist a largest
a. Disadvantages of SHEV: The Internal Combustion Engine and the motor which convert the electrical energy to mechanical energy are proportion to assign with the maximum force of the vehicle. In this way, the aggregate load, value and area of the drivetrain can be over the top. Amid long-separate expressway driving, the aggregate productivity is mediocre compared to traditional transmission because of the few vitality changes.

b. Profits of SHEV: The vehicle which contain pivot and combustion engine are not having any mechanical connection. The motor generator gathering can be found all over. In the not having traditional mechanically transmit components like Gear Box in motor vehicle. Isolate pivot motor must executed effortlessly.

B. PHEV or Parallel hybrid electric vehicles:

Vehicles which have parallel hybrid configuration, have an engine and electric motor which work together to move the vehicle. Smaller battery packs are used in parallel hybrids compared to series drivetrains. Parallel hybrid rely on regenerative braking to keep the battery charged. When battery is low parallel hybrids make use of the motor as a generator for charging the batteries, like a generator in series hybrid. Since the engine and motor are connected directly to the drive shaft of the vehicle, both the engine and motor can drive the vehicle making it best suitable in highways and traffic conditions.

Figure 1: Model of series hybrid vehicle
Figure 2: Model of parallel hybrid vehicle.

a. Disadvantages of PHEV: Battery charging relay only on regenerative braking, so battery gets drained faster when only motor is used making parallel hybrid non relay able in motor mode.

b. Profits of SHEV: Since parallel hybrid has both engine and electric motor connected to the driving shaft, we can use it in any type of road conditions.

C. Combined hybrid electric vehicles:

Combined drivetrains have the merits and problems of the parallel and series hybrids. By merging these two designs, the electric motor can drive the vehicle directly as in the series hybrid when high torque is required, and can be disconnected, with only the engine driving the vehicle when high RPM is required.

With electric and gas options, the engine operates at higher efficiency than other hybrids. At lower RPM it operates like a series vehicle as vehicle requires more torque. While at higher RPM, where the series drivetrain is less efficient as torque required is less at high speeds, the engine comes into action and makes the vehicle more efficient.

Combined hybrid is costlier than a pure parallel hybrid since it has a generator, a larger battery pack, and more processing capacity to manage the combined system. Despite its higher cost its more efficient than any other hybrid, they can perform better and consume less fuel.
Figure 3: Model of combined hybrid vehicle

a. Disadvantages of combined hybrid vehicles: Exceptionally confounded framework, more costly than parallel hybrid. The effectiveness of the power train transmission is reliant on the measure of force being transmitted over the electric way, as numerous transformations, each with their own productivity, prompt to a lower proficiency of that way (~70%) contrasted and the absolutely mechanical way (98%)

b. Profits of combined hybrid vehicles: Most extreme adaptability to switch amongst electric and ICE power. Decoupling of the power provided by the engine from the power requested by the driver takes into account a lighter, and more effective ICE outline.

D. Plug-in Hybrid:

Plug-in hybrid electric vehicles are a combination of electric motor and internal combustion engine. Unlike other hybrids, plug in hybrid can be plugged-in and recharged from an external power source, allowing the vehicle to charge at charging outlets. When the battery is low, the internal combustion engine takes over and drives the vehicle. Plug-in hybrid can be of series, parallel or combined the only difference in other hybrids is that engine refuels at a fuel station and the batteries are charged while the vehicle is running. A plug in hybrid has the same feature, but it also has the ability to charge using external power source. The plug-in hybrid is designed in such a way that they can be charged using domestic electric sources.

a. Disadvantages of plug-in hybrid vehicles: Charging the plug in vehicle takes lot of time as they have large battery packs and the vehicle need to stationary when it’s charging through external sockets. When charging through external power supply we have to pay for the power consumed
b. Profits of plug-in hybrid vehicles: Since plug in hybrid have larger battery packs they can be used for long trips giving it the biggest advantage compared to other hybrids.
3 BLDC MOTOR SPEED CONTROL

A BLDC motor is controlled by energizing the stator windings by rotor position. The position of rotor is determined by using Hall Effect sensors. By differing the voltage given to the stator of BLDC, the speed of the motor is changed. When utilizing PWM to control the condition of the six electrical switch of the three-leg bridge, voltage to the stator windings is changed by changing the duty cycle. Speed and torque of the electric motor rely upon the amount of the magnetic field created by the stator of the motor, which rely upon the current flow through them. Thus to change the motor speed we should change the voltage and current to the stator windings. The motor speed depends just on the sufficiency of the connected voltage. This can be balanced utilizing PWM system. The required speed is controlled by a speed controller. This is actualized as an ordinary proportional Integral controller. The distinction between the real and required RPM is given as contribution to the controller. In view of this information PI controller controls the voltage given to stator windings which in turn changes the PWM system. If there should arise an occurrence of closed loop control the genuine rpm is measured and contrasted with the reference rpm which discover the mistake speed. The fundamental structure of closed loop control of the BLDC motor is shown in the figure 5. It comprises of an external speed control feedback loop to compare reference speed and actual speed, and inward PWM control loop for firing the MOSFETS. Speed loop is generally slower than the control loop.

A. Power supply Unit

The DC electric potential, typically 48V is used which is made of lithium iron phosphate (lifepo4), The LiFePO4 batteries have different properties, they have a operating voltage of 3.2V – 3.3V, they discharge at a voltage of 2.8V and when they are charged to their maximum they have a voltage of 3.4V. These batteries are used for high power applications, such as Electric cars, electric bike, power Tools and RC hobby.

The LiFePO4 batteries are considered to be safer when compared to other lithium ion batteries as they are less prone to explosion. These batteries can be charged very fast using special switched mode supplies and they can discharged at higher rates without affecting the cells. They usually have higher number of recharge cycles, which implies longer life. LiFePO4 life expectancy is approximately 5-7 years.

B. Switching Sequence

Before starting the electric motor, rotors position information is the first info that should be given by Hall Effect sensors to the control microcontroller. From that point onwards, Table 1 determines the MOSFETS switching arrangement that takes place. All the MOSFETS should be logically controlled so that...
the right switch is turned on. North and South Pole are formed in the starter windings according to switching pattern. In the Figure 4, the switches on and off are compared with Hall Effect sensors output. In this strategy, the on and off determines which winding should be energized, the more extensive the PWM duty technique, the quicker BLDC turning

<table>
<thead>
<tr>
<th>POS</th>
<th>Hall OUT</th>
<th>Phase A</th>
<th>Phase B</th>
<th>Phase C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L L H L</td>
<td>M1 M2 M3</td>
<td>M4 M5 M6</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>L H L L</td>
<td>L H L L</td>
<td>L L L L</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>L H H L</td>
<td>L H L L</td>
<td>L L L L</td>
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<tr>
<td>4</td>
<td>H L L H</td>
<td>L L H L</td>
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<tr>
<td>5</td>
<td>H L H H</td>
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<tr>
<td>6</td>
<td>H H L L</td>
<td>L L H L</td>
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**Table 1:** Switching sequence of controller.

**Figure 4:** Waveforms of Hall Effect and gate signals.

**C. Proportional-Integral (P-I) controller and closed loop speed control**

P-I controller is used to remove the steady state error which is caused due to proportional controller. Speed response and over stability of the P-I controller is very low. The P-I controller produces a overshoot that is enough for the vehicle to gain.
the future errors it cannot be used to decrease rise time and

\[ A(t) = K_i \int_0^t e(t) \, dt + K_p e(t) \]

equipments.

The three specification are
1) \( k_p \) is proportional gain
2) \( k_i \) is integral gain
3) \( E \) is error

4 RESULTS

A. SIMULATION RESULTS

Simulation is done using MATLAB SIMULINK. Figure 5 shows the model of BLDC motor. Figure 6 shows the no load speed of the BLDC motor. Here reference speed is taken as 3000 rpm. Figure 7 shows the torque of the BLDC motor. Motor produces more than enough torque for starting the vehicle without any problem. Figure 8 shows the speed-torque characteristics of BLDC motor.

Figure 5: SIMULINK Model of BLDC motor.
Figure 6: Torque characteristics of BLDC motor.

Figure 7: Speed characteristics of BLDC motor.

Figure 8: Ideal Speed-Torque characteristics of BLDC motor.
B. Experimental Results

Hardware implementation is done on 48v, 750W, 3000rpm BLDC motor. Speed is measured through tachometer. Torque of the motor is determined using the equation $T=9.81*(w_1-w_2)*r$

Where

$W_1=$ weight of spring balance1.

$W_2=$ weight of spring balance2.

$R=$ radius of pulley.

Figure 9: Hardware implementation of BLDC motor.

Figure 10: Speed-Torque characteristics of BLDC motor.
5 CONCLUSIONS

Permanent-magnet brushless dc motor are used in many applications which require high-performance because of their higher efficiency, higher torque at lower rpm, higher power density for lower size, low maintenance and less noise than other motors. In this paper architecture of hybrid electric vehicles is discussed. Finally the speed control of BLDC motor is analysed by using Matlab/Simulink. Simulation and hardware implementation results are presented. The speed-torque characteristics of BLDC motor gives detailed information on how speed varies with torque.

6 REFERENCES

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