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Development of an Integrated Motor Controller for a Plug-in Parallel Two-Wheeler Hybrid Vehicle

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Summary

Electrification is the next big thing in the automobile industry, but its dependency on the infrastructure is quite significant. Hence there is a good possibility that before we enter to an electric era, HEV (Hybrid electric Vehicles) can pave the way to bridge the two technologies. Concept and benefits of a hybrid vehicle is well known, there are many hybrid busses and cars available in market, yet hybridization of any two-wheeler model has not happened yet. A two-wheeler hybrid vehicle will be less complicated from a four-wheeler hybrid vehicle but still additional components like traction battery, motor controller and a traction motor have to be integrated along with the IC engine.

In this paper some of the key integration issues have been addressed which were encountered during development of a hybrid two-wheeler. The focus of the paper is not into detail design of the controller, battery or motor but to resolve their integration issues. Since the technology is already available, hence for every problem, multiple solutions are possible. All these options were evaluated and then the appropriate solution was adapted in order to successfully design a low-cost hybrid two-wheeler delivering all the benefits of a modern HEV

Keywords: *PHEV, Wheel Hub Motor, MCU, VCU, DC-DC Converter,*

1 Introduction

In recent years a lot has been discussed about the possibility of merging both the powertrains of IC engine and traction motor for building a hybrid two-wheeler. For example, in the paper [6] a nice possible solution has been discussed for integrating the powertrains. Building a hybrid two-wheeler is not limited to integrating the two powertrains. There has to be a well thought strategy for the energy sharing among the two power sources. The contribution from the two power sources will vary when the vehicle is being driven on the highway to when it is driven in the city traffic. The engine starting strategy can create a huge difference, its frequency and timing decide main driving logic of a hybrid vehicle. In order to provide a seamless driving experience to a customer it is important to ensure uninterrupted power flow to the wheel.

Deciding capacity and method of replenishment of the electric power source itself is a challenging task. The size of the battery pack which can be accommodated in a hybrid two-wheeler is limited because of space constraints. For building a hybrid vehicle additional space have to be arranged for the traction battery, traction motor, hybrid control unit, DC/DC converter apart from having the regular engine, it's transmission, engine starting system and engine control system. Hence it is obvious space and weight management is one of the biggest challenges in integration of a hybrid two-wheeler.

For a proper strong hybrid two-wheeler, it is important to offer a limp home option too. The vehicle should be mobile even when, one of the power sources is depleted or one of the power train develops a malfunction. This function plays a very crucial role in finalizing the architecture of the vehicle. It is very important to evaluate all the possibilities before finalizing the best integration solution for the chosen segment of customers.

2 Options of Integration for a hybrid two-wheeler

As discussed in summary and introduction, building a two-wheeler is all about choosing the right strategy and developing a close integration among the controllers. In the following section different possibilities of powertrain and various opportunities of integration has been explained for building a two-wheeler hybrid vehicle. In section 3 based on these options, the solution development will be discussed.

2.1 Chassis mounted motors vs Wheel hub mounted Traction Motor

In a two-wheeler hybrid configuration two options are available from traction motor selection point of view, first one is the usage of a chassis mounted shaft rotating traction motor. The traction motor is connected to the wheel via chain, belt or gear mechanism. This provides the flexibility of introducing different transmission ratios, but requires more space for packaging

Second option is to use a wheel hub mounted traction motor. A hub mounted motor obviously eliminates the requirement as well as any possibility of transmission. But there is a limitation on the maximum size and power of the traction motor. In a commuter segment two-wheeler if the motor power is in the range of up to 4 kW it is possible to have a hub mounted traction motor.

2.2 Series hybrid vs Parallel hybrid

In series hybrid configuration the traction motor is the main propeller of the vehicle, whereas the engine is primarily used to charge the traction battery and the wheel is not connected to the engine powertrain directly. For this configuration a bigger battery and an adequate motor power is required to deliver the vehicle requirements such as acceleration, top speed and basic min range (without switching ON the engine). Once the battery reaches the threshold the controller would switch ON the engine, which would charge the battery back. Normally such engines are of constant speed type and have an alternator in order to charge the battery back.

In parallel hybrid configuration both the engine as well as the traction motor can propel the wheel together or independently. It largely depends on the type of hybrid vehicle being developed whether the traction motor would support the engine in the initial phases of its operation or whether it would support the engine at the higher RPM zone. The first option would result in more fuel saving whereas the other one would result in more power being delivered to the wheel. This characteristic of parallel hybrid provides the possibility of two distinct driving modes. First one being mode - in which the wheel is driven only by the traction motor during initial speeds and then engine takes over. Second one being the power mode where both the traction motor and the engine drives the wheel together.

2.3 Plug in HEV vs HEV

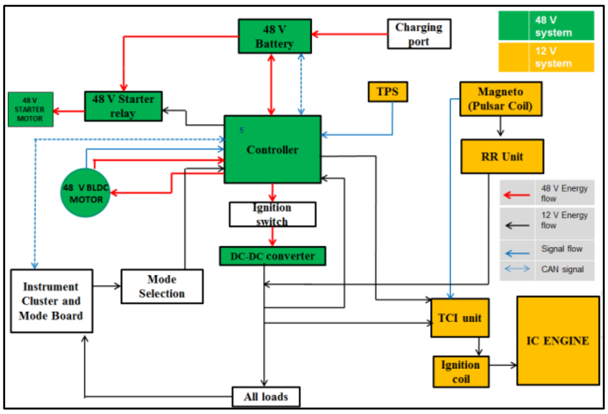
For a hybrid vehicle its traction battery charging strategy is very crucial in deciding the type of HEV it is. If the traction battery is only charged via the alternator and the engine itself and no external charging is required, it is called a normal HVE (hybrid electric vehicle). In a HEV separate battery charger is not required as alternator does the activity. Essentially a HEV battery charges itself back from the engine itself

But the moment the battery size is big enough that the alternator alone cannot charge the battery pack completely and external charging is required, it is called PHEV (Plug in Hybrid electric vehicle). Charging from grid reduces the cost of running drastically as grid electricity is cheaper than gasoline, but it also brings the burden of battery charger. For a two-wheeler both on-board charger or off-board charger can be used as the size of the traction batteries are not as big as cars. It also requires a charging socket to be installed in the vehicle which shall meet required safety norms.

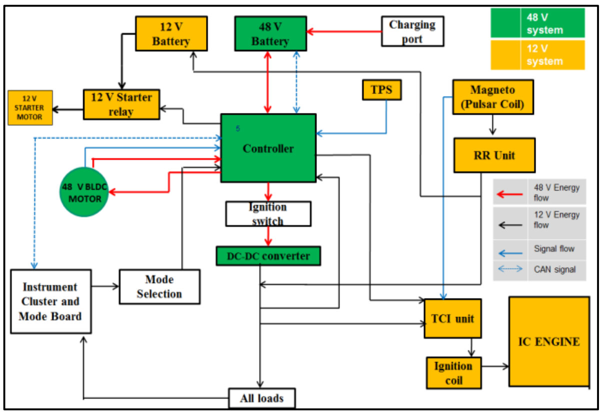
2.4 Engine starting system 12 V vs 48 V starting system

For a hybrid vehicle the methodology of starting the engine is governed by the control system and not by the customer always. Based on the torque demanded by the system as well as based on the State of charge (SOC) of the battery the controller decides when to switch on the engine. In a traditional IC engine two-wheeler, the engine is started via 12 V starter motor supported by 12 V batteries. For hybrid vehicle the control system should find a method of cranking the starter motor based on set of inputs without customer pressing the crank switch. If the two-wheeler is having a magneto then the 12 V battery can be charged via the AC/DC converter. Alternatively, the 12 V battery can also be charged by a DC/DC converter using the traction battery.

There is a second possibility available for cranking the engine using a 48 V starter motor. The advantage of using a 48 V starter motor is that, a separate 12 V battery is not required and the same 48 V traction battery can be used for cranking the engine also. This concept has been explained in the paper titled "*Development of 48 V starting systems for a two-wheeler parallel hybrid*" [1]. The aim of the paper is to evaluate multiple options for possible starting system but it provides a good overview of the key electrical components and their integration for a possible two-wheeler hybrid vehicle.



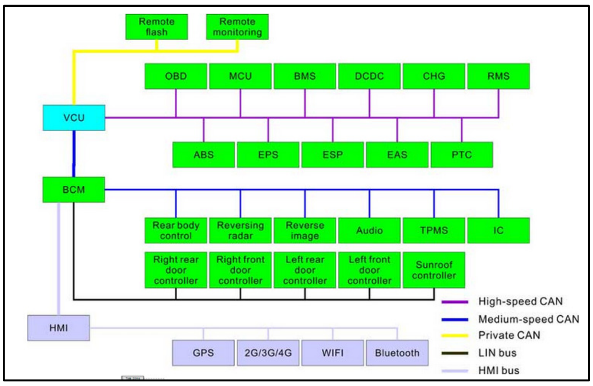
Block diagram 1 [1] –48 V starting system



Block diagram 2 [1] –12 V starting system

2.5 Combining multiple controllers in the vehicle

There are multiple control units required for running a hybrid vehicle. The primary ones are Battery management system, Engine controller, Traction motor controller, Vehicle controller unit managing the hybrid functionality, diagnostic controller, and a DC/DC unit. These are the basic units required to operate any hybrid vehicle. There can be a many other controllers depending on the use case, features and type of vehicle.



Block diagram 3 - *Four -Wheeler Architecture for a possible hybrid vehicle- [7]*

In the above block diagram, it is explained how a VCU, BCM and an HMI unit is connected with other control units in a 4 W hybrid vehicle. The VCU is connected to the 11 separate controllers including BMS (Battery Management System) and MCU. The second interfacing unit is BCM (Body Control Module) which controls most of the user control units. The third is HMI (Human machine Interface) Unit - HMI brings the connectivity to the vehicle architecture and connects the vehicle with user when the user is not using the vehicle.

For a development of a two-wheeler hybrid if the design is from scratch, theoretically it is very much possible to combine all other units – the BMS +MCU+ VCU+ Engine controller + DC/DC. Such an approach would mean that any part which is having power electronics and microcontroller, they can be combined. There are two problems with such an approach, first is that a single team should be having the knowledge of all the mentioned field and in general it ends up in having a very safe and over designed unit which might not be the most efficient solution. Second is that though the hardware can be built but the calibration becomes an issue.

Going forward another approach which can be opted is to decentralized each of them. In this concept all of the individual units would perform only their function and a central control unit which may be the VCU would integrate them, but the challenge in this approach for a two-wheeler is mentioned in section 1 which are space and ensuring uninterrupted power flow to the wheel.

3. Development of the solution

In this project all the options of integration were discussed and evaluated. The objective was to offer a significant improvement in millage along with all the benefits of a regular two-wheeler scooter. Being a hybrid two-wheeler, it was decided to offer better acceleration possibilities in compare to similar class of IC engine vehicles and make sure the customer is never stranded on the road because of absence of either fuel or battery charge.

To offer all these benefits it was proposed to develop a Parallel Plug-in hybrid electric vehicle (Parallel PHEV) with the traction motor being fitted in the rear wheel.

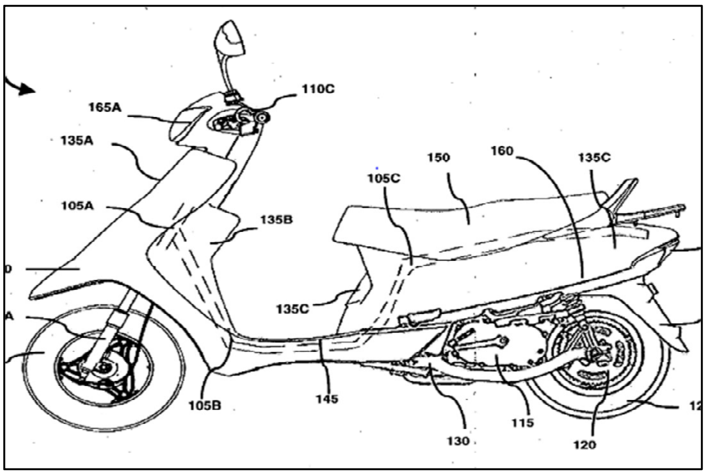
3.1 Powertrain solution

Electric powertrain- In order to utilize the available space in the vehicle and offer the comfort of a regular utility/storage box for the hybrid vehicle, it was decided to opt for a hub mounted traction motor. The rotor of the motor is welded to the wheel rim whereas the coils are winded on the stator which is connected to the wheel shaft. It's a Brushless DC motor (BLDC) and the phase information is provided by the 3 hall sensors mounted on the stator. Such an arrangement is beneficial for a hybrid two-wheeler proposal as the wheel size is big enough to offer plenty of traction motors of various powers.

Engine power train

For this project a compact IC engine was designed. The type of the vehicle was a scooter, hence the engine was mounted on the swingarm and the traction motor was connected to the engine via a chain drive. A special sprocket was designed to integrate on the traction motor which connects up with the chain drive as it is located on the hub of the rear wheel.

One challenge which remains in this kind of power train is how to decouple the hub mounted traction motor from the engine, because otherwise the wheel when rotated by traction motor would end up rotating the piston. Hence a mechanism is required to allow the power to transfer from the engine to the wheel always but the reverse should be avoided. Traction motor being mounted in hub, whenever it rotates the wheel will rotate. A unique decoupling mechanism has been explained in detail in the paper "*hybrid power train smoothness improvement"* [4]. In this paper a solution was provided in the engine transmission itself so as the rotating wheel should not connect to the piston when the engine is off. This methodology was used for this project also. Below image is showing the powertrain arrangement.



Picture 1 *Line diagram of 2W Plug in PHEV*

In the picture above the traction motor 120 is mounted on the rear wheel, the engine 115 is mounted on the swingarm 130.

It is very important to manage both the power train in such a way that the power delivery to the wheel is always uninterrupted. The hybrid two-wheeler central control system should decide the share of power between the IC engine and electric motor based on the customer's driving requirement. The vehicle control system has to be in constant communication with the motor control unit (MCU), battery management system (BMS), Engine status, throttle position and other operating controls.

3.2 Mode of operation

In order to enable the customers to choose the vehicle behavior based on their requirement on a given day, two modes of operations were proposed.

Power Mode- When the customer selects the power mode the control system would triggers both the traction motor as well as the engine together. The vehicle is powered with both the powertrains together from the beginning of the trip, hence the acceleration is more than conventional IC engine vehicles of similar engine capacity. But while getting more acceleration compared to IC engine scooters, because of the additional motor assist the fuel consumption by the vehicle is less as the motor is powered by the battery. The traction motor is designed in such a way so that it can assist up to a speed of 50 km/h beyond which the engine alone is capable of driving the vehicle to its top speed

Eco Mode – If the customer's priority is fuel consumption reduction then the Eco mode should be selected. In Eco mode the traction motor is started first and continues till the predefined vehicle speed is reached. Once the speed is reached the control system triggers the starter motor which in turn cranks the engine. The engine continues to drive the vehicle till its top speed. When the vehicle speed is reduced below the threshold speed the engine is again switched off by the control system and the traction motor is switched on.

The control system was designed in such a way that the customer would not feel the changeover from one powertrain to another apart for the engine sound. This is one of the key challenges in deigning a hybrid two-wheeler as highlighted in section 1. In order to achieve the smooth drive, feel the traction motor is not switched off instantaneously when the threshold speed is reached rather it is slowly reduced to zero. It requires a special tuning and algorithm to constantly shift between two power sources seamlessly so that the customer did not notice any change

3.3 Electric power source and its control

In an electric vehicle there is no other way to replenish the battery other than charging it from the grid but in a hybrid two-wheeler there are other means of charging the battery and it has to be very efficient in order to derive maximum for the battery. The electric power source is a very critical element in the designing of a HEV. In order to achieve the weight and performance targets including longer life it was proposed to use lithium-ion based battery packs. These battery packs consist of multiple individual cells which are arranged in series -parallel combination in order to achieve the required voltage and current ratings. These individual cells have to be monitored constantly and hence most of the time the BMS is fitted inside the battery Pack.

Plug in Charging

Since the project was to develop a hybrid two-wheeler which could provide huge fuel saving it was decided to go ahead with Plug in charging for the traction batteries so that the load on the engine can be kept minimum and the traction battery can be charged from the grid after every trip. This requires a lithium-ion battery charger. For the want of space, the charger was kept outside and an off-board charger was designed. When the battery is getting charged the HCU is powered because the charger connects to the DC bus power line and it is required to do so in order to keep the vehicle immobile during charging. During charging if the user in hurry forgets to unplug the charging cord and by mistake gives the throttle, the vehicle might move. Hence to avoid any situation of unintended vehicle runaway, the HCU was designed to sense the ignition key state as well as the battery charge state and accordingly enter into a deactivated mode while the battery is getting charged.

Regeneration strategy

Second source of charging the traction batteries in a hybrid vehicle is via the HCU. HCU works as inverter converts the AC power form the motor and converts it to DC and charge the battery back.

Whenever the brakes are applied the back emf generated from the traction motor can be converted and used to charge the batteries. In this process the traction motor acts a load and provides additional braking for the vehicle known as regenerative braking. The battery being lithium ion in nature has the ability to accept high amount of current resulting from the regenerative braking. Hence it is equally important to select the right chemistry for the power source if the regenerative braking advantage has to be utilized. But it is difficult to convert the back emf throughout the speed range. In traction motor since they have permanent magnets, they do produce very high back emf above certain speed. Converting such a high back emf to regulating voltage in order to charge the traction battery would result in very expensive circuity inside the HCU. Hence normally above certain speed the battery charging during regeneration is stopped. [*] In the proposed HCU during these times (high vehicle speed) also using the DC/DC converter the 12 V loads are driven by the back emf generated.

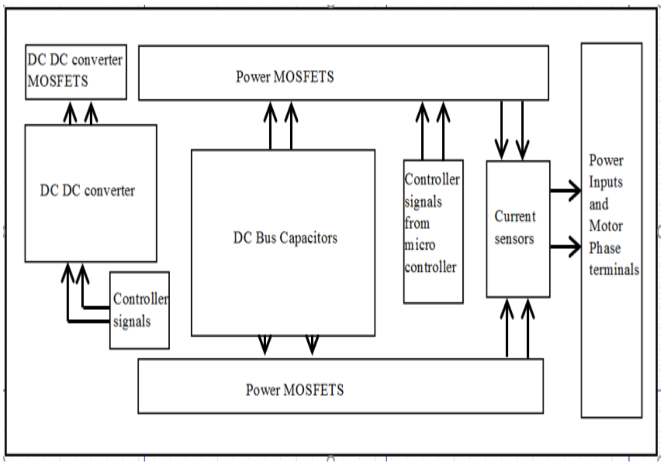
3.4 Vehicle load & control management

The Proposed HCU apart from managing the powertrain also controls the 12 V load system of the two-wheeler. There were two possibilities of engine starting system described in section 2.4. For this project a 12 V starting system was selected along with an independent 12 V battery to support for the cranking.

Integration of DC/DC converter along with the HCU

In the two-wheeler-PHEV wiring harness system, DC/DC converter is a device which handles both the 52 V as well as the 12 V, hence the operation and safety requirements are very high for a DC/DC converter. In case of a malfunction or a short circuit there are chances that the 52 V can appear across the 12 V loads and damage them. Even worse many 12 V devices have electrolyte capacitors which are rated for less than 12 V, in case 52 V appears across these capacitors it can even result in blast of capacitors.

The DC/DC converter is switched ON the moment the vehicle is switched ON and it does operate at a switching frequency which falls under EMI/EMC range. The HCU is well designed to handle designed to meet the required EMI/EMC regulations as well as all kinds of probable short circuit. In order to make the DC/DC safer as well as to solve the Space & packaging constraints it was proposed to integrate the DC/DC converter along with the HCU. [*]

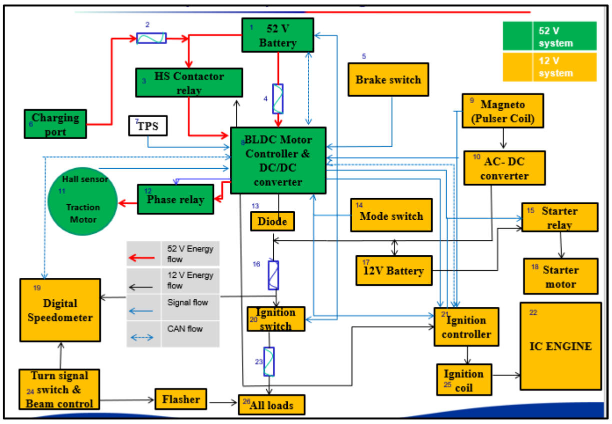


Block diagram 4- *Proposed Schematic Representation of the HCU internal layer including DC/DC converter*

When the vehicle is running only on battery power the 12 V battery would be supporting all the lighting, cluster, horn and other loads. In a heavy city traffic, it is quite possible to not to hit the min threshold speed to start the engine, hence the 12 V battery should be charged from the main traction battery via a DC/DC converter. The decision was taken in order to support the limp home requirement explained in introduction. The detail logic of limp home is explained in next section.

3.5 Hybrid control system design- Integrating multiple control options

In section 2.5 various controller required to operate a hybrid vehicle has been explained. For this project it was decided to combine the Traction motor controller and the vehicle control unit. The combined unit is called Hybrid control unit (HCU). The key control strategy which was discussed in section 3.2 is residing in this unit. Below is a block diagram representation of the key units involve in making the hybrid two-wheeler.



Block Diagram 5 – *Proposed block diagram for integrated MCU, VCU & Integrated DC/DC*

The HCU would control the hub mounted traction motor and operate on 52 V power from the battery. The battery management system is inbuilt inside the traction battery pack. The HCU is connected to the BMS, Instrument cluster and the Ignition unit via CAN bus. While operating the traction motor the HCU receives all the critical information from the BMS about the health and battery SOC, and engine RPM and timing information for Ignition unit.

Limp Home Option- In order to provide stand alone limp home mode to the customer it was decided to not to integrate the engine ignition control along with the HCU. The advantage having a separate ignition unit, separate AC/DC converter and a separate magneto is that in the event of battery SOC being completely depleted or in case of a serious malfunction with HCU, still the user can start the vehicle reach to nearest service station or home. As discussed in section 2.4 there are multiple options available for deciding the starting system. In this project considering the above limp home requirements, it was decided to use 12 V starting system. The HCU would control the starter relay which in turn will crank the starter motor.

Since the HCU is also performing the functions of VCU it is directly connected with the control switches, brake switch and the throttle position sensor. All these inputs allow the HCU to understand the customer driving requirement which in turn helps in managing the traction motor power deliver as well as engine starting requirements.

EV Powertrain Thermal Protection-In order to provide good initial acceleration for the vehicle at zero speed, it is required that the battery, the traction motor and the HCU should work together for supply of high power. The initial acceleration requirement is not continuous and it's not very efficient solution to increase the motor power rating in order to meet the initial acceleration requirement. Hence it was decided to provide high current to the motor for a short duration of period. But repeated short time high current, supplied to the traction motor in order to achieve high initial acceleration may results in damage to the traction motor winding due to the sudden rise in temperature of traction motor.

In order to resolve the above potential failure mode thermal sensor were added to the traction motor, so that the HCU can continuously monitor and reduce the high phase current to the motor if the stator coil temperature is high. But whenever the temperature reading is dependent on wired sensor there is always a possibility of wire damage and HCU not reading the correct temperature of the motor. Hence along with the thermal sensor s separate temperature estimation algorithm was also developed which would independently calculate the rise in coil temperature based on the phase current and duration of the high current. [*]

In similar fashion the HCU must reduce the DC bus current taken from the battery too if battery cell temperature is high. Hence the HCU control system was designed with the temperature coefficient in mind of all the components including the HCU for thermal stability of the powertrain. The HCU control system has been designed to protect the EV powertrain components as they are more expensive and prone to electric fire. Hence in case of any probable malfunction or high temperature the HCU switches off the functions of EV powertrain and starts the engine. This might result in a confusion to the customer as it may differ for the two modes of operation explained in section 3.2. To resolve this problem the HCU is always connected to the information display unit via CAN as shown in block diagram 4. [*]HCU always indicate a possible high temperature or a malfunction whenever the HCU start the engine by default In the patent titled "*Control apparatus for a hybrid vehicle and vehicle information display thereof*" [5], it is explained which are the conditions in which the HCU would switch on the engine earlier than the predefined speed, OR in which conditions though user selected the Power mode, but the EV powertrain is not activated. [*]

Sensor less Gradient Detection

The hybrid two-wheeler by virtue has two different powertrains in order to bring the best of both worlds. The EV power train is used in the ECO mode to start the vehicle smoothly up to the pre-defined speed, after which the IC engine takes over. During the electric operated duration if the two-wheeler goes through a slope or high gradient (typical in shopping malls basement parking) with one pillion rider, then the power only from the traction motor was not sufficient to continue the drive smoothly without any break.

One obvious solution is to increase the power of the traction motor, but that would require a higher power controller and bigger battery. In an electric two-wheeler this is the solution which has to be opted for but in a hybrid, there is another powerful energy source available. So, the smart solution is to sense the gradient and manage the share of powertrain. [*] For making it cost effective, as well as in order to eliminate any possibility of failure it is proposed to make the system sensor less. With combination of vehicle speed and throttle position sensor along with the change in vehicle speed the logic of gradient detection was developed. Now whenever when the vehicle is travelling only on battery power (ECO mode) and if the HCU sense gradient or overload before it is reaching the threshold speed, it can switch on the engine and communicate the same to the customer via the information display unit. [*]

Once the VCU functions were integrated with the HCU it become very easy to incorporate many customer convenience features in the vehicle. These additional functions do not form the core hybrid functions but helps in making the vehicle more convenient and smarter to use as well as service. For example, side stand switch integration, Parking assist & diagnostics

Side stand function- It is absolutely necessary to disable the EV powertrain when the side stand in ON, otherwise it might lead to unintentional accident. Hence it is proposed to combine this function with HCU. Reverse Parking Assist- A standard two-wheeler does weight more than 100 kg. in order to park the vehicle in tight spots and specially to reverse the two-wheeler needs a substantial effort from the customer. It becomes relatively easy to implement the reverse function in electric power train as it does not require any change in the drive train or gear box, just by changing the direction of rotation of the traction motor, the reverse feature can be activated. But the reverse function activation has its own failure modes specially since a two-wheeler vehicle has to be balanced on two wheels by the rider. When a set of predetermined conditions are satisfied and when the vehicle is manually pushed backwards, then HCU detects reverse turn of the rear wheel and allow the vehicle to move in the reverse direction by rotating the hub mounted traction motor in reverse direction at a predefined speed and torque limit. [*].

Diagnostic-The HCU is connected with the BMS, Engine ignition unit and the cluster via CAN bus, at same time it is controlling the 12V system. The primary control system required for controlling a hybrid two-wheeler is present inside the HCU, it is having the integrated DC/DC and plays the functions of a VCU too. Hence it is possible for the HCU to diagnose the state of error if any one component is not behaving properly. Moreover, it is also having the information of the control units as it is only taking the alternate decisions to control the driving mode. Hence the diagnostic function of the whole vehicle was included in the HCU unit only. In only one condition the HCU is not able to display the fault code which is n limp home more where the HCU itself is having some problem. In such cases the cluster and the diagnostic tool has been programed in such a way that it can detect the malfunction of the HCU.

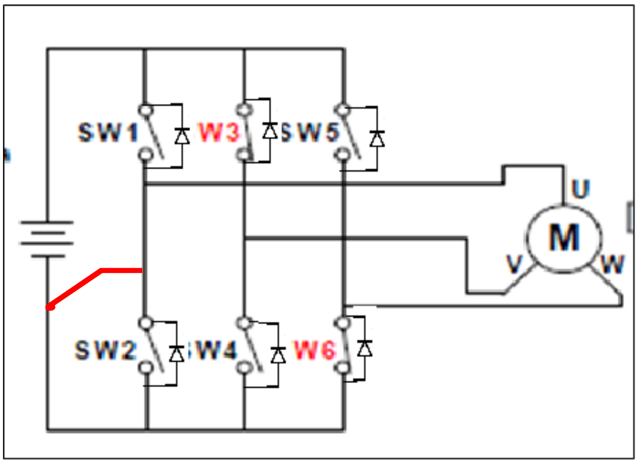
4. Testing of the vehicle

After the prototype vehicles were developed, they were subjected to testing. The vehicle was found to be meeting the expectations of fuel efficiency improvements as well as was able to deliver the power to the wheel without any interruption. Overall performance of the vehicle was quite satisfactory and it was good to see the benefits of a two-wheeler PHEV which was like having two different vehicles in one.

After initial performance when further extreme conditions were tested to test the control system few new failures modes were found. One of them have been explained in below.

Unique scenario in parallel two-wheeler hybrid vehicle with hub mounted motor

In a hub mounted hybrid vehicle, the wheel is always rotating while running irrespective of whether it is driven by the motor or engine, unlike the body mounted shaft rotating motors which can be decoupled from the wheel when engine is powering the wheel in a hub mounted motor it keeps on rotating. So, in case of a malfunction or a short circuit it is possible that the even though all the switches could be switched off immediately the moment high current is sensed by the controller current sensor, still there is a possibility of device getting damaged because of very high current flowing via the freewheeling diode as the rotor (having the magnets) will be rotating against the stator and keep producing the back emf. Hence just by stopping the power to the motor, the HCU cannot be declared safe from any damage and special protection measures have to be taken in order to protect the system.



Block diagram-6 - *The commutation sequences of the 3 -phase BLDC control [3]*

Above is a typical 3-Phase BLDC motor commutation sequence. Now assuming there is a short between the phase U and Ground shown above via the red line. A very high current proportionate to the back emf / coil resistance would be flowing through the freewheeling diode. In case, if any of the switch is ON then immediately it will get damaged

The best possible solution is to physically disconnect at least two-phase wires so that even though the traction motor can be driven by the engine, the back emf would not flow through the switch circuit. A electro mechanical switch which can handle the phase current and voltage was developed and introduce in the hybrid powertrain. Additional benefit of implementing the electro mechanical switch was that now before initial startup a self-check could be performed by the HCU to determine whether any short is persisting in the motors or not. One of the possible electro mechanical solution was deployed in the form of Normally open relays named Phase relays installed in the phase wires from the BLDC motor to the HCU which can be controlled by the HCU.

5 Conclusion

Currently IC engine vehicle strategies are managed and controlled by ECU (Engine Control Unit) and in an EV, traction motor is controlled by MCU. In a two-wheeler PHEV the engine and motor propulsion control strategy have to be integrated through a VCU. In this paper the integrated DC/DC, VCU & MCU concept is explained from hardware development point of view as well as the parameters to be taken care of while developing the control system of a hybrid two-wheeler is also discussed. Along with standard control functions some unique features like park assist, gradient detection and side stand detection were also integrated as part of safety and convenience of customer.

The results are very promising and it reconfirms the benefits of a PHEV. For a two-wheeler segment a PEV can act as the missing bridge towards electrification from existing IC engine drive vehicles. It is also verified that though the space constrain is a big challenge for developing a two-wheeler hybrid vehicle but if the integration of various system is done carefully, this challenge can also be met.

Most of the ideas were prototyped, developed and evaluated. The results are very promising and meeting the expectations. It has met the expectations of developing a two-wheeler PHEV. Below is an image of one of the early prototypes of a two-wheeler parallel PHEV which was demonstrated in an exhibition.

Picture 2 *Working Prototype of 2W Plug in PHEV [2]*

[*] Patents Pending

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