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ARTICLE

ENERGY EFFICIENT SWITCHING CONTROL FOR HYBRID VEHICLES

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ABSTRACT

Development of energy efficient and eco-friendly hybrid vehicle model is discussed in this paper. The power train test bed of a hybrid two wheeler system is physically modeled and a switching control methodology is developed to achieve electrical switching between electric motor and engine for efficient fuel consumption. The complete test bed for the power train of the hybrid vehicle is designed and fabricated. A conventional sequential and condition based switching control algorithm is developed to operate the system with electric motor at low speeds and the engine at higher speeds, using the speeds of the power components in terms of revolution per minute (rpm) as the parameter for switching. The analysis on the efficiency of the hybrid system resulted with a 21.4% efficient more than the conventional two wheeler system.

KEY WORDS
Hybrid vehicles, Switching Control, Efficiency, Power Train

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INTRODUCTION

Improvements in fuel economy and emission reductions are the most important challenging goals that are presented before the automotive industry. The eco system is under potential threat due to the increase in the number of vehicles and its effect on environmental pollution with its emissions from internal combustion engines (ICE), used for their propulsion. The attempt of leaving the nature unaffected and allowing it to stay as it was, will bring us closer to the concept of hybridization. Hybrid electric vehicles (HEV) are beginning to demonstrate their capability to satisfy these requirements, and they will become a viable alternative to conventional vehicles in the future [3, 5]. The hybrid power train is an integrated system that may consist of the following components: an internal combustion engine (IC engine), a battery pack, and an electric machine (EM) which can be utilized as a traction motor or generator. In such a system, each sub-system is also a complex system which has its own functionality and desired performance [6]. These systems are versatile in nature and thus can be configured in different ways to deliver power. The different configurations of hybrid vehicles include Parallel Hybrid, Series hybrid, Series-Parallel or Combined hybrid and Plug-in Hybrid Electric Vehicle (PHEV) [4]. Generally the combined hybrid vehicles involve front wheel drive which is connected to the power sources through transmission systems and clutch in order to engage one of the sources to the wheel axle. The switching process is electro-mechanical in nature and power is transmitted through a dedicated transmission system. This system is limited to four wheelers such as cars and SUV's. Also a complete automatic switching mechanism is seldom implemented in such vehicles and this is the one highly required in field of biking sector for improved fuel efficiency. Hence considering all these factors, a simpler switching methodology is being adopted with the components matching the dynamics of a two wheeler and the sources being coupled by a chain transmission [1]. The focus of this paper is to develop energy efficient switching control strategy used to control combined HEVs.

PROPOSED DESIGN

The test bed is a platform which houses the engine and the motor in a fixed position. The shaft of the engine is fitted with a toothed disc. Another toothed disc of same dimensions and teeth count is fitted to the motor shaft. The engine and the motor are placed such that they are a distance apart and their axis of rotation of the shafts is parallel to each other. Also the plane faces of the disc are maintained in the same plane and line, so that the two sources can be coupled effectively. The coupling is done using a chain. Thus when any one of the shaft is rotated, the other rotates in the same direction and speed. The parameter for switching is taken to be the speed of the shafts of motor and the engine individually in terms of rotations per minute (rpm). In order to read the speed of the shaft a Hall Effect sensor is incorporated in the shaft of both motor and the engine to read the number of rotations of the shaft. The motor speed is varied using a motor controller and the engine speed is varied using a throttle control system. In order to perform the throttle action of the engine, a servo motor is used to open the throttle valve to the pre-defined angle which provides the required amount of acceleration to the system. [Fig. 1] shows a schematic diagram of the simplified structure of a combined hybrid electric vehicle system considered in this paper and its technical specifications are shown in [Table 1].

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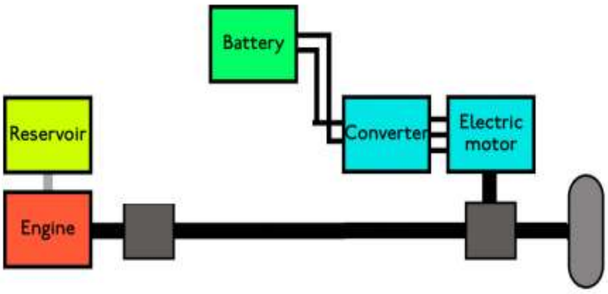

Fig. 1: Simplified structure of a combined hybrid electric vehicle

Table. 1: Technical specifications of the vehicle used in this work

Engine	Honda Activa – 109cc
Motor	Rating : 24V, 19.2A, DC Speed : 2750 rpm Power : 350W
Electronics Unit	Power Relay : 30 A Servo Motor : 5V, 300 mA Arduino Boards : 12V, 1A

SYSTEM DESCRIPTION

The developed test bed for the proposed hybrid vehicle is shown in [Fig. 2] and the block diagram with various system components is depicted in [Fig. 4]. The various components involved in the system comprise of dedicated relays, servomotor, RPM measurement and display modules. This system also used an arduino based microcontroller in place of a full-fledged engine control unit. For ease of understanding the circuitry in the system can be broken down into different parts as follows,

1. RPM measurement and display modules
2. Relay switch modules
3. Servo motor
4. Control unit.

Fig. 2: Developed test bed for the hybrid vehicle

RPM Measurement and Display Modules

The RPM measurement modules are arduino based, to which LCD panels serve the display function. This system uses separate and exclusive modules to measure the RPM of motor and engine. The RPM is measured using two Hall Effect sensors which are housed near the shafts of the engine and the motor, which constantly measure and feed the RPM data to the control unit. The control unit is already fed with a set RPM value in order to carry out switching in bi directional manner (i.e. motor to engine and engine to motor). The LCD displays the measured rpm values for ease of observation as shown in [Fig. 3] .

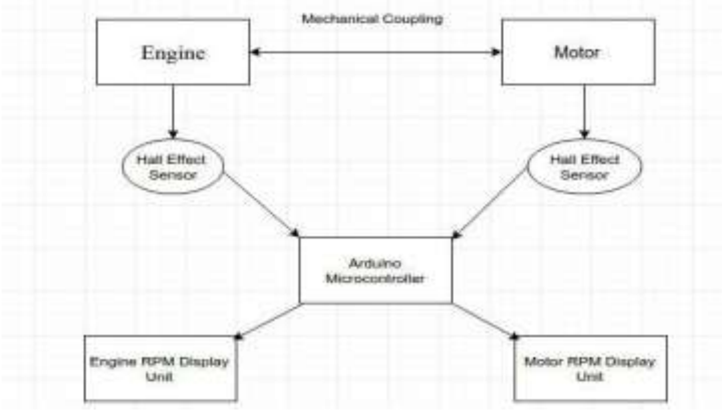

Fig. 3: Speed display module

Relay Switch Modules

The relay switches are the actual members that actuate the switching process by receiving signals from the controller when the set point is reached or crossed. Three dedicated relays are used for the purpose of engine start, engine stop and motor start/stop as shown in [Fig. 4]. The relays maintain normally open state when the system is idle. Thus they actuate either the engine or the motor when they receive a signal at their respective relay ports. The relays work such that when the system is switched ON; initially the motor relay closes first and actuates the motor until the motor reaches the set point, wherein the meantime the engine start and engine stop relays remain open. But when the set point is crossed the motor relay opens and the engine start relay closes and the engine starts immediately, picking up from the current rpm of motor where the motor has disengaged.

Servo Motor

As the engine takes on the system, the throttle wire is simultaneously pulled by actuating the servo motor which turns stepwise at defined angles. The actuating signal is given to the servo motor by and when the control unit senses that the set point is crossed. Once the servo has pulled the throttle to the maximum defined position, it returns back to null thereby causing deceleration of the engine. This gradually causes a decline in engine shaft rpm which falls below the set speed in the control unit, thereby rising a case to switch back to DC motor [7]. This operation can be related to the real time driving.

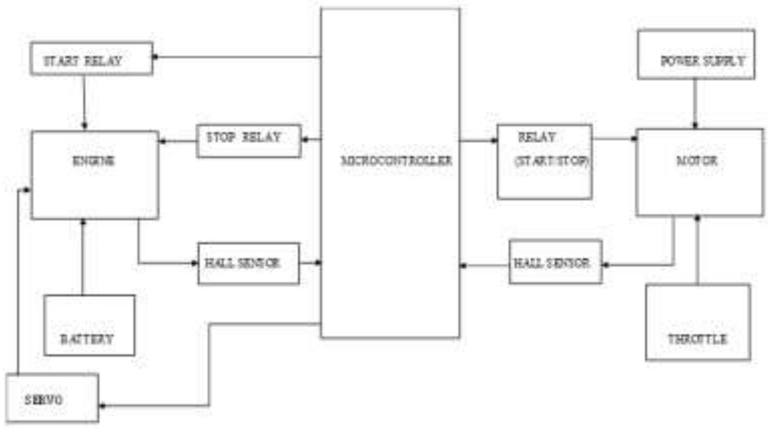

Fig. 4: System design

Control Unit

The control unit is fed with the defined speed as set point value and a condition based switching algorithm. The input parameter-(rpm values) is fed to the control unit for internal comparison and condition checking to enable bi-directional switching. Thus when there is an ascending crossover of the set point, the power is switched from DC motor to engine and when there is a descending crossover of the set point the power switches back to the DC motor from the engine, making the entire process completely automatic and repeatable for 'n' cycles [2].

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SWITCHING ALGORITHM

The flow chart of the switching algorithm is shown in [Fig. 5]. The algorithm mentioned is condition based programming. The switching process takes decisions based on the feedback values obtained from the engine and electric motor speed sensors. The vehicle is started using the electric motor to gain initial momentum and run until vehicle reaches the cutoff speed in rpm. Once the vehicle surpasses the cutoff speed, the engine is given the control to pull the vehicle switching off the motor. In case of deceleration, the controller checks for the feedback from speed sensor of engine shaft for cut off speed, to switch from engine to the electric motor. Once dropped below the cutoff, controller gradually loses the grip from the engine throttle servo motor and transfers the control to motor.

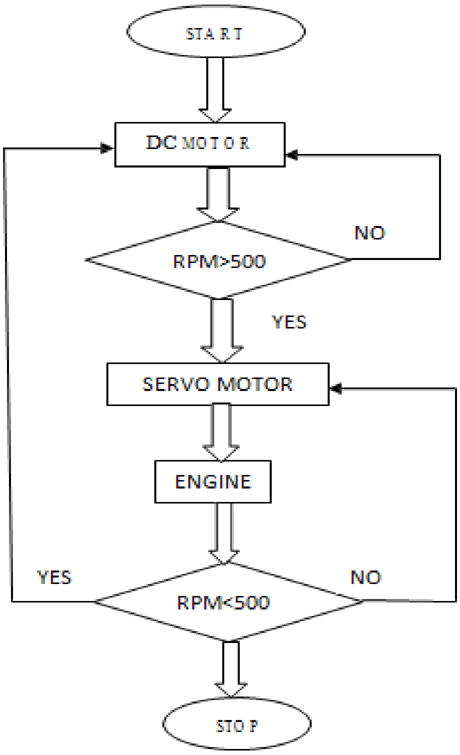

Fig. 5: Developed switching algorithm

EXPERIMENTAL ANALYSIS

The proposed energy efficient hybrid system is implemented against the considered conventional gasoline two wheeler engine system and checked for mileage. For ease of observance 100 ml of petrol is kept as reference mark of input supply for the gasoline engine. The test bed is operated on the following two different modes,

1. Normal Mode
2. Hybrid mode

Here normal mode is the mode in which the test bed is operated with gasoline engine to understand the consumption rate of conventional gasoline two wheeler engine system under no load condition whereas the hybrid mode is the mode in which the gasoline engine is operated in conjunction with the electric motor under no load condition. Both the modes of operation are tested using continuous run test.

In order to run the hybrid mode testing, the throttle of the engine is controlled by a servo motor and the measured engine shaft speeds with respect to various servo angle position is tabulated and given in [Table 2] and [Table 3].

Table 2: Calibrated acceleration settings

SERVO ANGLE (Degrees)	Speed (rpm)
180	0
160	300
120	1800

Table 3: Calibrated deceleration settings

SERVO ANGLE (Degrees)	Speed (rpm)
120	1800
160	300
180	0

Continuous run test

The system was run in two different modes. Initially the system was run in normal mode with 100ml of fuel and it was followed by the hybrid mode where the test was conducted with same amount of fuel as it was done in the normal mode. It was observed that the former mode of operation utilized a sizable amount of fuel to make the initial start and then regulated its consumption. In the latter system the initial speed was attained by electric motor and then it switches to engine to have the speed maintained with gasoline. The hybrid mode of operation consumed 20 ml less fuel compared to the normal mode drive. The output response of the hybrid mode operation of the test bed is logged and plotted in [Fig. 6].

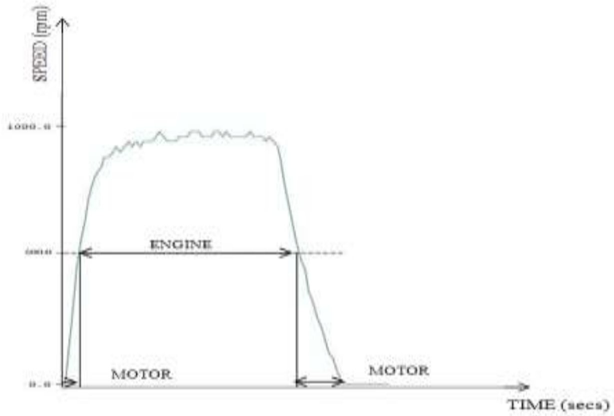

Fig. 6: Output response of hybrid mode of operation

DISCUSSION

The results of the above experimental analysis are given in [Table 4].

Table 4: Mileage analysis on different modes

SYSTEM MODE	FUEL supplied in ml	Observed mileage in km
Normal Mode	100	4.2
Hybrid Mode	100	5.1

The above mentioned result is discussed having considered mileage as the parameter for efficiency. Thus comparing the mileage of the two systems, the efficiency value can be calculated as,
η= (mileage of the hybrid system /mileage of the conventional system) × 100
i.e. (5.1/4.2) ×100= 121.4%
Since efficiency cannot be greater than 100, this calculation is understood as; hybrid system is 21.4% more efficient than the conventional gasoline engine for the same amount of fuel. The calculated distance covered is plotted and compared in [Fig. 7].

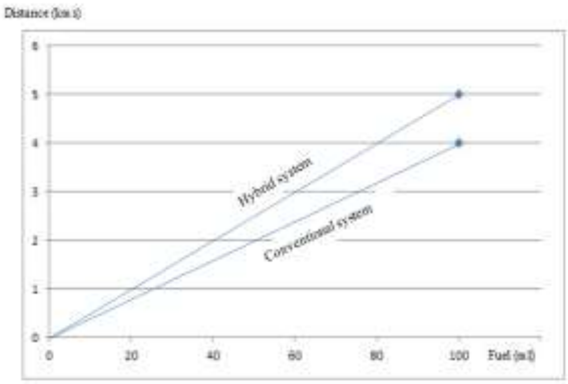

Fig. 7: Comparison of distance covered using different modes of operation

CONCLUSION

This paper reviews briefly on the existing works in the area of hybrid modeling of various vehicles. This research shows the development of hybrid based two wheeler vehicle test bed and development of switching control strategy and its consideration towards the experimental proceedings. The results of the study analysis have presented a competitive area of research to provide solutions to the potential problems available in relation to the hybrid vehicles and energy efficient systems supporting the safer and cleaner environment.

The developed system lags the smoothness in switching which needed to be addressed by the modern and sophisticated control methodologies. Increased parameter considerations apart from engine and electric motor speed can fetch better switching and improved understanding on the behavior of the system and enables the control designer to enhance its switching dynamics. The system can also be provided with an option of simultaneous manual or automatic control based on the user's preference. Also hybrid two wheelers can be built and tested with this design and they can be further mass produced like the hybrid cars for a safer eco-system.

CONFLICT OF INTEREST

The authors declare no competing interests in relation to the work.

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None

FINANCIAL DISCLOSURE

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