



Switching Control in Hybrid Vehicle System Based Two Wheeler

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Abstract: This paper develops a test bed for a hybrid vehicle's power train along with a switching control methodology to address the time delay experienced in electrical switching between engine and motor power to achieve smooth power transmission to the wheels, thus reducing fuel consumption. A complete test bed for the power train is designed and fabricated. A conventional sequential-based switching control algorithm is developed to operate the system with a motor at low speeds and the engine at higher speeds, using the number of rotations per unit time as the switching parameter. The logged output is analyzed and the performance efficiency of the hybrid vehicle powertrain is compared against conventional internal combustion (IC) engines.

Keywords: hybrid vehicles, switching control, efficiency, power train

Introduction

Any real-time system is subject to time delay in terms of measurements, state or control input. Generally delayed systems are infinite dimensional in nature and time delay is the prime reason for system instability. This raises theoretical and practical factors for smoothing performance stability issues specific to the control system. Transportation systems are among the most critical to modern human society, and transportation technology has steadily developed since the invention of the Internal Combustion Engine (ICE). Hybridization is a recently innovation which combines an internal combustion engine (ICE) and an electric motor for vehicle drives, and provide numerous advantages over conventional gasoline-powered vehicles [1]. These versatile systems can deliver power in a variety of configurations including Parallel Hybrid, Series hybrid, Series-Parallel or Combined hybrid and Plug-in Hybrid Electric Vehicle (PHEV) [5]. The combined hybrid and plug-in hybrid provide the highest efficiency. PHEVs are not very popular because they need dedicated charging stations. Combined hybrid vehicles are generally front wheel drive, with the drive chain

connected to the power sources through a transmission system and clutch. An electro-mechanical switching mechanism is used and power is transmitted through a dedicated transmission system. This system is limited to four wheelers such as cars and SUV's. Completely automatic switching mechanisms are seldom implemented in such vehicles. This paper proposes a simpler switching methodology with the components matching the dynamics of a two wheeler and using a chain transmission to connect the power source to the drive chain [2].

Proposed Design

The test bed is a platform which houses the engine and the motor in a fixed position. The engine shaft is fitted with a disc that contains teeth. Another disc of the same dimensions and tooth count is fitted to the motor shaft. The engine and the motor are not adjacent and the axes of rotation of the shafts are parallel. Also, the disc faces are kept in the same plane, so that the two sources can be coupled effectively. Coupling is accomplished using a chain. Thus, when one of the shafts rotates, the other rotates in the same direction and at the same speed. The



switching parameter is the individual speeds of the motor and engine shafts in terms of rotations per minute (rpm) as determined by a Hall Effect sensor. The motor speed is varied by a motor controller and the engine speed is varied using a throttle control system. To throttle the engine, a servo motor is used to open the throttle valve to a pre-defined angle which provides the required amount of system acceleration [8]. Figure 1 shows the developed hardware setup.



Figure 1. Developed hardware setup of the hybrid vehicle test bed.

RPM Measurement and Display Modules

The RPM measurement modules are Arduino based, using LCD panels for displays. Two modules are used to separately measure the RPM of the motor and engine, each using a Hall Effect sensor housed near their respective shafts. These sensors constantly measure and feed the RPM data to the control unit. The control unit is already fed a set RPM value to carry out bi-directional switching (i.e., motor to engine and engine to motor), and the attached LCD displays the measured values for ease of observation. Figure 2 shows the RPM measurement and display module.

Relay Switch Modules

The relay switches are the components that actuate the switching process by receiving signals from the controller when a set point is reached or crossed. As shown in Fig. 3, three dedicated relays are used for engine

start/stop and motor start/stop. The relays maintain an 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, the motor relay closes first and actuates the motor until the motor reaches the set point. Meanwhile, the engine start/stop relays remain open. When the set point is crossed, the motor relay opens, the engine start relay closes and the engine starts immediately, picking up from the current RPM of the motor where the motor has disengaged.

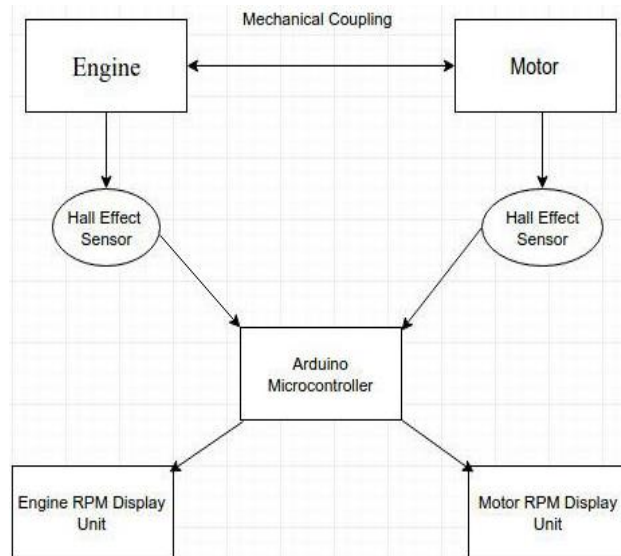


Figure 2. Speed display module.

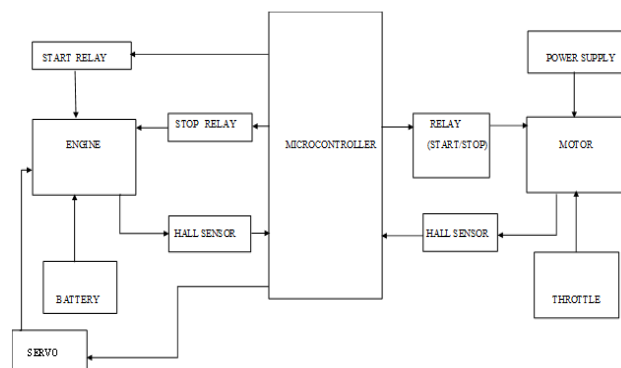


Figure 3. System design.

Servo Motor

As the engine takes over from the motor, the throttle wire is simultaneously pulled by actuating the servo motor which turns stepwise at defined angles. The actuating signal is transmitted to the servo motor by the control unit when it senses that the set point is crossed. Once the servo has pulled the throttle to the maximum defined position, it returns to null thereby causing the engine to decelerate. This gradually causes a decline in engine shaft RPM which falls below the set speed in the control unit, thereby causing the system to switch back to

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the DC motor [7].

[4] Control Unit

The control unit is fed a defined speed as a set point value and a condition based switching algorithm. The input parameter (RPM value) 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 the DC motor to the engine and vice-versa, making the entire process completely automatic and repeatable for n-cycles [3].

Switching Algorithm

The developed nominal linear system with a time-varying delay can be represented as,

$$\begin{cases} \dot{x}(t) = Ax(t) + A_d x(t - d(t)), t > 0, \\ x(t) = \varphi(t), t \in [-h, 0], \end{cases} \quad (1)$$

where $x(t) \in \mathbb{R}^n$ is the state vector; A and A_d are constant matrices with appropriate dimensions; the delay $d(t)$ is a time-varying continuous function; and the initial condition, $\varphi(t)$, is a continuously differentiable initial function of $t \in [-h, 0]$.

The delay is assumed to satisfy the following condition,

$$0 \leq d(t) \leq h \quad (2)$$

Based on the above problem formulation [9], we designed a condition-based switching algorithm as shown in Fig. 4. 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 the vehicle reaches the cutoff speed in terms of RPM. Once the vehicle exceeds the cutoff speed, the engine is given the control to pull the vehicle switching off the motor. In the case of deceleration, the controller checks cutoff speed feedback from the engine shaft speed sensor, and then switches from the engine to the electric motor. Once the speed drops below the cutoff point, the controller gradually eases the grip of the engine throttle servo motor and transfers control to the motor.

Experimental Analysis

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

In normal mode, the test bed is operated with the gasoline engine to determine the fuel consumption rate of the conventional gasoline two wheeler engine system under no-load conditions. In the hybrid mode, the gasoline engine is operated in conjunction with the electric motor under no-load conditions. Both modes of operation are tested in a continuous run test and an intermittent braking and running test.

In hybrid mode testing, the engine throttle is controlled by a servo motor. Table 1 presents measured engine shaft speeds with respect to various servo angle positions.

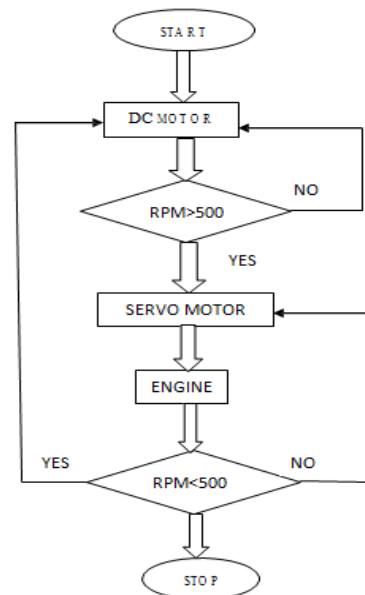


Figure 4. Developed switching algorithm.

Continuous run test:

In the continuous run test, the system initially runs in normal mode with 100ml of fuel, followed by the hybrid mode with the same amount of fuel. Normal mode used a sizable amount of fuel to make the initial start and then regulated its consumption. In the latter system, the initial speed was attained using the electric motor before switching to maintain speed with the gasoline-powered engine. Hybrid mode consumed 20 ml less fuel compared to the normal mode drive. The output response of the hybrid mode operation of the test bed is shown in Fig. 5.

Table: 1. Calibrated acceleration settings

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

Intermittent braking and running test:

In this test, both configurations gradually increased acceleration and then recursively applied a timed brake to

better approximate real world driving conditions. The fuel-only drive was initially run with fuel consumption significantly exceeding that of the continuous drive mode. The same test was performed on the hybrid system for the same period. The battery's engagement increased significantly, and fuel consumption fell by 50% of that of the other drive.

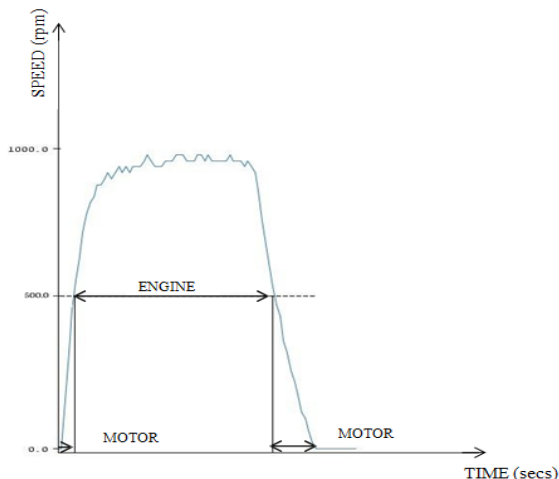


Figure 5. System output response during switching.

Efficiency

Mileage is taken as an indicator of efficiency. The proposed system is implemented against the conventional gasoline two wheeler vehicles and checked for mileage. For ease of observance, 100 ml of gasoline was used in a HONDA ACTIVA two-wheeler with identical engine specifications to that of the hybrid system test bed. The vehicle is parked on the center stand and driven such that the back wheel does not contact the surface until all 100 ml of fuel is consumed. Test mileage under no-load conditions was 4.2 kilometers.

Given the same fuel amount and no-load conditions, the hybrid system reached 5.1 kilometers. Comparing the mileage of the two systems, the efficiency value can be calculated as,

$$\eta = (\text{mileage of the hybrid system} / \text{mileage of the conventional system}) \times 100$$

$$\text{i.e. } \eta = (5.1/4.2) \times 100 = 121.4\%$$

Thus the hybrid system is 21.4% more efficient than the conventional gasoline engine given the same amount of fuel.

Future Scope

The scope of the study can be extended to analyze stability as a time delay system. This requires an appropriate Lyapunov – Krasovskii functional to obtain conditions for sufficient stability.

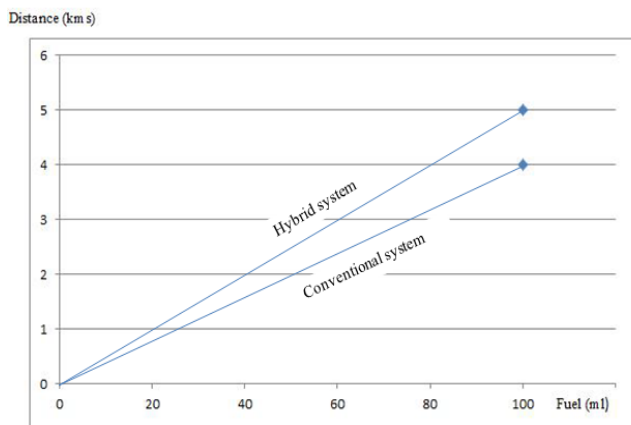


Figure 6. System efficiency comparison.

Based on the stability analysis, smoother switching between the power sources can be developed and implemented with higher order predictive controllers [9]. Additional parameters can be considered as criteria for switching. A higher number of parameters will provide a clearer understanding of system behavior and enable designers to enhance switching dynamics. The system can also provide the user with an option of manual or automatic control. Hybrid two-wheelers can be built and tested with this design, and later mass produced to improve overall environmental conditions [6].

Conclusion

A hybrid-based two wheeler vehicle test bed and switching control strategy are developed. The developed system is tested in a continuous run test and intermittent braking and running test. Experimental results show that that the efficiency of the proposed hybrid system is 21.4% greater than conventional IC engines. This proves that there is a considerable improvement in the fuel efficiency in the use of hybrid systems.

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