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INCREASING EFFICIENCY OF CONTROL SYSTEMS FOR HYBRID ELECTRIC VEHICLES AT CRITICAL ENERGY LEVELS

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Abstract

In this research, an optimization algorithm for controlling a hybrid electric vehicle's (HEV) powertrain control and energy usage is proposed. The algorithm is used on a vehicle prototype that is created by equipping an all-terrain vehicle (ATV) with an electric motor. An embedded micro-controller unit (MCU) is used in the construction of the control system. This study's primary goals are to minimize the use of ICE and increase the efficiency of electric energy consumption. The ATV's automatic transition between its internal combustion engine and electric motor is managed by the MCU. Additionally, the system provides instructions to the driver on how to effectively use the scarce resource at the crucial energy level. The driver's performance is limited through the use of pulse width modulation (PWM). To maximize the travel distance and provide optimal performance, the PWM duty cycle is modified. In this study, different driving circumstances are examined. Considerations have been made for variables including stop-and-go frequency, energy level, and travel speed. The trials revealed a notable advancement.

Keywords: *Control Systems, Critical Energy Levels, Hybrid Electric Vehicles (HEV), micro-controller unit (MCU).*

1. INTRODUCTION

Optimizing control systems for hybrid electric vehicles (HEVs) is essential, especially at key energy levels, as the automotive industry moves more and more toward these vehicles to address environmental and energy efficiency problems. In order to maintain performance and fuel efficiency, hybrid electric vehicles—which combine traditional internal combustion engines with electric propulsion systems—must balance power sources. When regulating the switch between power sources, these control systems' effectiveness is crucial, especially when they're operating close to important energy thresholds. Fuzzy logic and telemetry-based management are examples of advanced control systems that are starting to emerge as crucial ways to improve energy efficiency and guarantee optimal vehicle performance. It is feasible to generate notable improvements in total vehicle performance, energy consumption, and environmental effect by enhancing control systems at these crucial points. This will ultimately accelerate the adoption of HEVs and contribute to more environmentally friendly transportation options.

2. LITERATURE REVIEW

Dawei et al. (2017) conducted research on intelligent fuzzy energy management for a uniaxial parallel hybrid electric vehicle, emphasizing the application of fuzzy logic to enhance energy efficiency. Their study demonstrated that fuzzy logic controllers can improve the performance of hybrid vehicles by optimizing energy management in real-time, thus addressing challenges associated with traditional control methods.

Jordan (2004) provided a foundational introduction to hybrid electric vehicle control systems and hybrid couplers in his honors thesis. This work outlined the basic principles and components of hybrid control systems, offering a comprehensive understanding of how these systems manage power distribution and vehicle performance. Jordan's research remains relevant for those studying the evolution and development of hybrid vehicle technologies.

Lin, Peng, Grizzle, and Liu (2003) explored the development of control systems for medium-duty hybrid electric trucks. Their SAE Technical Paper highlighted advancements in control technologies that are essential for enhancing the operational efficiency of hybrid trucks. The authors focused on the integration of advanced control strategies to improve vehicle performance and fuel economy, contributing valuable insights into the design and implementation of hybrid truck systems.

Ma et al. (2019) examined fuzzy logic control energy management strategies for parallel hybrid electric vehicles. Their study, published in Energy Procedia, utilized numerical simulations to evaluate the effectiveness of fuzzy logic in managing energy distribution between power sources. The findings indicated that fuzzy logic can provide a more adaptive and efficient energy management approach compared to conventional methods.

Manzie et al. (2012) investigated the optimal use of telemetry in parallel hybrid vehicles, particularly in urban driving scenarios. Their research, published in Transportation Research Part C: Emerging Technologies, highlighted the potential of telemetry data to enhance vehicle performance and energy efficiency in urban environments. The study emphasized the importance of real-time data analysis in optimizing hybrid vehicle operation and reducing energy consumption.

3. RESEARCH METHODOLOGY

3.1. ICE-EM Switching Control

A microprocessor called an Arduino Uno, combined with sensors for speed and battery state-of-charge (SOC), and relays, make up the ICE-EM switching control system. A speedometer that converts voltage pulses into kilometers per hour is made using a magneto-resistive PNP Hall Effect sensor in conjunction with a neodymium magnet.

a. The first all-terrain automobile.

b. The revised structural plan and its execution, which included the addition of an electric engine

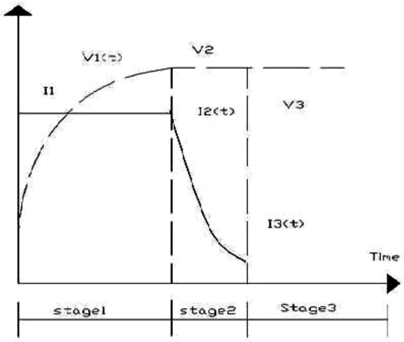
c. Testing the last prototype HEV and installing the batteries.

Figure 1: Steps taken to modify the prototype HEV by equipping an all-terrain vehicle (ATV) with an EM

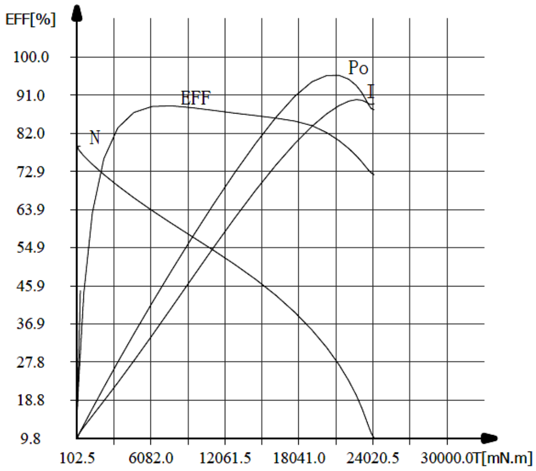
Lithium-ion battery level is indicated via a four-level battery SOC indicator that is connected to an MCU and display module and displays a percentage.

A. Switching Algorithm

In order to guarantee safe operation and prevent battery damage, Figure depicts ICE-EM switching control using speed and battery SOC criteria based on 40 km/h speed and 25% battery level.



a. The charging curve of batteries



b. EM test curve.

Figure 2: Specifications for batteries and electromagnetic fields.

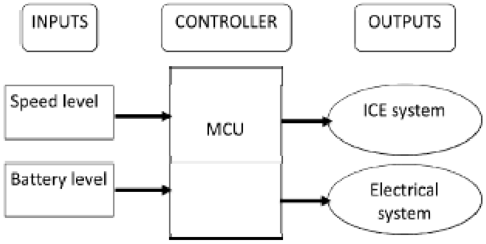


Figure 3: The ICE-EM switching control system's operational flow

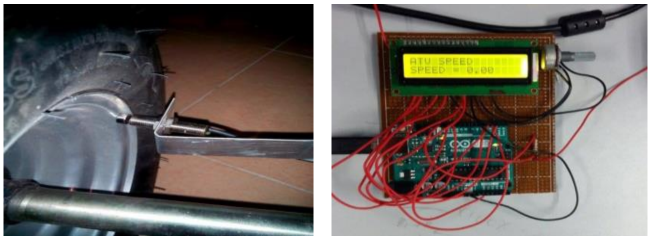


Figure 4: Utilizing a neodymium magnet-equipped magneto-resistive sensor to gauge the speed of the vehicle and display the speed reading on the display module

Enhancing fuel efficiency is the primary goal of the employed technique. As a result, the suggested method only turns on the ICE in two scenarios. When the speed exceeds ST, we have the first scenario. As previously noted, exceeding this speed may result in battery damage and/or burning of the battery fuse. The other scenario involves a nearly depleted battery. In this instance, employing the EM is the only option.

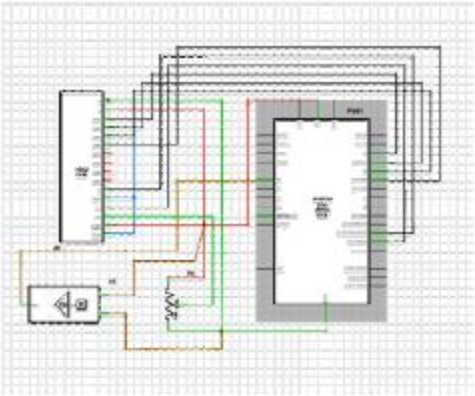


Figure 5: Schematic for a speedometer

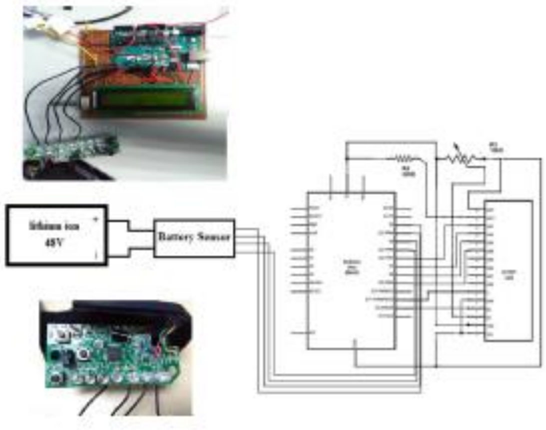


Figure 6: SOC sensor for batteries and its schematic

The "Critical case" calls for a unique algorithm with constrained resources since it involves empty fuel tanks and battery SOC < 25%. Tests of energy efficiency confirm the advantages of HEV conversion.

3.2. Critical Case Method

In order to ensure safe power access, this study use pulse width modulation (PWM) to intelligently manage a vehicle's battery while the fuel tank is empty and the battery level is lower than BT.

A. The Proposed Method

The distance traveled and travel speed are displayed in the table; the ideal speed is 15 km/h. In order to safely optimize energy sources, the target is modifying speed. A 2.33 V throttle voltage guarantees a speed of 15 km/h.

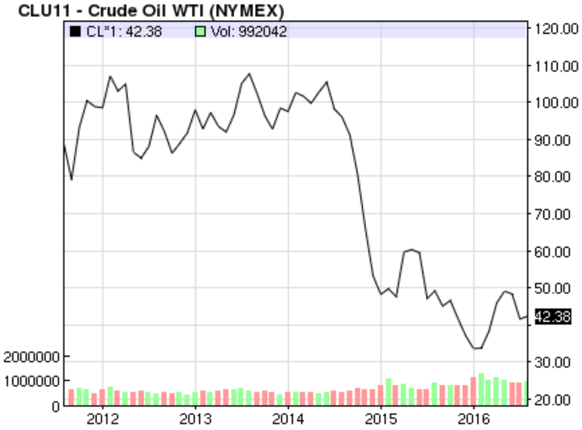
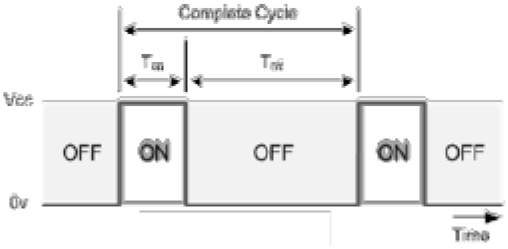


Figure 7: For the previous five years, WTI (NYMEX) crude oil price quotes in USD/bbl



$$Duty\ Cycle = \frac{T_{on}}{T_{on} + T_{off}} \times 100\ \%$$

Figure 8: Duty cycle of PWM

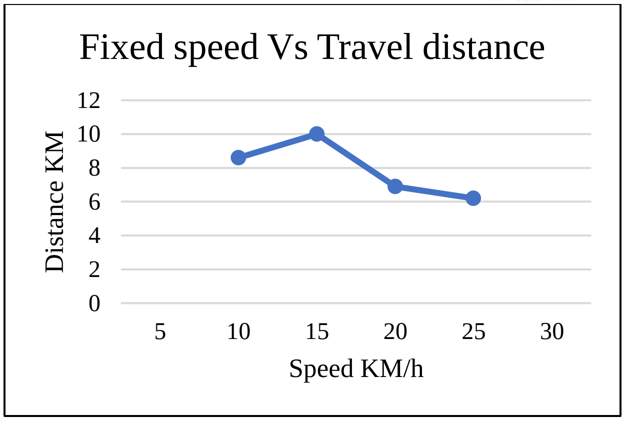


Figure 9: Relationship between the maximum distance traveled at a given speed and electricity consumption

Table 1: The Connection Between Vehicle Speed and Throttle Voltage Vin

Speed (km/h)	Vin (V)
5	1.7
10	1.86
15	2.44
20	2.83
25	2.85
30	3.63
35	3.83

The Arduino Uno MCU regulates the speed of a DC motor by converting an analog output into PWM signals. The vehicle's speed is linked to the electromotive force (EMF) in its coil, and the duty cycle is calculated using specific formulas. However, the sine wave controller used in this study does not support PWM.

$$V_{out} = D \times V_{in}$$

$$D = \frac{V_{out}}{V_{in}} = \frac{2.33V}{5V} \approx 47\%$$

A relay manages the sine wave controller's input signal while flattening PWM with RC filters. The throttle is used by the driver to manage the vehicle, although frequent stop-and-go operations reduce the maximum distance.

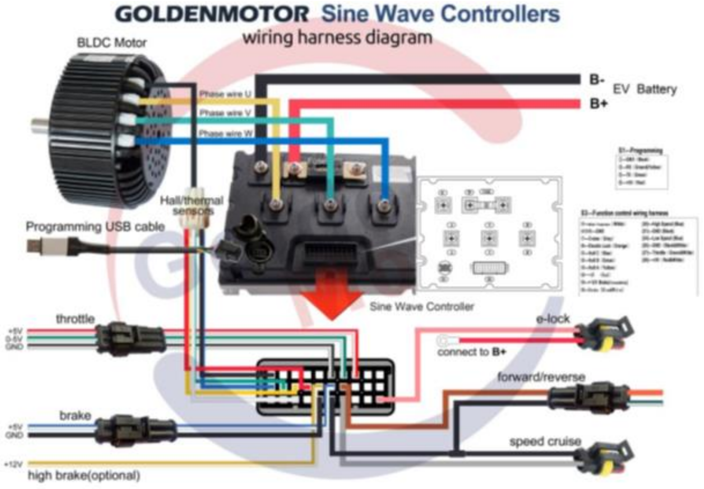


Figure 10: The supplier's supplied wiring diagram for the motor and controller

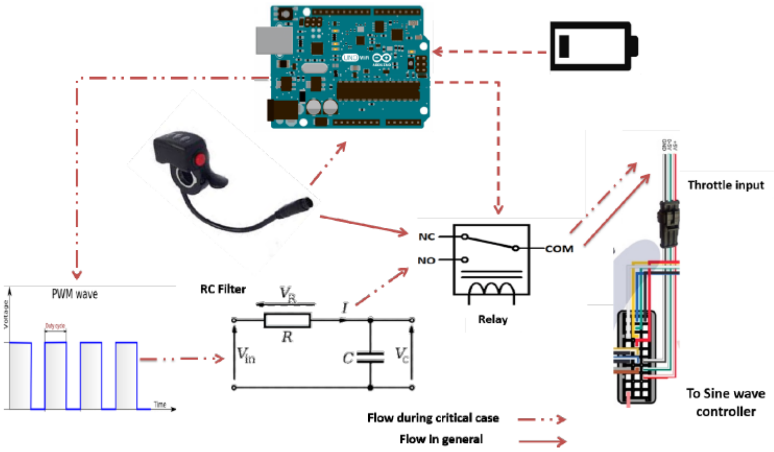


Figure 11: Changing between sources of voltage control in emergency situations.

B. *Experiment and results*

Even with the battery SOC at 25%, a validation experiment revealed that turning on the PWM critical case approach greatly increased travel distance.

Table 2: Test Results for Electric Power Consumption at Various Speeds

Participant	PWM	Average Speed (km/h)	Travel Distance (km)
1	Activated	15.9	11.2
	Deactivated	21.2	8.2
2	Activated	15.8	10.8
	Deactivated	23.4	6.8

3.3. The Prototype Vehicle Specification

In order to create the HEV prototype that was studied, an all-terrain vehicle (ATV) was outfitted with an electric motor (EM). Figure shows the ATV modification process. This vehicle falls under the category of electric parallel plug-in hybrids. The table provides the essential details of the hybrid electric vehicle (HEV) used in this research. Figure shows the supplier's charger and EM test curves for the battery.

Table 3: Details of the vehicle.

Part	**Specification**
ATV Engine	
Engine	1100 cc DZR-800
Starter	Electric (Push button)
Transmission	Semi-automatic: front / Neutral / rear
Fuel Tank Capacity	3.8 liters
Transmission System	Chain drive
Wheels	16" tire / 8" Rim
Brake Type	Disc Brake
Front Axle Weight	72 kg
Rear Axle Weight	82 kg
Electric Motor	
Type	BLDC Motor
Rated Power	3KW-7.5KW
Speed	2000-6000 rpm
Weight	11 kg
Controller	Field-Oriented sine wave Controller (FOC)

Rated Voltage	48V
Rated Current	120A
Battery	
Battery Type	Li-Ion
Battery Mode	48V 40Ah
Nominal Voltage	51.2V
Source Resistance	<40 mΩ
Cell Combination	16*14
Cell Type	3.2V 3000mAh
Maximum Continuous Discharge Current	80A
Maximum Continuous Charge Current	20A
Standard Charge Current	2A
Fast Charge Current	5A
Charge Time Under Standard Charge	24 hours
Charge Time Under Fast Charge	8 hours
Weight	40 kg
Charger Specification	
Model	CE-4805
Input Power	334W
Output Power	292W
Output Current	5A

4. DATA ANALYSIS

4.1. Energy Efficiency Testing Results

A. Fuel Consumption

The fuel consumption test results prior to EM installation are included in the table. Approximately 0.27 liters of fuel are consumed every km on average, or 27 liters per 100 km.

B. Electric Consumption

According to the charger standard, a power output of 334 watts is required to fully charge the battery, which takes approximately eight hours. To estimate the trip distance until the battery is nearly depleted, an average distance of 25 kilometers is used. The electricity consumption is calculated as the power in kilowatts multiplied by the time in hours: 0.334 kW × 8 hours, resulting in 2.67 kWh. Dividing this electricity usage by the journey distance yields 2.67 kWh / 25 km, which equates to 0.1 kWh/km or 10 kWh/100 km. The electric power consumption test results for different speeds are shown in a table, with each fixed speed test conducted after a full battery charge. Measurements are recorded once the battery level drops to 25% of its capacity.

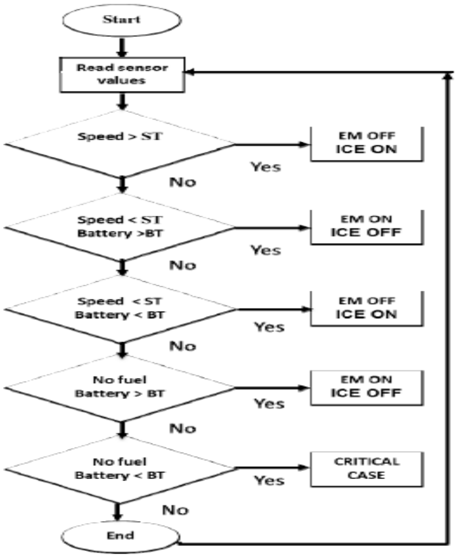


Figure 12: The way the ICE-EM switching control operates

Table 4: Fuel Usage Prior to Eminstallation

Distance (km)	Amount of Petrol Used (liters)	Fuel Consumption (liter/km)
0.6	0.15	0.30
3	0.56	0.385
12	2.10	0.27

C. Analyzing the Cost Benefits of the HEV1

Using the rate offered by Tenaga Nasional Berhad (TNB), the national electric power supply provider, the energy cost of an EM system is computed. The home rate starts at 21.80 Sen/kWh for the first 200 kWh used each month, according to TNB's website. After that, the charge progressively rises, hitting 57.10 Sen/kWh for monthly consumption above 901 kWh. As a result, the cost of electricity may be computed as follows: multiplied by the energy rate of the electrical energy used. For instance, if 10 kWh were used, the lowest possible cost per 100 km would be RM 2.18 (10 kWh X 0.218), and the highest possible cost would be RM 5.78 (10 kWh X 0.578).

Table 5: Electric Power Usage Test Results at Various Speeds

Travel Type	Speed	Travel Time	Travel Distance
Fixed	10 km/h	49.5 min	8.7 km
Fixed	15 km/h	40 min	10.0 km
Fixed	20 km/h	21 min	6.8 km
Fixed	25 km/h	16 min	6.3 km
Frequently stop-and-go up to	15 km/h	20 min	7.8 km
Frequently stop-and-go up to	20 km/h	16 min	4.2 km

The ICE system's energy cost is computed utilizing the current worldwide lowest price of RON95 gasoline. Hybrid cars with electric motors are more economical in terms of costs and fuel consumption, which lowers pollution emissions even in times of low oil prices. Higher speeds still require the fuel mode.

5. CONCLUSION

This study included the presentation, testing, and analysis of a prototype HEV. According to test results, running a hybrid electric vehicle (HEV) in electric mode is more cost-effective and reduces fuel consumption, which in turn lowers emissions of pollutants. Also covered was an optimization approach for controlling HEV powertrain control and energy consumption. Significant optimization and improvement were demonstrated by the experiment. This study's system is tested only on straight, level roads with little turns. A thorough analysis that takes into account various road geometric designs is required in order to establish more reliable procedures based on more precise specifications. More optimization can be achieved by using more resilient control strategies. Neural networks and fuzzy logic algorithms are potential options for enhancing braking and energy efficiency. An additional method for improving these aspects is regenerative brake control. Integrating regenerative brake control with an anti-lock braking system (ABS) is one approach to achieve better braking performance. Additionally, testing various modes of operation, including motor-only, engine-only, power-aid, recharge, and regenerative modes, can be beneficial.

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