# STUDY OF DESIGN AND MANUFACTURE OF THE CONTROLLER OF HYBRID POWERTRAIN SYSTEM

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DOI: http://doi.org/10.57001/huih5804.2024.191

**ABSTRACT**

The study has designed and manufactured a controller for hybrid powertrain system with series-parallel configuration. The general model was manufactured completely including three main parts such as: a hybrid powertrain system, an information display panel, and a box of controllers. The electronic board was designed using Proteus Design software. An Arduino programming environment (IDE -Integrated Development Environment) was used to program the electronic controller for hybrid powertrain system. The system operated with eight working modes as: Charging BAT mode, Start mode, Normal driving mode, Low load mode, Full load mode, Deceleration mode at gearbox of D mode, Deceleration mode at gearbox of B mode, and Reverse mode. The experimental operation results showed that the model operated stably, and the controller could control the hybrid powertrain system effectively to achieve optimal management of the energy and power flow among internal combustion engine, electric motor, and battery in each working mode. The system model operated with working modes almost identically to the actual vehicle.

***Keywords:*** *Series-Parallel Configuration, Electric Motor, Battery, Hybrid Electric Vehicles, Working Mode.*

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Received: 02/3/2024
Revised: 12/4/2024
Accepted: 25/5/2024

## 1. INTRODUCTION

Nowadays, the economy and people's living standard have been developing rapidly. Along with that, the number of vehicles is increasing. Currently, conventional vehicles (CVs) using internal combustion engines have become the most common. Thus, some social problems arise such as oil resources depletion and environmental pollution [1]. These are also major challenges that the automobile industry has to face [2]. Therefore, automobile companies in the world have been making efforts to research and develop efficient new energy vehicles [3].

New energy vehicles include three main types such as: hybrid electric vehicles (HEVs), battery electric vehicles (BEVs), and fuel cell vehicles (FCVs) [4]. BEVs and FCVs can be considered effective technology for reducing fuel consumption and environmental emissions in future. However, they are not still widespread and are limited by the battery capacity, higher cost-effectiveness, and more complete supporting facilities. Hybrid electric vehicles would be the effective choice for urban transportation, in which, the combination of internal combustion engine (ICE) and electric motor is the effective technology and a practical alternative to the CVs [5]. The main component of hybrid electric vehicles is the powertrain system. The hybrid powertrain system is composed of two energy sources such as electric and mechanical. Based on the structure of the hybrid powertrain system, there are three basic types: series, parallel, and series-parallel [6]. The structure diagrams of three basic types of hybrid powertrain are shown in Fig. 1, where EM, INV, and BAT indicate electric motor, inverter, and battery.

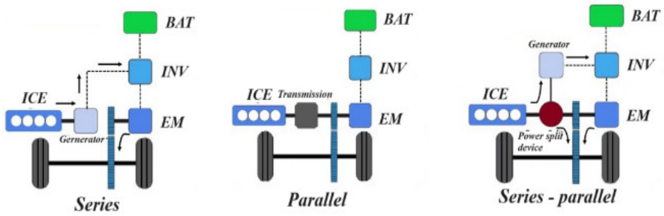


Fig. 1. Basic types of hybrid powertrain

The hybrid powertrain system is structured to adapt to different working modes of the hybrid vehicle so that the electro-mechanical energy could be effectively converted in hybrid powertrain. So, an energy management strategy (EMS) should be considered so that the energy flows in hybrid powertrain could be governed effectively. The main function of EMS is to control the energy and power flow among internal combustion engine, electric motor, and battery appropriately to adapt to the different vehicle's operating modes [7-9]. Thus, the fuel consumption is minimized and the energy flow in vehicle is optimized. There were some studies of EMS for HEVs to get the most effective performance of HEVs. Luo et al., studied the control strategy with the combination between thermostat with DC-link voltage, and the better fuel economy performance of HEVs was obtained in an efficient working area of the engine [10]. Zhao et al., proposed a torque distribution control for parallel HEVs and the fuel consumption was reduced by 10%

as compared with conventional vehicles [11]. Liu et al., studied an EMS based on the road load recognition, and the results showed that dynamic performance and driving performance for HEVs were improved with smooth effective engine operation and emission reduction [12]. Kim et al., proposed a frequency domain power distribution strategy with the results showing that the electric load was reduced, and engine transients were smoothed [13]. Jing et al., conducted the design of motor controller for HEVs using vector control algorithm with the results showed that driving system has the performance of low speed and high torque, wide range of variable speed and high comprehensive efficiency [14]. Hangyang et al., proposed an optimal control strategy using control-oriented algorithm for HEVs with a parallel configuration. The result showed that the optimal torque split factor and continuously variable transmission speed ratio were obtained, and the fuel consumption reduced [15]. Daobao et al., proposed a control strategy for HEVs transmission system based on improved genetic algorithm (GA) algorithm. The control strategy could improve the fuel consumption and power of HEVs [16].

This study conducted the design and manufacture of a controller for hybrid powertrain system of series-parallel-configuration HEVs. An energy management strategy (EMS) was built to control the energy and power flow among internal combustion engine, electric motor, and battery appropriately to adapt to the different vehicle's operating modes based on the chosen modes of transmission and accelerator position.

## 2. THE RESEARCH SUBJECT AND METHODS

### 2.1. The Research Subject

The study focused on a controller for hybrid powertrain system of series-parallel-configuration HEVs. The series-parallel-configuration was shown in Fig.1. The controller was programming to control the energy source coordination among the internal combustion engine, electric motor, and battery appropriately to adapt to the vehicle's operating modes such as: Charging BAT mode (M1), Start mode (M2), Normal driving mode (M3), Low load mode (M4), Full load mode (M5), Deceleration mode at gearbox of D mode (M6), Deceleration mode at gearbox of B mode (M7), and Reverse mode (M8).

### 2.2. The Electronic Board Design Software

The electronic board was designed using Proteus Design software. Proteus Design is software from Lab Center Electronic used to draw principal diagrams, simulate and design printed electronic circuits. Proteus Design provides almost designing electronic components so that working principal circuits can be created, tested and compared with actual results effectively.

### 2.3. The Control Programming Software

Devices based on the Arduino platform are programmed in their own language. This language is based on the Wiring language written for general hardware. And Wiring is a variation of C/C++ also known as "Arduino language". The Arduino language originates from C/C++, which is very popular today [17-19].

To program as well as send commands and receive signals from the Arduino circuit, an Arduino programming environment called Arduino IDE (Integrated Development Environment) was used to program the electronic controller for hybrid powertrain system.

The control algorithm flow chart was presented as in Fig. 2.

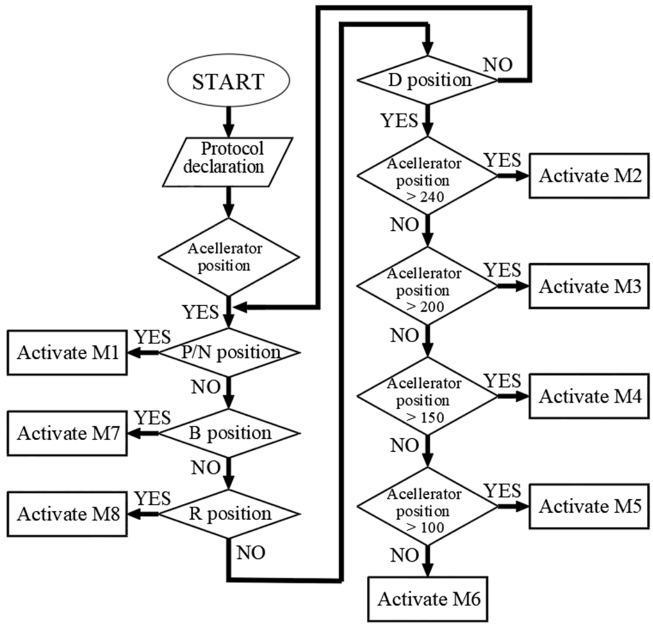


Fig. 2. The control algorithm flow chart

## 3. THE DESIGN AND MANUFACTURE OF THE CONTROLLER FOR HYBRID POWERTRAIN SYSTEM

### 3.1. The Working Principal Diagram of the Controller for Hybrid Powertrain System

The working principal diagram of the controller for hybrid powertrain system was described in Fig. 3.

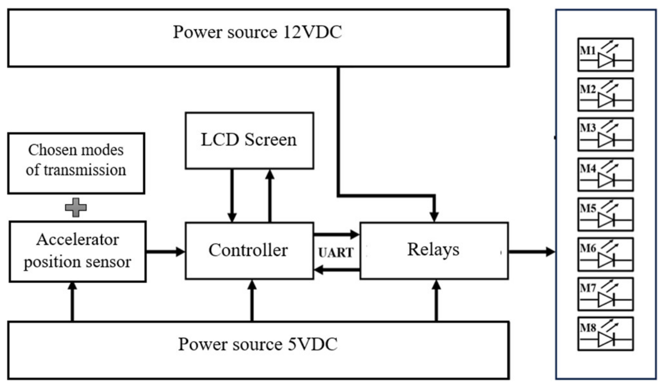


Fig. 3. The working principal diagram of the controller

The Power source 12VDC provides power for the relays of activating the working modes. 12V power is taken directly from the battery, turned off and on by the engine switch and emergency stop button. Power source is connected in series through a fuse to protect the system.

The power source 5VDC provides 5VDC power to the controller, sensor, and relays. The 5VDC power source is voltage reduction source from the 12VDC power source through a voltage reduction circuit.

The accelerator position sensor used is a Hall type sensor and connected to the microcontroller pin via a voltage divider bridge to protect the microcontroller from overvoltage.

The controller has the function of receiving signals from the accelerator position sensor and the signal of chosen modes of transmission, then processing, and transmitting relay control signals to activate working modes via UART communication method. The controller is composed of the main microcontroller Arduino Nano with specifications presented in Table 1.

Table 1. Specifications of Arduino Nano

| Category | Specifications |
|---|---|
| Microcontrollers | ATmega328 - 8bit |
| Operating frequency | 16MHz |
| Consumption current | 30mA |
| Limited input voltage | 5VDC - 20VDC |
| Digital pin number I/O | 14 |
| Analog pin number | 8 |
| Flash memory | 32 KB (ATmega328) |

The relays of activating the working modes use the translation control method through IC 74HC595 that supports communication with many Modules. Relays are controlled through the ATMega328P microcontroller, which activates the relay to switch on and off in the correct working mode.

The LCD screen displays the system's working status. The screen uses a 20x4 LCD text type combined with an I2C LCD conversion module. The screen transmits and receives data from the microcontroller through two pins of SDA and SCL.

### 3.2. The Design of Different Working Modes of Hybrid Powertrain System

The different working modes of hybrid powertrain system were designed to adapt to the driver's operating conditions. There were eight working modes of hybrid powertrain system as shown in Fig. 4.

i. Charging BAT mode: GEN is driven by ICE to generate electricity to charge BAT

ii. Start mode: when the vehicle starts, power from the BAT is supplied to EM that works to create torque to rotate the active wheels.

iii. Normal driving mode: the vehicle is driven by EM and GEN acts as an electric motor to start the engine when the vehicle receives additional load.

iv. Low load mode: the vehicle is driven by EM and ICE, and ICE turns GEN.

v. Full load mode: the vehicle is driven by EM and ICE, and BAT adds power for EM.

vi. Deceleration mode at gearbox of D mode: at gearbox of D mode, GEN is driven by the wheels to generate electricity to charge BAT.

vii. Deceleration mode at gearbox of B mode: at gearbox of B mode, the power generated by EM was supplied to GEN and BAT, and GEN drives the ICE to provide additional braking force.

viii. Reverse mode: only EM drives the car in reverse, the engine does not work when reversing.

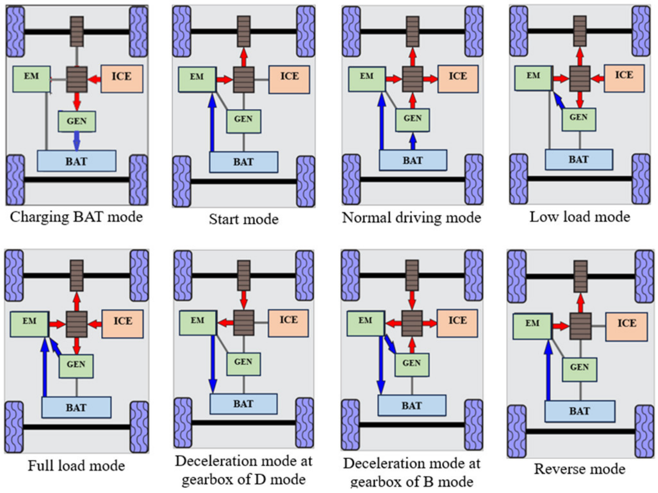


Fig. 4. The different working modes of hybrid powertrain system

### 3.3. The Manufacture of the Controller for Hybrid Powertrain System

The control system model which was manufactured was divided into three main parts such as: hybrid powertrain system, information display panel, and box of controller.

The hybrid powertrain system was manufactured and shown in Fig. 5. In which, 1. fuel tank, 2. Internal combustion engine, 3. Electric motor, 4. Differential unit, 5. Accelerator.

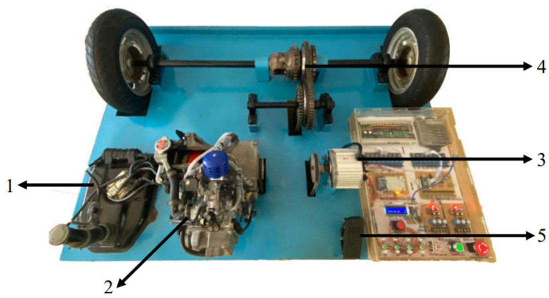


Fig. 5. The hybrid powertrain system model

The information display panel was manufactured and shown in Fig. 6. The information display panel displayed eight operating modes. Besides, there was also an LCD that displayed the engine speed and battery capacity.

The box of controllers was manufactured and shown in Fig. 7. In which, 1. Engine ECU and EM ECU, 2. Relays, 3. Control circuits, 4. Power source circuit, 5. LCD screen, 6. Buttons of choosing mode. Two ECUs have the function of controlling the engine and EM operating in each mode. The relays receive controlling signals from the control circuit to activate the operating modes. The control circuit has the function of processing signals about working modes and then encoding them to control the powertrain system. The power source circuit has the function of converting voltage from 12VDC to 5VDC to provide voltage for the control circuits.

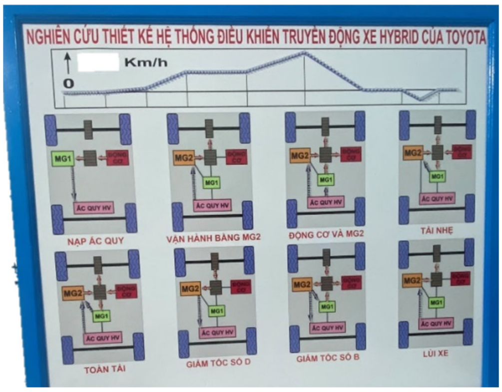


Fig. 6. The information display panel

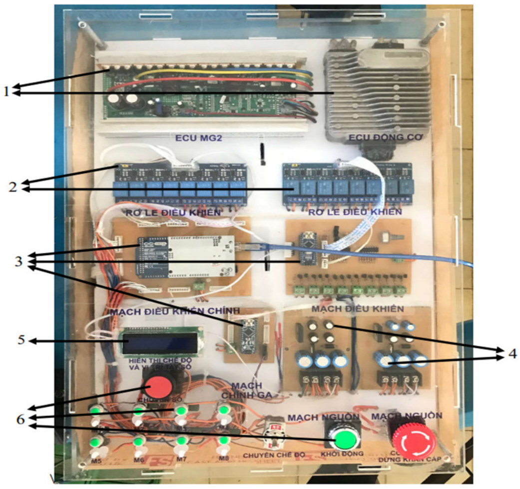


Fig. 7. The box of controllers

These main three parts of the control system model were installed on the steel frame to complete the model as shown in Fig. 8.

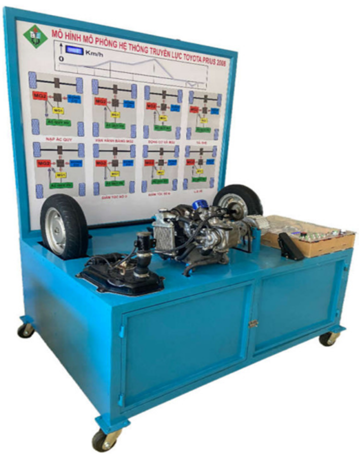

Fig. 8. The control system model for hybrid powertrain

**3.4. The Evaluation of the Operation Efficiency of Control System Model**

The control system model was operated following the steps below:

i. Check the safety of electricity of the model.

ii. Supply the power to the system.

iii. Operate the system based on choosing modes of the transmission by buttons and changing the throttle opening angle by pressing the accelerator.

The controller would control the hybrid powertrain system to adapt each working mode, in which, the ICE, GEN, EM and BAT were controlled and coordinated with each other to achieve optimal management of the energy and power flow among internal combustion engine, electric motor, and battery. The power transmission and energy supply lines in each operating control mode were displayed specifically on the information display panel. The experimental operation results showed that the model obtained stable operation. The controller operated stably and accurately controlled each working mode of the powertrain system with simulation results shown on the information display panel exactly as designed.

## 4. CONCLUSION

A controller for hybrid powertrain system was designed and manufactured completely. The general model was manufactured completely including three main parts such as: hybrid powertrain system, information display panel, and box of controller. The model was operated with eight working modes to evaluate the operation efficiency. The experimental operation results confirmed the stability of the model's operation. The controller accurately controlled each working mode of the powertrain system as designed. In each working mode, the optimal management of the energy and power flow among internal combustion engine, electric motor, and battery was achieved. The information display panel exactly displayed the control information of the power transmission and energy supply lines.

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