

RESEARCH AND APPLICATION OF FUZZY LOGIC TO CONTROL THE EXHAUST GAS RECIRCULATION AND FUEL IN DUAL FUEL ENGINES (LPG - DIESEL)

NGHIÊN CỨU ỨNG DỤNG LOGIC MỜ TRONG ĐIỀU KHIỂN HỒI LƯU KHÍ THẢI VÀ LƯU LƯỢNG NHIÊN LIỆU CHO ĐỘNG CƠ NHIÊN LIỆU KÉP (LPG – DIESEL)

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ABSTRACT

Research to reduce emissions from the engines diesel is very difficult mission, because the current emission standard is becoming very strictest NOx, HC, CO etc. Recently, dual fuel diesel engines which use Liquefied Petroleum Gas (LPG) and diesel fuel are being studied to control emissions and improve fuel efficiency. The research will propose using fuzzy logic to control the Diesel and LPG into the engine and diesel as a pilot fuel. Combined with the exhaust gas recirculation system (EGR) to reduce NOx levels in the exhaust. Both EGR and LPG are controlled by a fuzzy control system to improve the performance of the dual fuel engine.

Keywords: Dual Fuel Engines, Fuel Flow Control, Fuzzy Logic, Engine Control.

TÓM TẮT

Nghiên cứu giảm mức độ phát thải (CO, NOx, HC) từ các động cơ sử dụng nhiên liệu Diesel là nhiệm vụ rất khó khăn, bởi vì hiện nay tiêu chuẩn về khí thải đang trở nên rất nghiêm ngặt về NOx, HC, CO, vv. Thời gian gần đây, động cơ Diesel sử dụng nhiên liệu kép với khí dầu mỏ hóa lỏng (LPG) và nhiên liệu Diesel đang được nghiên cứu để kiểm soát khí thải và nâng cao hiệu quả sử dụng nhiên liệu. Trong nghiên cứu sẽ đề xuất sử dụng phương pháp logic mờ để điều khiển cung cấp đồng thời LPG và nhiên liệu Diesel làm nhiên liệu phun môi vào động cơ. Kết hợp với hệ thống tuần hoàn khí xả (EGR) sẽ làm giảm hàm lượng NOx trong khí thải. Cả EGR và cung cấp LPG được điều khiển bởi một hệ thống điều khiển mờ để cải thiện khả năng đáp ứng của việc điều khiển động cơ nhiên liệu kép.

Từ khóa: Động cơ nhiên liệu kép, Điều khiển lưu lượng, Logic mờ, Điều khiển động cơ.

1. INTRODUCTION

With the new emission standard and orient the development of clean technologies purpose reduce harmful emission components of internal combustion engine. Dual Fuel Engines (LPG - Diesel) shows that can be applied in many different fields such as: generator, agricultural machine,

transportation, ship... Liquefied petroleum gas (LPG) has several advantages compared to engines using conventional fuel (gasoline, diesel) as: the harmful emissions caused environmental pollution reduce, ensuring and maintaining of performance engine, low fuel costs and easy conversion [1]... Dual Fuel

Engines (LPG - Diesel) shows a part of diesel fuel is replaced by LPG that makes saving fuel; significantly reduce emissions of HC, NO_x, CO and PM; the parameters of performance, moment of engine is improved; cost of conversion fuel system low and the engine's structure not change much ... [2]. The process control rate of LPG - Diesel provides into engine has an important role to determine operating and emission characteristics of dual fuel engine. LPG injector is controlled by electronic that provide LPG into cylinder at the injection timing and the exact amount of fuel on the various operating conditions of the engine, to ensure the highest engine performance and the lowest harmful emissions.

With many studies have been conducted based on the foundation of electronic development control systems (ECU) to control fuel flow and emissions of internal combustion engines by the using controller (P, PI and PID) at various operating conditions of the engine. In fact, this control is very difficult and may not achieve the desired operating conditions of the system. In addition, designing PID controller is very difficult for non-linear systems, especially in engine control.

The fuzzy controller is a good alternative to compared conventional controllers. Fuzzy system is a knowledge system which developed based on foundation of experience and practical skills. This controller consists of three parts: the fuzzy inference system, the basis of the rules and fuzzy reduction. Simulink models of diesel engines is developed by simulation tools and using relationships of mathematic. The Mandeni fuzzy controller was developed in Matlab which used to control the LPG flow and EGR following to the load of engine by fuzzy

inference system, the basis of rules and fuzzy reduction.

The study showed that fuzzy logic control system has many advanced features compared to conventional PID controller. The study shows a method to control LPG flow supply and exhaust gas recirculation flow through the EGR valve of a dual fuel engine when different load conditions to improve performance and emission characteristics of the dual fuel engine

2. FUZZY LOGIC CONTROL SYSTEM

The theoretical basis of fuzzy logic control mainly includes three parts. They are:

- The fuzzy inference system
- The basis of fuzzy logic rules
- Fuzzy reduction.

Fuzzy logic processed the input variable based on the rules. The rules are commands of function that is used to control system. These rules are fundamental creating fuzzy control system.

2.1. Fuzzy inference system

Fuzzy logic control system is the process of converting the input variable to control algorithm also known as member functions. In this study, loads of the dual fuel LPG – Diesel engine are considered as input parameter and fuzzed have 9 sections fuzzy shown in Figure 1.

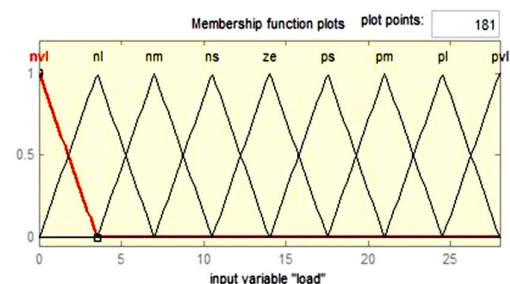


Figure 1. The membership function of input load signal

Similarly, we also have 9 membership functions for output variable to control LPG injectors and EGR valve shown in Figure 2.

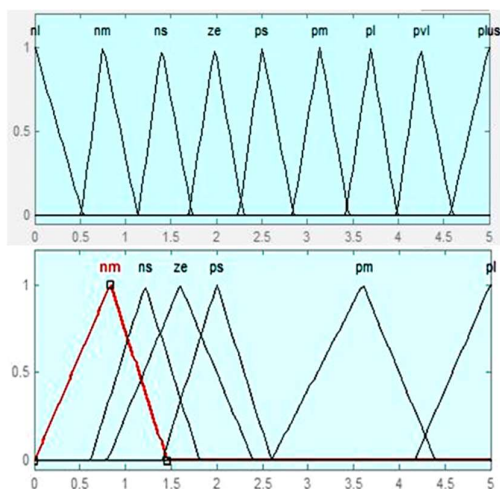


Figure 2. The membership function for output load signal to control of control LPG injectors and valve EGR

2.2. The basis of fuzzy logic rules

The rule is commands of the functions which are used to control the system. These rules are fundamental to make fuzzy control system. The rules of the system are shown in Figure 3.

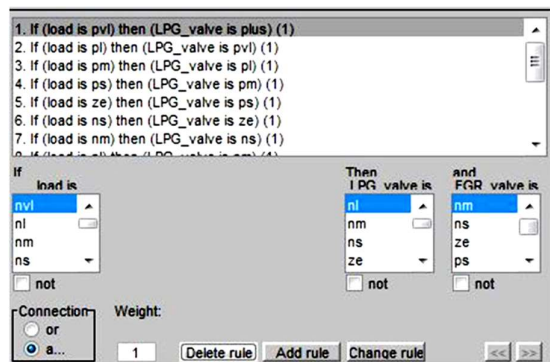


Figure 3. The window to import rules

A total of 25 rules are used for the control of the system. And these rules include almost all the load variations and control the output variables. Fuzzy Rule is designed by using MATLAB FIS toolbox and system inference is used fuzzy logic as follows.

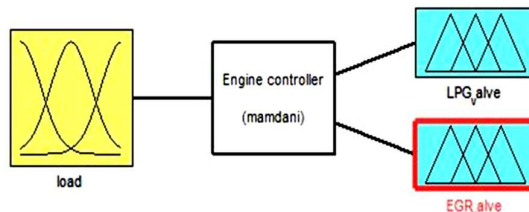


Figure 4. Fuzzy logic inference system

2.3. Fuzzy reduction

Reducing fuzzy is the last step of the process which is used convert membership functions back into the control data. Therefore, the control achieved higher performance.

3. MODEL CALCULATION AND SIMULATION OF ENGINE (LPG - DIESEL) USING FUZZY LOGIC SYSTEM

From the theoretical foundation of control Diesel engine by electronic, researchers have designed a control circuit dual fuel LPG - Diesel with application of fuzzy logic shown in Figure 5 [3].

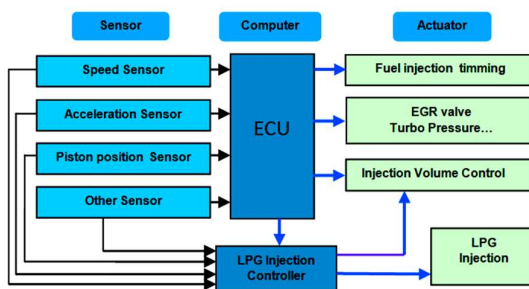


Figure 5. Diagram engine control systems for dual fuel LPG- Diesel

Fuzzy logic control system is possible control many system of engine as: fuel supply system, emission control system... A method of control fuzzy is proposed to limit air/fuel ratio in diesel engine. Fuzzy algorithm is being processed in the microcontroller to control the flow of LPG fuel and improved performance of dual - fuel engine. Fuzzy logic controller was controlled effective

operation of the output parameters compared to PID controller.

In addition, fuzzy logic controller is used to control emission by control EGR valve, it allow a part of the exhaust return manifold to reduce NOx emissions. And fuzzy logic control system using detonate sensor to check the intensity of detonation with reasonable level and guess performance of dual fuel engines (LPG – Diesel).

Control system based on fuzzy logic is used load as input parameters and position signals of EGR, LPG valve as output parameters. And these two variable will change when load change. Fuel flow is controlled by engine controller when load of engine change. A block diagram of the system is shown in Figure 6.

To study the characteristics of dual- fuel engines when load engine constant, mathematical models for diesel engines is performed as follow:

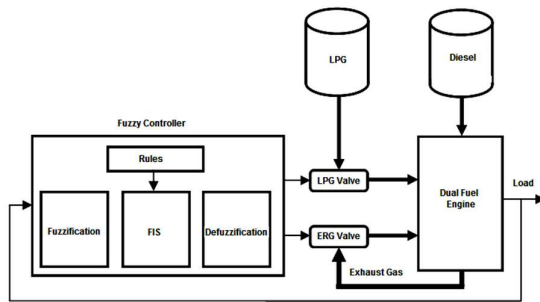


Figure 6. Diagram of the control system using fuzzy logic

3.1. The mass of air in the intake system

Manifold is a part where the throttle control intake air into the engine. The rate change of pressure on the intake manifold (P_m) is proportional with the rate of air mass in intake manifold (\dot{m}_θ) minus the rate of intake air mass ($\dot{m}_{\theta_{cyl}}$) in the cylinders. Using the formula (1) to describe the dynamics of the manifold as follows:

$$\frac{d(P_m)}{dt} = K_m (\dot{m}_\theta - \dot{m}_{cyl}) \text{ with } K_m = \frac{R \cdot T}{V_m} \quad (1)$$

Where: R: Private constant of gas;

T: temperature (K)

V_m : volume of manifold.

The rate of air through the intake manifold is a function which is relationship between the intake manifold pressure and engine speed, shown in equation 2.

$$\dot{m}_\theta = -0.366 + 0.08979NP - 0.0337NP^2 + 0.0001N^2P_m \quad (2)$$

Where: N: engine speed

P_m : intake manifold pressure

LPG alternative fuel by the method of energy balance and calculated following the formula (3)

$$\text{LPG alternative fuel} = \frac{\text{engine power} - \text{amount of diesel fuel} \cdot 43000}{46000} \quad (3)$$

3.2. Gas-air mixture in the intake manifold

The ratio mixture of LPG fuel and air through the manifold is a function of the relationship between angle throttle (engine load) and the pressure in the intake manifold

$$\dot{m}_\theta = f(\theta) g(P_m) \quad (4)$$

$$f(\theta) = 2.821 - 0.05231\theta + 0.1029\theta^2 - 0.00063\theta^3 \quad (5)$$

$$g(P_m) = \begin{cases} 1 & \text{if } P_m \leq P_o \\ \frac{2}{P_o} \sqrt{P_m P_o} - P_m & \text{if } P_m > P_o \end{cases}$$

3.3. Moment (T)

Torque is created by the self-combustion of diesel fuel forming flame to burn mixture of air and LPG, physical parameters is mentioned below:

$$T_{eng} = -181.3 + 379.36m_a + 21.91(A/F) - 0.85(A/F)^2 + 0.26\sigma - 0.0028\sigma^2 + 0.027N - 0.000107N^2 + 0.00048N\sigma + 2.55\sigma m_a - 0.05\sigma^2 m_c \quad (6)$$

σ : Ignition angle advanced; N: Engine speed;

m_c : Mass of circulation exhaust; A/F: Ratio of air/fuel

4. THE RESULTS OF SIMULATION AND COMMENT

The results of simulation applied the fuzzy controller by using Matlab Simulink model. A Simulink model of system is shown in Figure 7. This simulation using parameters

of the 3C - TE diesel engine which are controlled electronically. Engine speed is set at 1500 rpm and load condition various to compare performance with ratio alternative fuel LPG - Diesel (30% - 70%).

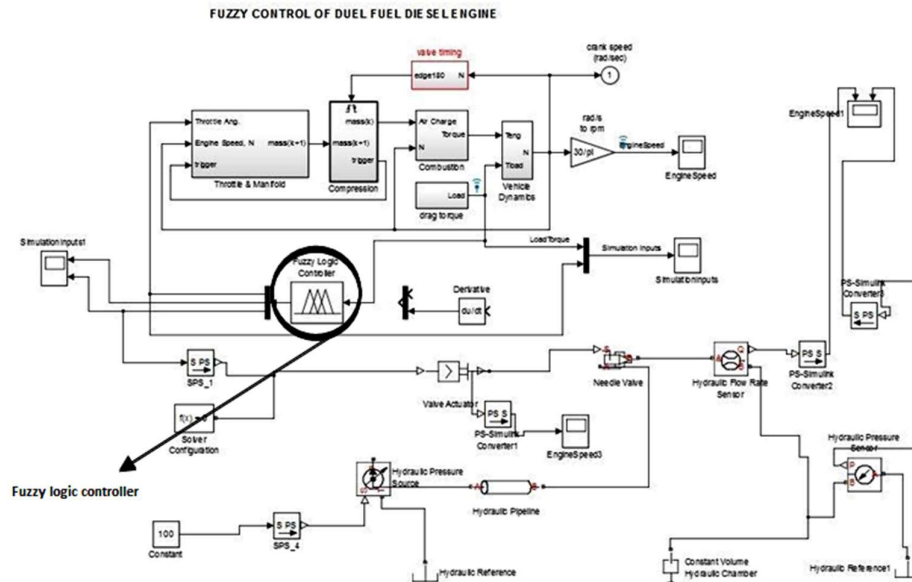


Figure 7. Diagram of simulation system with fuzzy logic control

Control model PID of similar system is shown in (Figure 8). This model, load signal is connected directly to the PID controller and it is adjusted as need. The adjustment will

change when the speed load condition various, then will stabilize with constant speed 1500 rpm after a short period of time

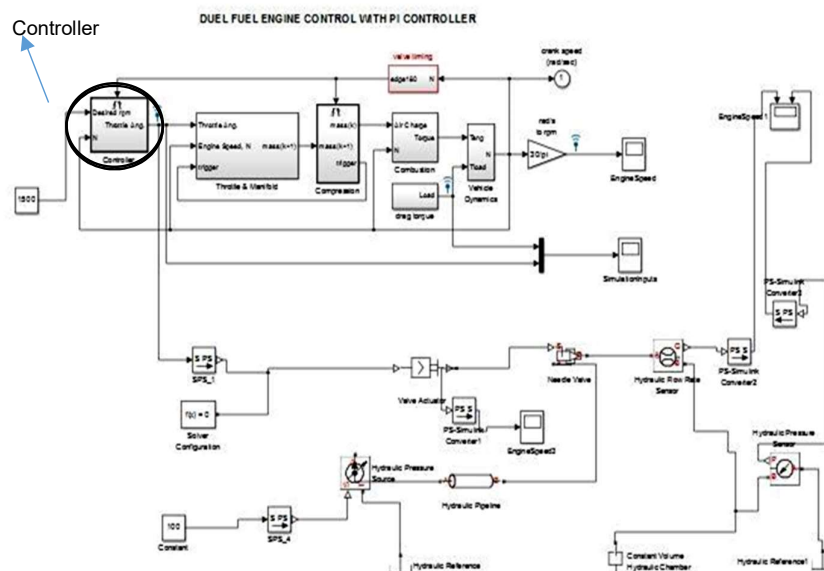


Figure 8. Diagram of simulation system with PID controller

During the process simulation, researchers have been the result of control LPG valve, EGR valve by using fuzzy logic and PID control system for the engine. Then the researchers have the following comments:

During the process simulation, changing engine load is proceed step by step at seconds the 2nd and 8th. Results of simulation have ability to control and the responses of the PID control system as follows:

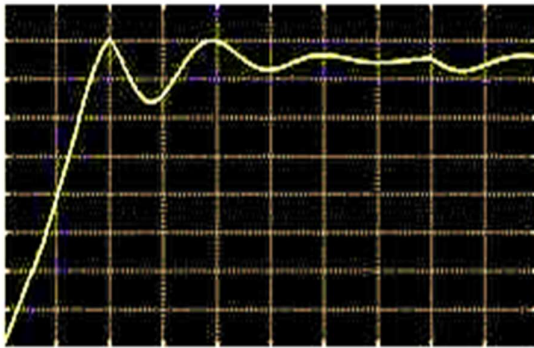


Figure 9a. The graph shows ability to responses the speed of the engine without fuzzy logic controller

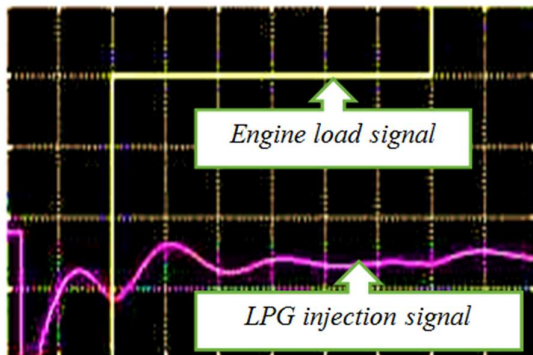


Figure 9b. Graph shows LPG injection signal and engine load signal without fuzzy logic controller

According to Figure 9a shows the ability to responses the engine speed when engine load increased that should take from 5 - 6 seconds to stabilize engine speed at 1500 rpm with conditions simulating.

According to Figure 9b shows the control signal of LPG injection is slower than change of engine load signal.

A traditional PID controller cannot provide control signal quickly with different load condition of the engine. The operation of the PID almost depends on the increase of the input signal and the constant time of the signal. On the other hands, control PID is a single processes because the parameter of system are chosen approximate with equal condition.

The same conditions with fuzzy logic control system shows it operate smoother and more stable compared to traditional PID controller, as shown below:

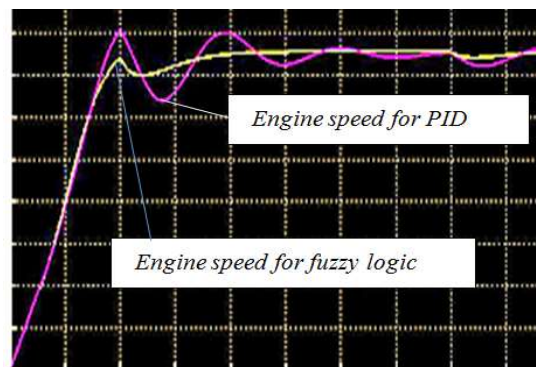


Figure 10a. The graph compares the ability to responses engine speed following controller

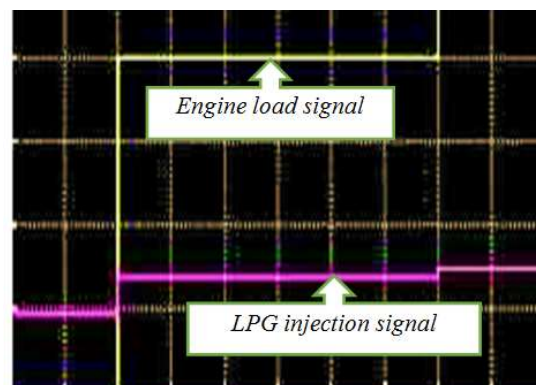


Figure 10b. Graphs shows LPG signal and load signal of engine with fuzzy logic controller

Figure 10b shows control signal for the LPG valve which responds rapidly at appear input signal and without delay time.

Similarly, control signal for the EGR valve is adjusted to change area of EGR valve at 2nd and 8th seconds following engine load signal as shows in figure 11.

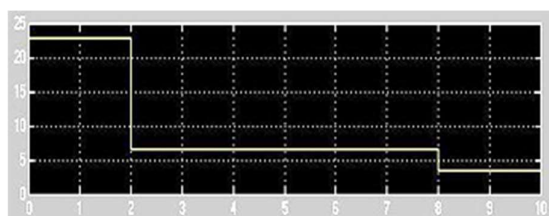


Figure 11. Control signal of EGR valve open following engine load

5. CONCLUSION

Responses and performance of fuzzy logic control system is better than conventional PID controller.

With PID controller cannot provide control signal to fast responses and exceed of minimum time following condition of engine load. PID control system adjust difficultly with complex systems and non-linear.

Therefore, research to apply fuzzy logic to control exhaust gas recirculation and fuel flow into the engine dual fuel (LPG - Diesel) is a new solution to control dual fuel engine.

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