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Fuzzy Logic Based Fuel Flow Control System in a Dual-Fuel Diesel Engine

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Abstract

Reducing emission from the engines is very difficult task these days since emission norms are becoming very strict on NO_x, HC, CO etc. Recently, duel fuel diesel engine which use Liquefied Petroleum Gas (LPG) and diesel fuel is widely employed for better emission control and fuel efficiency. Proposed system uses a Fuzzy logic approach to control the LPG flow into the engine and diesel as a pilot fuel. Also, Exhaust Gas Recirculation (EGR) system will reduce the NO_x content in the exhaust gas. Both EGR and LPG are controlled by a fuzzy control system to improve the performance of the dual fuel engine.

Keywords: Dual Fuel Engines, Flow Control, Fuzzy Logic

1. Introduction

With new emission regulations and a renewed push for clean technologies, dual fuel diesel engines finds many applications including irrigation, power generation, and transportation. In a typical dual fuel engine, part of the diesel fuel is substituted with Liquid Propane Gas [LPG], which results in cost savings and improved emissions through better combustion. Control of fuel supply plays a major role in determining the performance and emission characteristics of the dual fuel engine. Commonly, electrically operated solenoid valves are used to shut off the fuel flow to the cylinder for proper scavenging during intake and exhaust valve overlap. Under the variations of load conditions, a control system is required to provide an actuating signal to position the fuel valve to the appropriate position to admit the proper amount of fuel.

Many research works have been carried out on the development of fuel flow control system in internal combustion engines. Control approaches using Proportional Integral Derivative (PID) exhibits large overshoot and dip in transient responses which cause poor performance and emission. The tuning process of such control system, in fact, is a tedious task sometimes reaching to desire operating conditions would be impossible. Also design of PID controllers is very difficult for nonlinear system especially in engine controls.

A Multivariable Sliding Mode Control (SMC) is implemented for the control of air path in diesel-dual-fuel engine and the reduction of overshoot is observed as the control performance. Recently, fuzzy logic based control system were implemented in many other engine subsystem which includes fuel injection system, emission control system, etc. Fuzzy logic control system is applied to SI engine to control the fuel injection by taking engine speed and MAP as input values[2,3] and[4]. An adaptive fuzzy control approach is proposed to constrain the air fuel ratio in SI engines[5]. Fuzzy algorithm is implemented in microcontroller to control the flow of fuels in bi fuel engine for enhanced engine efficiency[6]. Fuzzy logic controller gives reduction in overshoot in output and time of accommodation as compared to PID controller[7].

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Fuzzy logic controllers can also be used for emission control. EGR (Exhaust Gas Recirculation) is a technique used for reducing emissions by recirculating a portion of exhaust gas back to the engine intake. Due to improper combustion NOx, HC, CO etc. gases would be present in the exhaust gas. EGR technique will reduce emissions considerably. At high loads EGR quantity is less and vice versa. A novel control system based on fuzzy logic is presented to regulate knock intensity at an appropriate level and predict the performance of dual fuel engines[8,9].

It is observed that most of the work shows fuzzy logic controller superiority over conventional PID controllers in terms of easiness of implementation, response and performance. This work presents a fuzzy logic control approach to control the fuel flow as well as the exhaust gas flow in exhaust gas recirculation EGR of a dual fuel engine under varying load condition, for improving the fuel efficiency as well as to ensure the better emission characteristics.

2. Proposed Fuzzy Logic Based Control System Design

Proposed Fuzzy Logic Control System takes load as input parameter and the control signals for the position of LPG valve and EGR valve is considered as output parameters. Based on the variations in the load conditions, the two output variables would change. Diesel flow is controlled by the governor in the engine for the given load conditions. The block diagram for such a system is shown in the Figure1.

Development of fuzzy logic inference system basically contains the following steps such as fuzzification, rule formation and de fuzzification and it is explained in the following sub sections:

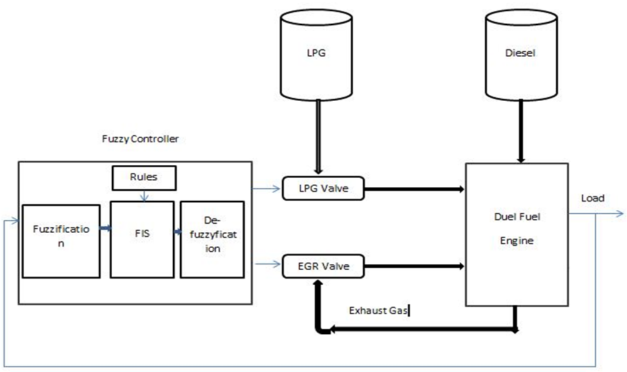

Figure 1. Block diagram of the proposed system.

2.1 Fuzzification

Fuzzification is the process of converting input variables into linguistic terms also known as membership functions. In the present work, load applied on the dual fuel engine is considered as the input parameter and fuzzified it to 9 fuzzy sets : Negative very large (nvl), Negative large (nl), Negative medium (nm), Negative small (ns), Zero (ze), Positive very large (nvl), Positive large (nl), Positive medium (nm), Positive small (ns) as shown in the Figure 2.

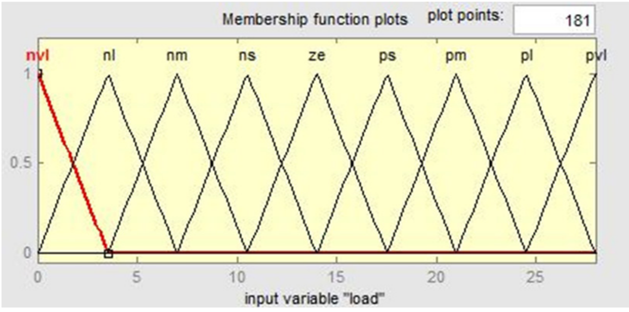

Figure 2. Membership function for input load.

Similarly, there are nine membership functions for the output variables LPG and EGR valve control signals are given below in Figure 3 and Figure 4. In the proposed system, LPG flow and EGR flow is controlled by a solenoid control valve with a signal range from 0 volts to 5 volts.

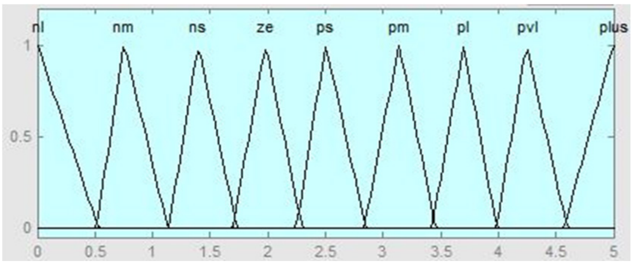

Figure 3. Membership function for LPG valve control.

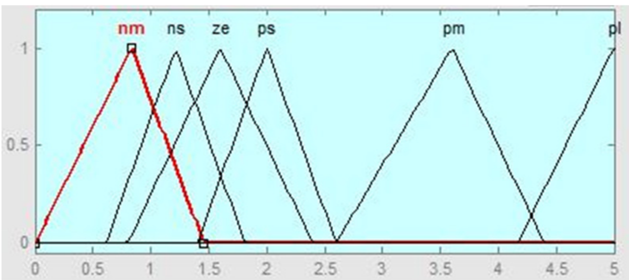

Figure 4. Membership function for EGR valve control.

2.2 Rule Formation

Rules are the set of instructions used to control the system. These rules are the basis of any fuzzy control system and are created with at most care. Rules for the proposed system are shown in Figure 5.

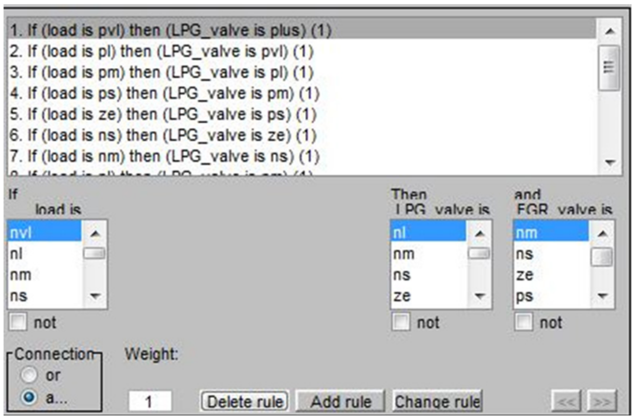

Figure 5. Rule editor.

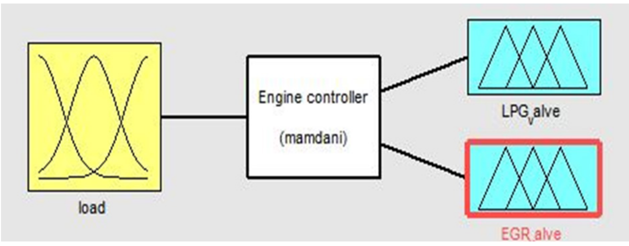

Figure 6. Fuzzy Inference System.

2.3 Defuzzification

Defuzzification is last step in the fuzzy operation is to convert back the membership functions to numerical values, So that control can be achieved with better performance.

3. Mathematical Model for Diesel Engine

In order to study the flow characteristics of a dual fuel engine for the given load conditions, a mathematical model for the diesel engine is developed and it is described in this section.

3.1 Mass Air flow Rate in Intake Manifold

The manifold is modeled as a single volume where throttle plate control the mass air flow into the manifold. The rate of change of the manifold pressure (P_m) is proportional to the mass air flow rate into the manifold ($\dot{m}_\theta$) minus the pumping mass air flow rate ($\dot{m}_{cyl}$) into the cylinders. A first order differential equation can be used to describe the manifold dynamics as shown in Equation (1).

$$\frac{d(Pm)}{dt} = K_m(\dot{m}_\theta - \dot{m}_{cyl}) \text{ where } K_m = \frac{R.T}{Vm} \qquad (1)$$

Where R is the specific gas constant, T is the temperature (K) and V_m is the manifold volume.

Mass flow rate through the intake manifold is the function of manifold pressure and engine speed which is represented in Equation (2).

$$\dot{m}_f = -0.366 + 0.08979NP - 0.0337NP_m^{\,2} + 0.0001N^2Pm \qquad (2)$$

N = speed of the engine

P_m = manifold pressure

3.2 Mass of LPG and Diesel Quantity

The LPG quantity for 70% load (3.08Kw) is calculated using equation 6 and were tabulated in Table1

$$amount\ of\ lpg = \frac{power - diesel\ quantity \times 43000}{46000} \qquad (3)$$

Table 1. Fuel quantity for 70% of the load

% Diesel	% LPG	LPG Quantity	Diesel Quantity
100	0	0.000000	1.031100
90	10	0.096385	0.927990
80	20	0.192771	0.824880
70	30	0.289156	0.721770
60	40	0.385542	0.618660
50	50	0.481927	0.515550
40	60	0.578313	0.412440
30	70	0.674698	0.309330
20	80	0.771083	0.206220
10	90	0.867469	0.103110
0	100	0.963854	0.000000

3.3 Manifold Air fuel Mixture Through Throttle

Manifold air fuel mixture through the throttle body is the function of the throttle angle and the manifold pressure.

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

$$f(\theta)=2.821-0.05231\theta+0.10299\theta^2-0.00063\theta^3 \quad (5)$$

$$g(P_m)=\begin{cases} 1 & \textit{if } \mathrm{Pm} \leq \mathrm{Po} \\ \frac{2}{Po}\sqrt{PmPo - \mathrm{Pm2}} & \textit{if } \mathrm{Pm} > Po \end{cases}$$

3.4 Torque Generation

Torque generated by the engine for the ignition of the charge, mixture formation and engine specific 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 = degree of spark advance, N = Engine speed
m_c = exhaust gas recirculation A/F= Air to fuel ratio

The intake air is allowed to get heated in order to obtain an optimal temperature for proper combustion. The entire operation is controlled by a fuzzy controller in which rules are formed based on the practical values. Simulink model of engine is incorporated with a fuzzy control for the fuel flow control system and it is shown in Figure 7.

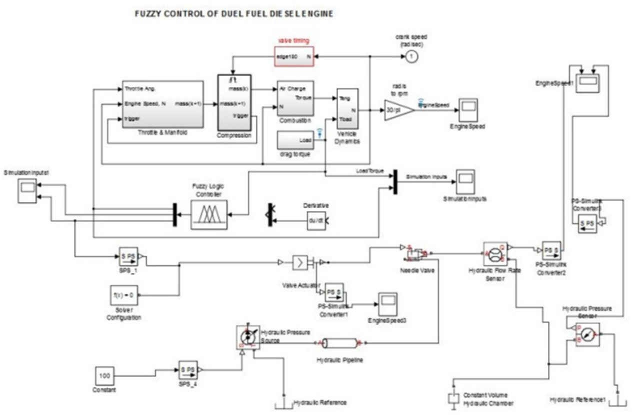

Figure 7. Simulink model with fuzzy controller.

4. Simulation Results and Discussion

In the present work, a simulation study was performed for constant speed (1500 rpm) direct injection diesel engine rated at 4.3 KW. In this section, the simulation results of the proposed fuzzy controller is presented and compared with PI controller using Simulink model. The performance of the proposed control system with the fuzzy logic controller is analyzed for the throttle valve control signal.

4.1 Control Signals for LPG and EGR Valve

Load is increased in a step manner at simulation time 2 sec and 8 sec. Figure 8 shows the valve control signal with the step input applied as load for a PID controller.

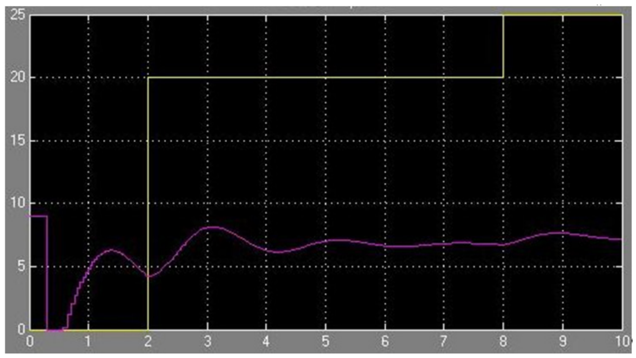

Figure 8. Valve control signal (Pink) and applied load (yellow) using PID controller.

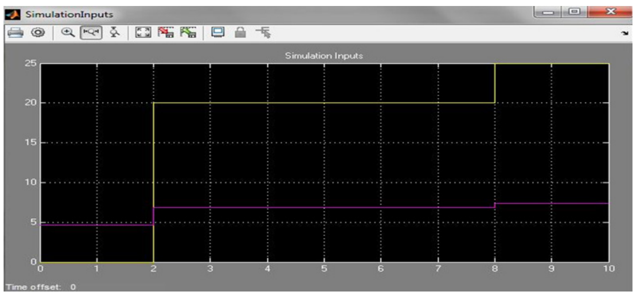

Figure 9(a). LPG valve and Load vs. time characteristics.

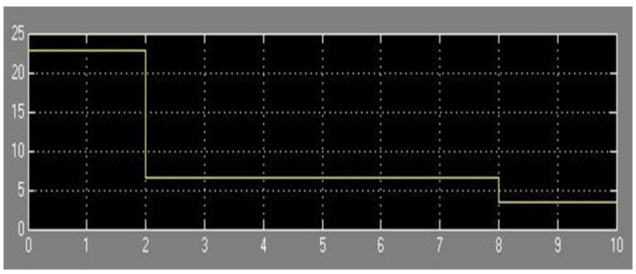

Figure 9(b). EGR valve signal v/s time.

Figure 9. Valve control signal (Pink) and applied load (yellow) using proposed fuzzy controller

It is found that the control signal of the valve have more transients which causes instability in the system.

Figure 9(a) shows the control signal for the LPG valve which follows the quickly input signal without any delay. Similarly, control signal for the EGR valve is also changes its magnitude at 2sec and 8sec respectively.

4.2 Speed Characteristics of the Engine

In order to analyze the speed characteristics, load of the engine is increased as a step function at simulation time 2 sec and 8 sec. Figure10 shows the speed characteristics of the engine for the PI and fuzzy controller.

It is found that there are a more variations in the speed due to change in load conditions for the PI controller but it settles to constant speed after a longer interval of time as compared to the proposed fuzzy controller. Also, tuning of the PID controller is a tedious process because chosen system constants should close to the balanced conditions.

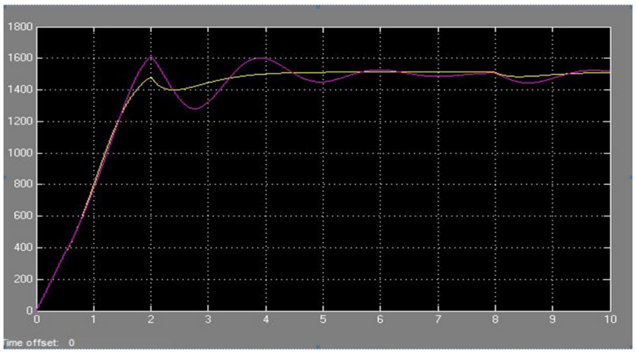

Figure 10. Speed Vs Time characteristics of fuzzy (yellow) and PI (pink) controller.

These simulation results prove the smooth and stable operation of the engine with the proposed fuzzy control system.

5. Conclusion

In the present work, duel fuel engine model is realized using MATLAB Simulink tool box and fuzzy inference is created in fuzzy tool box. It is used for simulating the LPG fuel flow and EGR control for various load conditions. From the simulation results, it is found that the proposed fuzzy control system gives a better performance compared to the conventional PI controller. A traditional PI controller cannot give a faster response with minimum overshoot and undershoot for varying load conditions. PI tuning is difficult processes for complex and non-linear systems, in such a situations, proposed fuzzy control system find a better solution.

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