Fuzzy Logic Controller for the Speed Control of an IC Engine using Matlab \ Simulink

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Abstract— the use of graphical dynamic system simulation software is becoming more popular as engines try to reduce the time to develop new control system. Dynamic system simulation software is an important tool and developing advanced reliable and high quality products and systems. This paper explains about one of the a tool MATLAB/SIMULINK used and the study of system dynamics of a four stroke IC engine which will give clear idea about speed control of IC engine using fuzzy logic. A Fuzzy Logic controller is thereby developed to control the speed of the IC Engine with variable load conditions.

Index Terms— internal combustion(IC) engine, fuzzy logic controller. Matlab /simulink.

I. INTRODUCTION

The purpose of the project is to design a legitimate engine control unit so that, it may be introduced to an electricity generator and there by stabilize the system output to generate the expected amount of power. The internal combustion (IC) engine is designed to produce power from the energy that is contained in its fuel. More specifically, its fuel contains chemical energy and together with air, this mixture is burned to output mechanical power. There are various types of fuels which can be used in IC engines namely; petroleum, diesel bio-fuels, and hydrogen [1]. Modeling of an entire IC engine is a very important and complicated process because engines are nonlinear, multi inputs-multi outputs (MIMO) and time variant. There have been several engine controller designs over the past 40 years in which the goal is to improve the efficiency and exhaust emissions of the automotive engine.

The fuzzy logic control provides an algorithm, which can convert linguistic control strategy derived from expert knowledge of the system into an automatic control strategy. Such a linguistic approach can have lots of benefits in applications where the mathematical model of the system is unknown or there are great uncertainties and complexities in the system. Implementations using fuzzy logic controllers can work well without having to construct any mathematical model of the system. Fuzzy logic control yields results superior to those using conventional control algorithms and their applications can also lead to reduced development cost. In many cases, fuzzy control can be used to improve existing controller systems by adding an extra layer of intelligence to the current control method.

Section I, serves as an introduction. Section II, introduces the system model description. Section III analyzes the proposed controller details. Section IV describes the simution of the model and their result analysis and the final section is describing the conclusion.

II. SYSTEM MODEL DESCRIPTION

Mathematical modeling of a system is a way of describing the entire system in terms of mathematical concept and language. A mathematical model may help the user to explain the functioning of the system and their by help in predicting the behavior of the system. . In general, mathematical models may include logical models, as far as logic is taken as a part of mathematics. In this section, the modeling of internal combustion engine is presented.

A. Internal Combustion Engine Model:

This paper demonstrates Simulink capabilities to model an internal combustion engine from the throttle to the crankshaft output. The ensuing sections (listed below) analyze the key elements of the engine model that were identified by Crossley and Cook [2]:

1) Throttle
2) Intake manifold
3) Mass flow rate
4) Compression stroke
5) Torque generation and acceleration

Throttle:

The first element of the model is the throttle body. The control input is the angle of the throttle plate. The rate at which the model introduces air into the intake manifold, m_{ai} can be expressed as the product of two functions - one, an empirical function of the throttle plate angle, θ only; and the other, a function of the atmospheric and manifold pressures, *Pm*. In cases of lower manifold pressure (greater vacuum), the flow rate through the throttle body is sonic and is only a function of the throttle angle. This model accounts for the low pressure behavior with a switching condition in the compressibility equations shown below.

$$m_{ai} = f(\theta).g(P_m) \qquad ..... (1)$$

$$f(\theta)=2.821-0.05231\theta+0.10299\theta^2-0.000630\theta3 \qquad ..... (2)$$

$$g(P_m)=1, \quad \text{if } P_m \leq \frac{P_{amb}}{2}. \qquad ..... (3)$$

$$g(P_m)=\frac{2}{P_{amb}}\sqrt{P_m P_{amb} - P_m^2}\ ; \text{ if } \frac{P_{amb}}{2} \leq P_m \leq P_{amb} ..(4)$$

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$$g(P_m)=-\frac{2}{P_{amb}}\sqrt{P_m P_{amb}-P_m^2}\ ;\text{if } P_{amb} \leq P_m \leq 2P_{amb}.(5)$$

$$g(P_m)=1,\quad \text{if}\ \ P_m \geq 2P_{amb}. \qquad ..... (6)$$

Where, θ →throttle angle (deg),

m_{ai}→flow rate into manifold (g/s) where,

P_m → manifold pressure (bar);

P_{amb} →ambient (atmospheric) pressure (bar);

Intake Manifold:

The simulation models the intake manifold as a differential equation for the manifold pressure. The difference in the incoming and outgoing mass flow rates represents the net rate of change of air mass with respect to time. This quantity, according to the ideal gas law, is proportional to the time derivative of the manifold pressure, $\dot{P_m}$ (see Equation 7). This model doesn't incorporate exhaust gas recirculation (EGR), although this can easily be added.

$$\dot{P}_m=\frac{RT}{V_m}(\dot{m}_{ai}-\dot{m}_{ao}) \qquad .... (7)$$

Where, R=specific gas constant, T= temperature (K), V_m= manifold volume (m^3), $\dot{m}_{ai}$= mass flow rate of air out of the manifold (g/s) $\dot{P}_m$=rate of change of manifold pressure (bar/s), the mass rate, $\dot{m}_{ai}$ is a function of the manifold pressure and the engine speed.

Intake Mass Flow Rate:

The mass flow rate of air that the model pumps into the cylinders from the manifold is described in Equation 8 by an empirically derived equation. This mass rate is a function of the manifold pressure and the engine speed.

$$\dot{m}_{ai}=-0.366+0.08979NP-0.0337NP_m^2+0.0001N^2P_m \qquad .... (8)$$

Where, N=Engine angular speed (rad/s), Pm=Manifold pressure (bar).

Torque Generation and Acceleration:

The final element of the simulation describes the torque developed by the engine. An empirical relationship dependent upon the mass of the air charge (m_a), the air/fuel mixture ratio (A/F), the spark advance (σ), and the engine speed (N) is used for the engine torque, (T_{eng}) computation.

$$T_{eng}= - 181.3 + 379.36ma + 21.91(A/F)$$
$$= 0:85(A/F)^2 + 0:26\sigma - 0:0028\sigma^2 + 0:027N - 0.000107N^2 + 0:00048N\sigma + 2.55\ \sigma m_a - 0.05\sigma^2 m_{a.}$$

Where m_a→ mass of air in cylinder for combustion (g); $\left(\frac{A}{F}\right)$→ Air to fuel ratio; σ→ Spark advance (degrees before top – dead - center); $Torque_{eng}$ → torque produced by the engine (Nm);

The engine angular acceleration is calculated using Equation

$$J\dot{N}=T_{eng}-T_{load}.$$

III. PROPOSED CONTROLLER

Fuzzy logic is a form of many-valued logic or probabilistic logic; it deals with reasoning that is approximate rather than fixed and exact. Compared to traditional binary sets (where variables may take on true or false values) fuzzy logic variables may have a truth value that ranges in degree between 0 and 1. Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false. Furthermore, when linguistic variables are used, these degrees may be managed by specific functions.

FLC contains three basic parts: Fuzzification, Base rule, and Defuzzification. FLC has two inputs which are: error and the change in error, and one output. The Fuzzy Controller structure is represented in fig.1. The role of each block is the following:

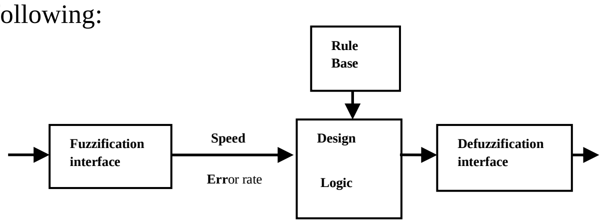

Fig.1: The general structure of Fuzzy Logic Controller

- Fuzzification Interface converts the input values (e; De) into linguistic terms of the input fuzzy variables (Speed error, Error rate), with a correspondent certainty value.
- The Rule base is defined by the rules for the desired relationship between the input and output variables in terms of the membership functions illustrated in Table I. The control rules are evaluated by an inference mechanism, and represented as a set of:

IF Error is ... and Change of Error is ... THEN the output will ….

For example: Rule1: IF Error is NS and Change of Error is ZE THEN the output is NS.

The linguistic variables used are:

NVL: Negative very large, NL: Negative large NM: Negative Medium, NS: Negative Small, ZE: Zero, PS: Positive Small, PM: Positive Medium, PL: Positive large, PVL: positive very large.

- the Decision Logic block applies the fuzzy rules to the input fuzzy variables to obtain the output values (Throttle angle),
- the Defuzzification Interface achieves output signals (θ_T) based on the output fuzzy sets obtained as the result of fuzzy reasoning.

Table 1: Control Rule Base for Fuzzy Controller.

DE Er	NVL	NL	NM	NS	ZE	PS	PM	PL	PVL
NVL	NVL	NVL	NVL	NVL	NL	NL	NM	NS	ZE
NL	NVL	NVL	NVL	NL	NL	NM	NS	ZE	PS
NM	NVL	NVL	NL	NL	NM	NS	ZE	PS	PM
NS	NVL	NL	NL	NM	NS	ZE	PS	PM	PL

ZE	NL	NL	NM	NS	ZE	PS	PM	PL	PL
PS	NL	NM	NS	ZE	PS	PM	PL	PL	PVL
PM	NM	NS	ZE	PS	PM	PL	PL	PVL	PVL
PL	NS	ZE	PS	PM	PL	PL	PVL	PVL	PVL
PVL	ZE	PS	PM	PL	PL	PVL	PVL	PVL	PVL

For designing the controller, there are nine membership functions for the inputs: error(Er) and derivative of error (DE). These membership functions are shown in Figs. 2 and 3. The output of controller is the throttle angle of the IC Engine.

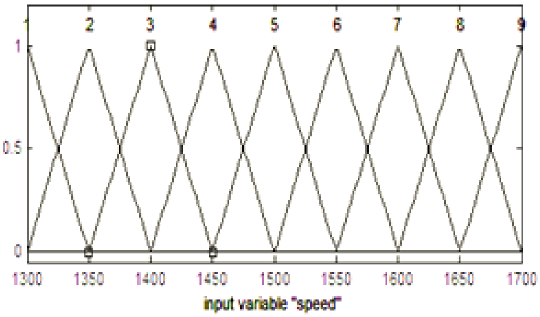

Fig.2: Membership functions of error in speed.

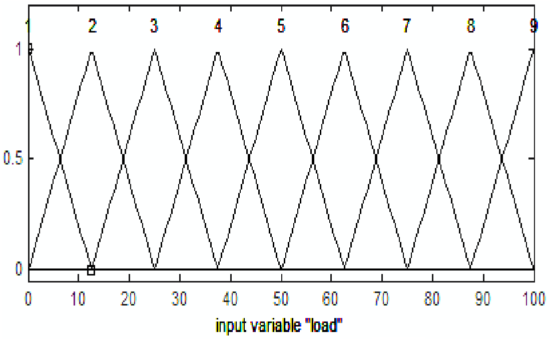

Fig.3: Membership functions of derivative of error in load.

IV. SIMULATION RESULTS AND ANALYSIS

The principle by which an engine can be controlled may be mainly classified into two types i.e. open loop and closed loop. Both of these have their own pros and cons.

A. Open Loop Simulation of the Engine:

The simulation of the engine lacking a feedback from output to input is given in the Fig 3. The open loop system provides us with accurate output to the mentioned inputs. Here we are introducing a varying load and throttle angle to the system.

In the open loop operation of the IC Engine, the engine speed is varying according to the throttle valve openings. But if there is any variation in the load torque, it affects the speed of the ICE. So if load is varying the engine speed will also vary. To incorporate these load variation one speed controller is needed. . Hence we design a closed loop controller which tracks the reference engine speed even when the load varies. The output of which is show in figure 6. Even though the closed loop controller can maintain the engine speed around the required value, it does not hold good for a large change in the load. Hence we introduce fuzzy logic into the controller,

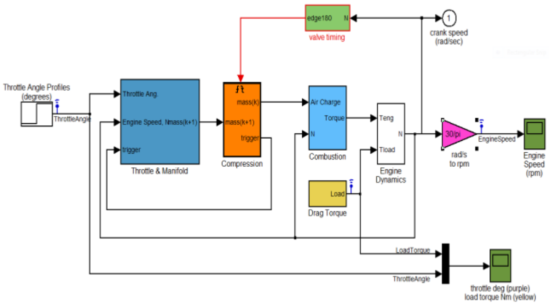

fig.4: Open loop model of IC engine.

B. Closed Loop Simulation of the Engine:

In the closed loop system shown in Fig.5 a feedback controller is employed that takes samples of speed (rpm) manipulates it to meet the requirements and then feeds it to the throttle valve (in degrees) given by Equation,

Throttle angle $\theta = 18.86 - \left(\left(\left(N_{rpm}\right) - 1500\right) \cdot 0.0215\right)$, where N_{rpm} → Engine speed in rpm;

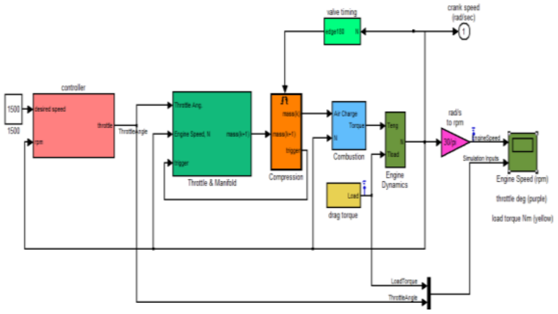

Fig.5: Closed loop model of IC engine.

The closed loop system has the ability to stabilize itself for a range of inputs. However the normal feedback controller takes certain time to come up with the variation in the input. The system relates its present output with the previous output, each time it generates a new sample. Initially and whenever there is a variation in load, there is an abrupt rate of change of speed, which can damage the whole system. Thus, for controlling the speed of the ICE, a Fuzzy controller is developed. This Fuzzy controller gives a better control action except for some rapid variations of the load torque and disturbances. Closed loop model with fuzzy logic controller model of IC engine as shown in figure.6.

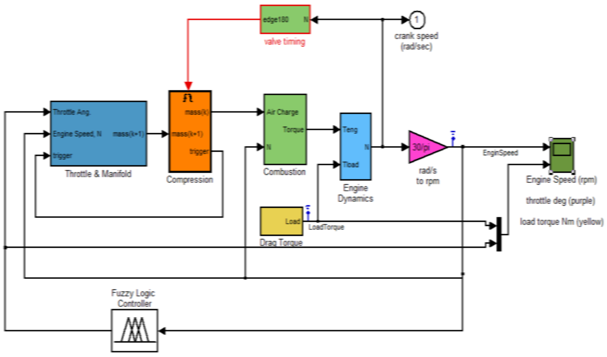

Fig.6: closed loop with fuzzy logic controller model of IC engine.

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C. RESULT AND ANALYSIS:

The introduction of a varying load to the open loop system gives us a huge variation in the speed in RPM .This variation is overcome by the closed loop controller. The figure 7 shows the load introduced to the closed loop system whose output is shown in fig 5. In spite of the huge variation of the load introduced to the system the closed loop controller manages to stabilize the speed of the system within an interval of 5sec

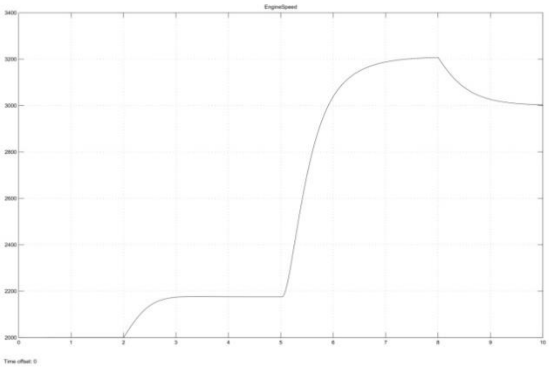

fig.6: Engine speed (rpm) Vs time (sec) response for Open loop model of IC engine.

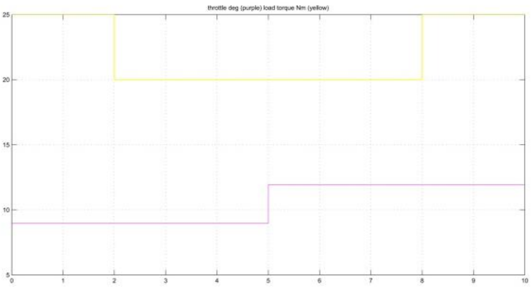

fig.7: Load and throttle angle inputs for open loop model of IC engine.

To obtain a smooth or stable speed, the controller is incorporated with fuzzy logic. The load applied to the system is shown in fig.9 and the result is shown in fig.8. It is clear from the result that after implementing fuzzy logic we get a smoother as well as stable curve. Result of closed loop with fuzzy logic controller model as shown in fig.10.

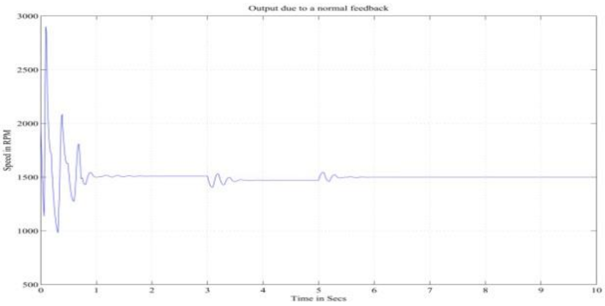

fig.8: Engine speed (rpm) Vs time (sec) response for closed loop model of IC engine.

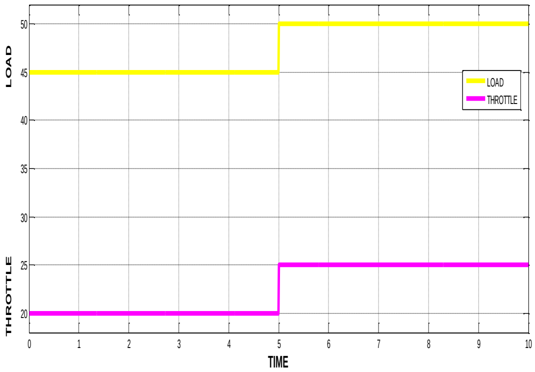

fig.9: Variation of the load torque applied to the controlled engine model

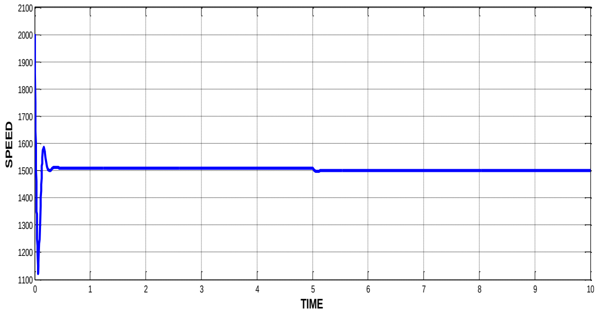

fig.10: Engine speed (rpm) Vs time (sec) response for closed loop with fuzzy logic controller model.

IV. CONCLUSIONS

A mathematical model of the IC Engine is realized using MATLAB and a fuzzy controller is used to control its speed when subjected to various load torque conditions. Although the fuzzy controller performs well for the majority of the test cases.

In terms of stability the closed loop implementation outruns the stability of open loop implementation. Since it requires a large interval to stabilize itself, fuzzy logic controller is implemented. From the figures and plots obtained by simulation, it is clear that implementing fuzzy logic in the modeling of the engine improved the functioning.

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