Fuzzy Controller for Controlling Speed of Hybrid Electric Vehicle

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Abstract - *Hybrid Electric Vehicles (HEVs) are becoming popular because of the advantages they provide. The popularity can also be attributed to increased emphasis on fuel economy and reduced emissions. The fuzzy logic controller (FLC) is gaining popularity as it provides better performance than the conventional PI controller. The FLC helps the HEVs to achieve good fuel economy and performance with reduced emissions. FLC is also useful modelling non-linear process in contrast to the conventional linear PI controller.*

Key Words: Hybrid Electric Vehicle, Fuzzy Logic, Fuzzy Controller, classical PI controller, Fuzzy Scheduled PI controller

1.INTRODUCTION

Due to increase in global warming and environmental pollution newer norms have been adopted to decrease the above-mentioned effects. HEVs have been developed and are gaining popularity because of the newer norms which stress on more fuel economy and reduced emissions. HEVs are vehicles with a conventional internal combustion engine (ICE) and an electric propulsion system. They combine the advantages of Electric Vehicles (EVs) and Internal Combustion Engine Vehicles (ICEVs).

HEVs are of three types based on their drivetrain: series, parallel, series/parallel and complex HEV (Power Split).[1]

In series hybrid vehicles, only the electric motor drives the wheels. The engine charges the battery which in turn drives the electric motor.

In parallel hybrid vehicles, there are two sources of power which drives the wheels. The two sources of power are the battery which drives the electric motor and the ICE.

In series/parallel hybrid vehicles, the benefits of series hybrid vehicles and parallel hybrid vehicles are combined. The power from the ICE is split using a power split device into a mechanical and electrical transmission path.

In power-split hybrid vehicle, an ICE is mechanically linked to two electric machines using a power split device (usually a planetary gear set). A fraction of the engine power is converted into electrical energy by one electrical machine and the excess power is used to drive the wheels.

A HEV requires a controller to control various parameters of a HEV. Some of the parameters that are controlled in a HEV are engine speed, engine torque and to maintain battery power.

Two of the controllers that are used in HEVs are: Proportional-Integral (PI) and Fuzzy Logic Controller (FLC). The FLC is a controller which provides an algorithm which can convert the linguistic based control strategy into an automatic control strategy. Many simulations have showed that the FLC is superior to the conventional control strategy such as the PI control strategy end of the paper.[2]

2. Speed Control of HEV

Generator Control of Desired Engine Speed: -

The desired speed in a power split HEV using generator control is done by controlling the generator torque. As the power split HEV uses a planetary gear system we can use the equations for planetary gear system to calculate a generator speed which is related to the desired vehicle speed. Generally, a PI controller is used to achieve the calculated generator speed and uses a generator torque as the feedback.[3]

Engine speed control based on battery power: -

Desired HV battery power is calculated using the by monitoring the state of charge (SOC). This desired HV battery power is used in a PI controller loop. It is added to the power requested by the driver. Using this PI controller, the engine power is determined to achieve the desired engine speed and engine torque.[4]

3 . Operation of Power Split HEV.

In a Power Split HEV two electrical machines are present: a motor and a generator. It combines the advantages and attributes of the parallel and series HEV. The system uses a power split device to split the power from the engine along two paths: one to generator and the other part goes to the gear system to the drive wheels. The power split device that the system uses is usually a planetary gear system. A part of the engine power is converted by one electric machine into electrical energy, the excess power being transmitted to the drive wheel, in parallel with the second electric machine power.

The ICE combined with the two electrical machines and planetary gear system results in an overall behavior of a continuous variable transmission (CVT). Therefore, the power split HEV is said to have a electric continuous variable transmission (ECVT).

4. Fuzzy Control

Operation of Fuzzy Controller

Fuzzy logic controller is an application of fuzzy set theory. Fuzzy sets are an extension of classical set theory. It allows an element to be partial member of a set i.e., an element has varying degrees of membership in the set. It contrasts with the crisp set (or classical set theory) where the elements are complete members of the set.

The values of degrees of membership can vary from 0 to 1. In crisp set the degrees of membership can only be 0 or 1. The fuzziness of fuzzy logic is described by using the membership function.

The FLC contains the following components: a fuzzifier, a knowledge base, a decision-making logic, and a DE fuzzifier.

1.Fuzzifier: The fuzzifier measures the input and scales it accordingly and converts the input to fuzzy values.

2.Knowledge Base: It stores the knowledge of the relationship between the inputs and outputs. It also has the fuzzy membership function which defines the input variables to the fuzzy rule base and the output variables to the plant under control.

3.Decision-making Logic: It simulates the human decision-making using the fuzzy set rules and can infer fuzzy control actions.

4.Defuzzification in: DE fuzzifier converts the fuzzy value into crisp values.

Operation of Fuzzy Control in HEV

In HEVs, usually a classical PI controller is used. But using a fuzzy controller is much more beneficial than using a classical PI controller. In HEVs, the desired power is obtained by adding the desired HV battery feedback power and the desired engine feedforward power. The fuzzy controller is unintuitive. To decrease this unintuitive nature a fuzzy scheduled PI controller was utilized. The fuzzy controller is formulated as follows: -

$$P(n) = \beta_f(n) K_p e(n)$$

$$I(n) = \sum_{i=1}^{n} \beta_f(n) K_i e(i) T_s$$

$$u(n) = P(n) + I(n)$$

This formulation is of the fuzzy scheduled PI controller with proportional gain of $\beta_f K_p$ and integral gain of $\beta_f K_i$. Here e the error between the desired HV battery power and actual HV battery power. T_s is the sampling time. The inputs are defined as follows: -

$$x_1(n) = |e(n)| = |P_{batt\_des}(n) - P_{batt\_act}(n)|$$

$$x_2(n) = |r(n)| = \left|\frac{d}{dt} e(n)\right| \approx \left|\frac{e(n) - e(n-1)}{T_s}\right|$$

$$x_3(n) = |\Delta\omega(n)| = |\omega_{eng\_targ}(n) - \omega_{eng\_act}(n)|$$

where, P_{batt_act} is the actual battery power and P_{batt_des} is the desired HV battery power. ω_{eng_targ} is the target engine speed and ω_{eng_act} is the actual engine speed. The rules of the fuzzy are decided such that they can distinguish between the HEV powertrain conditions and make appropriate decisions based on current and future conditions of the powertrain.

5. Comparison of Pi and Fuzzy Controller

The fuzzy controller eliminates the overshoot without compromising the settling time and rise time.

•The overshoot in the classical PI controller results in an unintuitive behavior for the driver as the overshoot is not expected by the driver as the output for the driver's input. This can lead to accidents if not handled correctly.

•The fuzzy gain scheduling PI controller has a very short rise time but the classical PI controller with such fast rise time and settling time leads to overshoot.

•The fuzzy scheduled PI controller achieves improved behavior by controlling the response in a non-linear manner.

•The fuzzy controller is better at handling non-linear responses as compared to the classical PI controller.

•The classical PI controller can windup and result in undesired behavior. In contrast to the PI controller, the fuzzy scheduled PI controller provides significant reduction in windup.

6. CONCLUSION

Fuzzy logic controllers have succeeded in many control problems that the conventional control theories have difficulties to deal with. By the help of FLC we can update control parameters on each cycle or in each gain. By the help of fuzzy controller, we can improve the controlling gain and increase the efficiency of speed control in better form.

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