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A Review on Performance of Dc- Dc Buck Converter Using Conventional and Self Tuning Fuzzy PID Controller

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Abstract— In this paper, digital proportional–integral–derivative (PID)-type and fuzzy- PID controllers are compared for application to the buck and boost dc–dc converters. Design of fuzzy controllers is based on heuristic knowledge of converter behaviour, and tuning requires some expertise to minimize unproductive trial and error. For the buck converter, the performance of the Fuzzy PID controller was superior in some respects to that of the conventional PID controllers. The fuzzy controller was able to achieve faster transient response in most tests, had a more stable steady-state response, and was more robust under some operating conditions. In the case of the buck converter, the fuzzy PID controller and conventional PID controller yielded comparable performances, where it is found that the maximum overshoot has reduced from 82.1% to 70% for open loop & 6.5% for closed-loop.

Keywords— Buck converter, Dc-Dc converter, PID controller, Fuzzy PID controller.

I. INTRODUCTION

Usually power electronic systems consist of one or more power converters which convert one form and/or level of electrical energy into another form or level of electrical energy at the load. The advances and availability of modern power semiconductor devices used in power converters have made the switching converter a popular choice in power supplies. Since the early 1970s, a large number of DC-DC converter circuits have been thoroughly analyzed and designed. Such a converter can increase or decrease the magnitude of the DC voltage and/or invert its polarity.

The Buck converter which uses the switch in series with the supply voltage is a topology that gives a lower voltage at the load. In contrast, in the topology known as the Boost converter, the positions of the switch and inductor are interchanged, which allows this converter to produce an output DC voltage that is greater in magnitude than the input voltage. In the Buck-Boost converter, the switch alternately connects the inductor across the power input and output voltages. This converter inverts the polarity of the voltage and can either increase or decrease the voltage magnitude.[2]

With the revolution of power semiconductor devices power electronics converters have been widely used in various areas. Dc-Dc Converter is widely used for traction motor in electric automobiles, trolley cars, marine hoists, and forklift trucks. They provide smooth acceleration control, high efficiency, and fast dynamic response. General idea of dc-dc converter is to convert a fixed voltage dc source into a variable voltage dc source. One of the key difficulties in control of non-inverting buck-boost topology is the smooth transition from buck to boost operation or boost to buck operation, depending on the input/output voltage relationship. Design and implementation of a control system require the use of efficient techniques that provide simple and practical solution in order to fulfil the performance requirement despite the system disturbances and uncertainties. The occurrence of nonlinear phenomena in DC-DC power converter makes their analysis and control difficult. Classical linear techniques have stability limitations around the operating points. Hence digital and nonlinear stabilizing control methods must be applied to ensure large-signal stability [1].

Fuzzy system can be considered a type of nonlinear function interpolator which was introduced for controlling variable structure systems. Its major advantages are the guaranteed stability and the robustness against parameter, line and load uncertainties. The fuzzy controller is relatively easy to implement as compared with other type of nonlinear controllers. Such properties make it highly suitable for control application in nonlinear system such as DC-DC converter [1].The fuzzy controller uses simple linguistic rules to achieve the control objective without involving the converter's mathematical models. Its major advantage is that expert knowledge can regulate the output voltage of the switching DC–DC Buck boost converter.

PID control is typically designed for one nominal operating point, but a dc–dc converter's small signal model changes with variations in the operating point .For a buck converter, the magnitude of the frequency response depends on the duty cycle. Duty cycle variations do not change the shape of the magnitude plot of the transfer function, but only shift the plot upward or downward [3]. Fuzzy controllers can be designed to adapt to the nonlinear property of buck converters under varying operating points. Linear PID control and fuzzy control are compared in the aspect of design and implementation issues[4]. In this paper, PID control and fuzzy PID control are compared in the aspects of design, implementation, and performance.

II. Linear PID Control For A Buck Converter

A PID controller was designed for the buck converter to improve the loop gain, crossover frequency, and phase margin. One zero was placed an octave below the cut-off frequency (approximately 260 rad/s) and the other one at 4.6 × 103 rad/s. The transfer function of the PID controller is given by [4]

$$G_c(s) = 0.5786 + \frac{142.4}{s} + 1.19 \times 10^{-4} s \qquad (1)$$

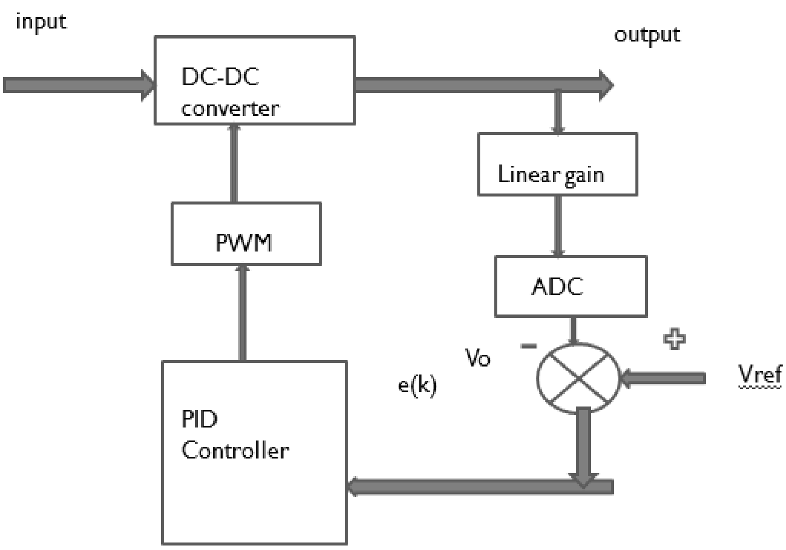

Fig.1 Block diagram of PID controlled Buck converter

The Bode plot for the compensated system is shown in Fig. 2. As shown in this plot, the gain at low frequency is high, the phase margin is 107◦ at a gain crossover frequency approximately 3 kHz. A PI controller was also designed for the buck converter to reduce steady-state oscillation. One pole was placed at the origin, and one zero was placed at 800 rad/s. The dc gain of the controller was adjusted to obtain sufficient phase margin and high crossover frequency. The transfer function of the PI controller is given by $Gc(s) = 0.75 + 600/s$ The Bode plot for the PI compensated system is shown in Fig. 2 and shows that the phase margin is 15.4◦ at gain crossover frequency approximately 1.7 kHz

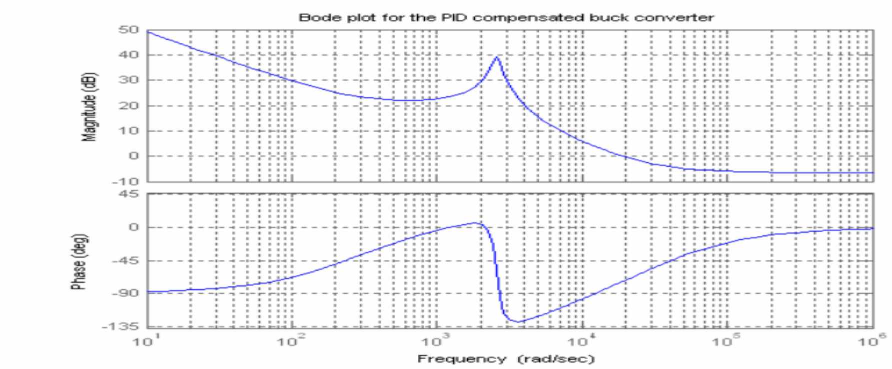

Fig 2. Bodeplot of PID controller compensated buck converter

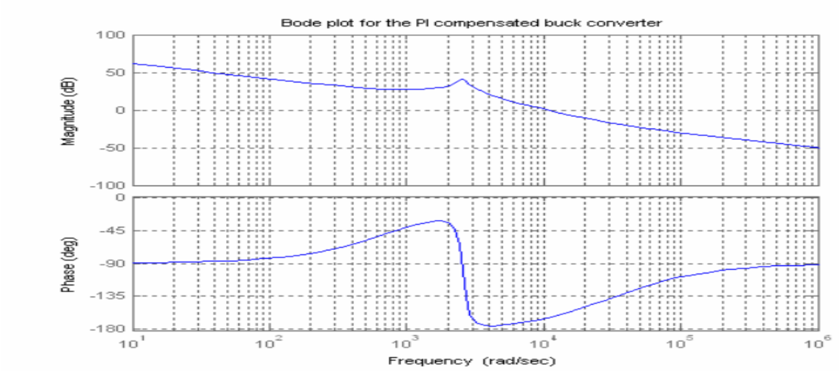

Fig3. Bodeplot of PI controller compensated buck converter

A. Operation Principle

Figure 4 shows a new multi-loop digitally controlled dc-dc converter. In this figure, and are the dc input voltage, load resistance and output voltage, respectively. L and C are the reactor and output smoothing capacitor. The controller senses the output voltage, output current and input voltage. The output current is detected as the voltage by a sensing resistor. Addition to above notations represents the desired output voltage of the presented circuit. In this case, is equal to the reference voltage. Furthermore, is the digital value of the reference voltage for digital controllers [5].

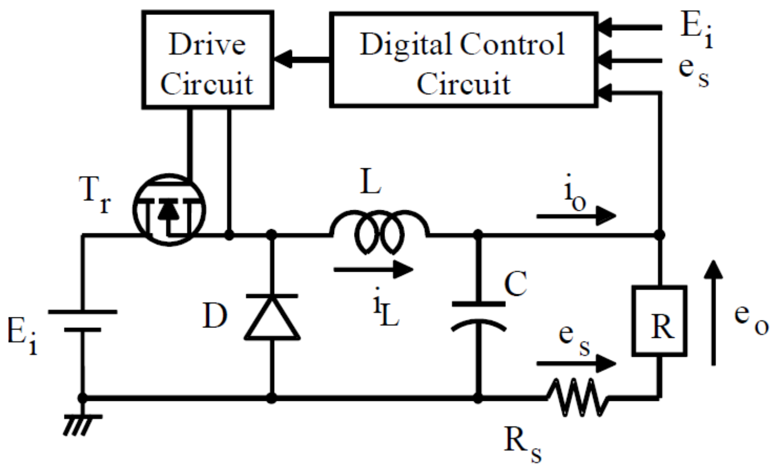

Fig 4. Basic configuration of the presented digitally controlled dc-dc converter

It is noticed that, in the following of this paper, the suffix *n* denotes the *n*-th period T_s
of the switching period.

The on-time switching interval $T_{on,n}$ in the drive circuit is obtained from following equation.

$$T_{on,n} = \left(\frac{N_{T_{on,n}}}{N_{Ts}}\right).Ts \qquad (2)$$

Here $N_{T_{on,n}}$ is digitally the calculated value of $T_{on,n}$ the by the digital control circuit and N_{Ts} is the digital value of Ts.Therefore, the purpose of the controller is to obtain the optimal value of $N_{T_{on}}$ [5]

B. Conventional P-I-D control

The P-I-D control is one of the widely used methods for the control of dc-dc converter. The P-I-D control is a feedback control and it works to reduce the error of the output value. So it always contains the time-delay about the change of the system.

In the P, I and D controllers of the presented circuit, the output voltage of dc-dc converter is input to the A-D converter through a preamplifier circuit, and converted to the . This is sent to the P-I-D controller. The controller term with the P-I-D controller is described as following;

$$N_{T_{on,n}} = -N_{T_{on_c,n}} + N_B \qquad (3)$$

Here is the bias term which is a fixed value to drive the circuit with the feedback control and is the term of P-I-D controller. This $N_{T_{on_c,n}}$ is calculated by the following equation.

$$N_{T_{on_c,n}} = K_P\left(N_{eo,n-1} - N_R\right) + K_1 \sum N_{I,n-1} + K_D N_{D,n-1} \qquad (4)$$

In Eq. (4), is obtained from following equation.

$$N_{eo,n-1} = A_{eo} \cdot G_{eo} \cdot e_{o,n-1} \qquad (5)$$

In this conversion equation, and are gains of the pre-amplifier and the A-D converter which sense the output voltage. On the left side of Eq. (4), the first term is the P element of the P-I-D controller. Here is the proportional coefficient. The second term is the I element where is also multiplied by the integral coefficient. The third term is the D element where is multiplied by the differential coefficient .In this case, the integration interval is the predetermined value in the I-control and corresponds to the desired output voltage of the dc-dc converter.

C. Transient Response

In this section, simulated and experimental results of transient responses are shown for the evaluation of the presented method. The simulator used here is PSIM. The switching frequency in all simulations and experiments is 100 kHz. The circuit parameters are =20V, =5V, *L*=192H, *C*=940F, *r*=0.12Ω, =0.25, =50, = 0.125, = 400, = 400, and = 400 respectively. The bit number of A-D converter is 11 bits. These parameter settings are same among all following simulations and experiments.

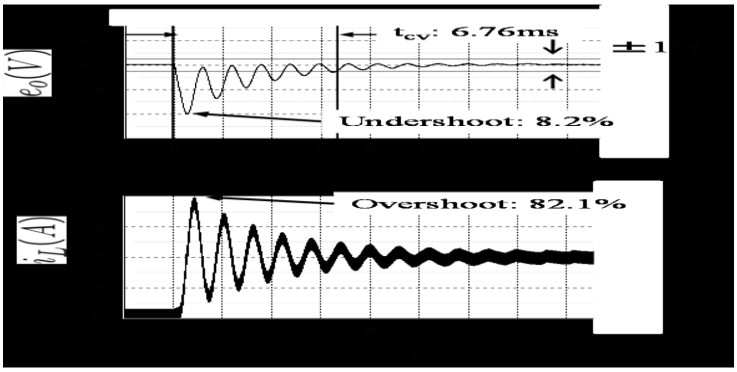

Fig.5.Simulation result of undershoot of output voltage and overshoot of reactor current with P-I-D control

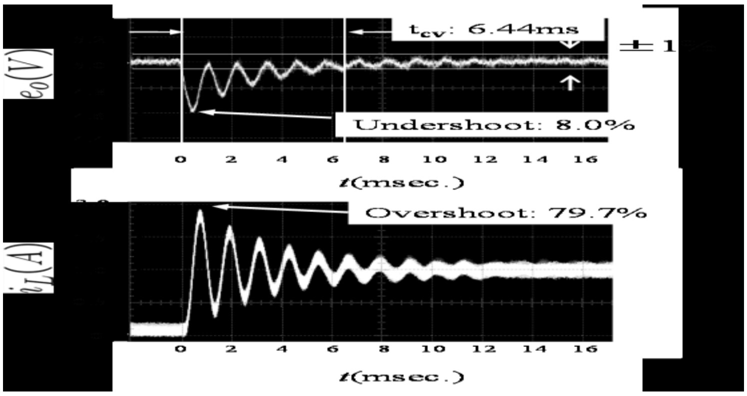

Fig.6. Experimental result of undershoot of output voltage and overshoot of reactor current with P-I-D control

III. DESIGN OF SELF-TUNING FUZZY PID CONTROLLER

The intent of this study is to design a self-tuning fuzzy PID controller so that a further improved system response performance in both the transient and steady states have been achieved as compared to the system response obtained when either the classical PID or the fuzzy controller has been implemented. Here the fuzzy controller is used to tune the parameter Kp, Ki and Kd of the PID controller. Simulations are performed on Matlab Simulink to illustrate the efficiency of the proposed method[1].

A. Simulated Model of Buck Converter

Simulated model of buck converter using Matlab Simulink is shown in Figure 1. It consist of 12 V input DC supply, GTO (gate turn on thyristor) as a switch, PWM (Pulse width modulator) generator for providing switching pulses to GTO. The capacitance C is 220 μF, L is 20 μH and RL is 2 Ω. The parasitic elements RC and RL are estimated to be 30 mΩ and 10 mΩ, respectively [4]. The desired output from this converter is 2 V DC.

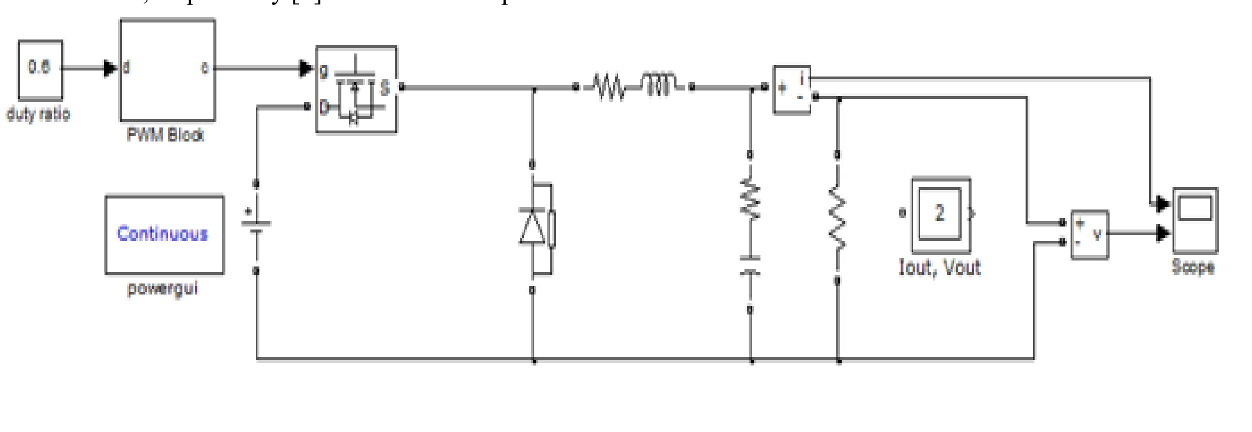

Fig.5. Simulink Model of Buck Converter

B. Overview of Fuzzy PID Controller

Fuzzy PID controllers in literature can be classified into three major categories as direct action type, fuzzy gain scheduling type, and hybrid type fuzzy PID controllers .The direct action type can also be classified into three categories according to number of inputs as single input, double input, and triple input direct action fuzzy PID controllers. The classification of fuzzy PID controllers can be seen in Figure 2

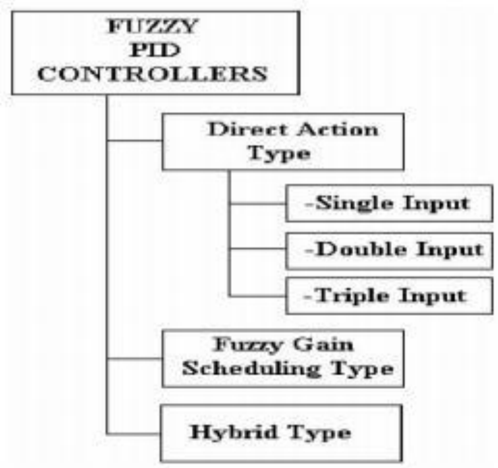

Fig. 6 Classification of fuzzy PID controller

C. Self Tuning Fuzzy PID Controller

The proposed controller that is given in Figure 4 is the modified version of the single input fuzzy PID controller. It possesses two main parts: the classical PID and fuzzy controllers. A standard PID controller is also known as the “three-term” controller, whose transfer function is generally written in the “ideal form” as where Kp is the proportional gain, Ki the integral gain, Kd the derivative gain. The ‘’three-terms’’ functionality are highlighted by the following:

1) The proportional term is providing an overall control action proportional to the error signal through the all-pass gain factor
2) The integral term is reducing steady-state errors through low-frequency compensation by an integrator
3) The derivative term is improving transient response through high-frequency compensation

In this paper the fuzzy controller will be used to tune the parameter Kp, Ki and Kd of the PID controller, based on certain function of the actuating error signal.

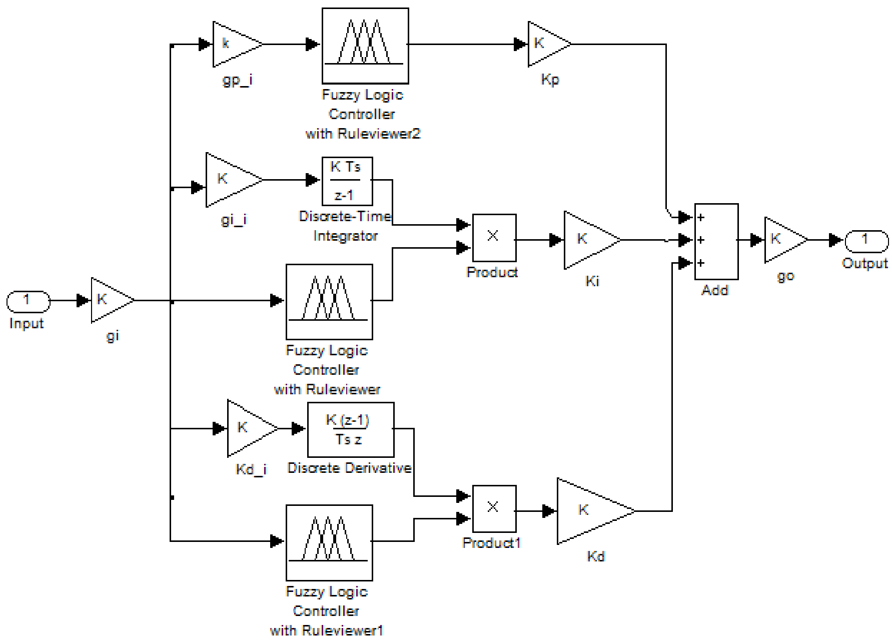

Fig.7 Simulink Model of Self-tuning FPID Controller

D. Controller Development

In this section a self-tuning fuzzy PID controller is developed. The FPID controller consists of three parallel fuzzy sub controllers, namely, fuzzy-based proportional, integral, and derivative controllers. These independent controllers are grouped together to form an intelligent self-tuning fuzzy PID controller. The FPID controller can account for nonlinearity and adaptable to varying operating condition.

Output Scaling

Output scaling allows the output of the FPID controller to be adjusted so it has the appropriate amplitude when applied to the DPWM of the buck converter. The FPID controller output is bounded in the universe of discourse between [-1, 1]. The change in duty cycle control ratio of the DPWM is bounded between [-D, 1-D], therefore the output gain must be selected such that VoFPIDgo ϵ [-D, 1-D], since Vo FPID=a, it is already bounded between [-D, 1-D] and g0=1.

IV. SIMULATION RESULTS

Simulation results of buck converter are presented in this section. The Matlab Simulink is used to test the transient and steady-state response of the system to various disturbances from the source and load side. The simulation results are used to compare the open-loop response of the system with the compensated closed-loop response of the system.

Response to 12 V DC Power Source

The response of the open-loop system and the system compensated by a fuzzy logic PID controller for a 12 V DC power source can be seen in Figure 5. Both responses have zero steady-state error since the initial condition of the duty-cycle, D is 0.2891, is chosen so that is met. The open-loop response has a maximum overshoot of 70 percent while the closed-loop response has a maximum overshoot of 6.5 percent. In addition, the settling time has been reduced from 2.75 msec to 1.10 msec. However, the rise time has been increased from 0.2 msec to 0.6 msec[1].

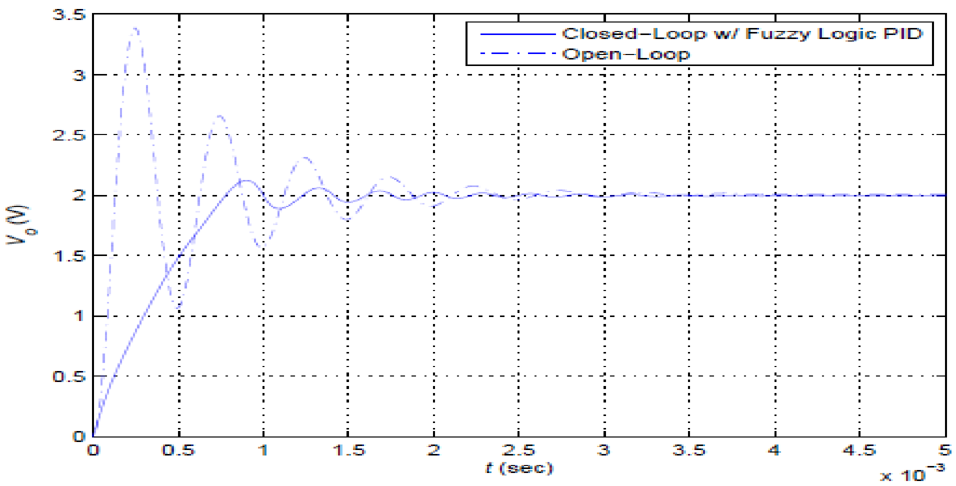

Fig.8 Time Response of Open-loop and Closed-loop System to 12 V DC Power Source

V. CONCLUSION

This paper discusses the performance of buck converter over conventional PID controller and the self tuning fuzzy PID controller. From the results were showing in above can be concluded that the fuzzy logic PID controller is much better in overall performance and term including rise time, peak time, settling time and robustness as compared to linear PID controller. After evaluating the performance of Fuzzy PID controller, it is concluded that this controller gives quicker response than the PID controller and the system settles at 1.10 msec. And the maximum overshoot is decreased from 82.2% to 70% for open loop response.

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