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FUZZY LOGIC CONTROL BASED PID CONTROLLER FOR STEP DOWN DC-DC POWER CONVERTER

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ABSTRACT

Power converters are vital part of many devices. Intelligent control for such a vital part is a high priority task. The paper describes about the implementation of standalone fuzzy logic controller and self-tuning fuzzy logic based PID controller in order to control a step down power converter. The software has been developed to simulate the real time situation based on the fuzzy logic technology. Simulation results of the fuzzy logic controller are shown for two intelligent control methods, a fuzzy logic control and self-tuning fuzzy PID reveal better performances than the PID conventional controller.

KEYWORDS: Fuzzy logic, controller, power converter, membership functions.

INTRODUCTION

DC-DC converters are used to provide power to DC load [5], which in turn is coming from a DC source. These circuits can be part of different devices, for instance computer power supplies, chargers for batteries and many other devices. Quality of control for DC-DC converter is a serious issue under line and load disturbance, because of the variance of input parameters such as current and voltage. A well-known technology named switch based DC to DC converter has been discussed by many researchers. Switching power supplies offer high efficiency than linear power supplies. This method for designing control for a power converter using equivalent resistors in series is based on linear theory [4].Thus the power switch was the key to practical switching regulators. The main idea is to limit the current slew rate through the power switch, otherwise action limits the high peak current that would be limited by switch resistance alone. However, still lots of academic research is going on to develop intelligent control for step-down DC-DC converters. Averaging state space model is considered to be a standard for modelling such systems. However to overcome the issues generated due to the hybrid nature of a system, average continues time model is the solution [1, 2]. With the development of control theory, the concept of nonlinear control is introduced to develop much more sophisticated control mechanisms. The introduction of such sophisticated control will perform well and robustly in closed loop systems [7]. Because of complexity involved due to switching characteristics, DC-DC converters are categorized as nonlinear systems. Many nonlinear mechanisms such as PID controller [8], Sliding Mode Controller [6], and fuzzy controller [3] are developed in last decades.

This topic focuses on applying a fuzzy logic controller (FLC) based PID controller in order to control a step down power converter, and investigate its effectiveness. Moreover, system performance is compared with conventional PID control and standalone Fuzzy logic controller.

This paper has been organized as follows. Section II presents explanation about the logic about the working of converter, section III give details of how to design a fuzzy logic controller and self-tuning fuzzy PID for step down DC-DC power converter. Section IV presents about the discussion of results. Finally, some conclusions are performed in section V.

DC-DC CONVERTER

A general controller procedure for switching regulator is shown in Figure 1.

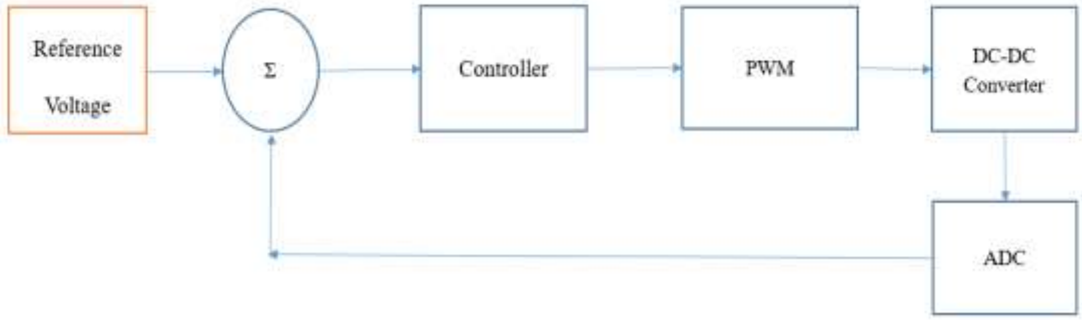


Figure 1: A General Controller for DC-DC Converter

Power controller is a circuit that used a power switch, an inductor, and a diode to transfer energy from input to output. The circuit diagram for DC-DC power converter control circuit can be seen in Figure 2.

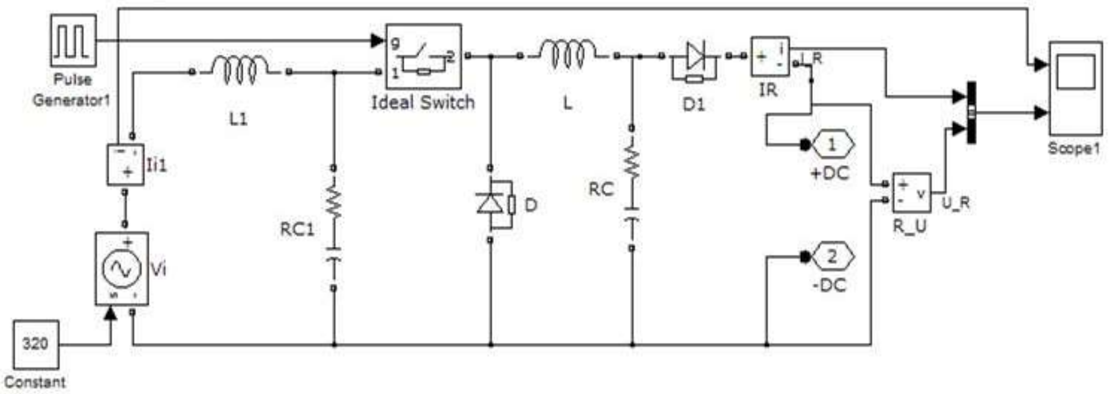


Figure 2: DC-DC to power converter control circuit

In switching regulators, to limit the current slew rate is through inductor, and the key advantage of using is it stores energy, which increases during on time and decreases during the off state. The energy stored in inductor L can be formulated by

$$\mathrm{E} = \frac{1}{2}\mathrm{L}.\mathrm{i}_\mathrm{L}^2 \tag{1}$$

- ***Charged Phase:***

When the switch is closed, current through inductor rises linearly and voltage across the inductor is $v_L = v_i - v_0$. No current flows through it as diode is reverse-biased by the voltage source V .

- ***Discharge Phase**:*

When the switch is opened, current i_L decreases and voltage across the inductor is $\mathrm{v_L} = -\mathrm{v_0}$ Moreover, the diode is forward biased. The rate of change of i_L can be computed using

$$V_L = L\frac{di_L}{dt} \tag{2}$$

With the two states: during on-state V_L equal to $V_i - V_0$, during the off-state V_L equal to $-V_0$.

Thus the change in current during the on-state where current increase and off state where current decrease are given by

$$\Delta i_{Lon} = \frac{(v_i - v_0)}{L} t_{on} \quad \text{and} \quad \Delta i_{Loff} = \frac{-v_0}{L} t_{off} \tag{3}$$

where $t_{on} = DT$ and $t_{off} = (1-D)T$, duty cycle $D\forall(0,1)$.

- ***Steady state operating phase***:

The average voltage across the inductor over the entire switching cycle is zero indicating steady stage of inductor, an important rule to govern switching topologies. The energy stored in each component doesn't vary till end of a commutation cycle T. Moreover, current i_L doesn't vary from t = 0 to t = T. So the resulting duty cycle is $D = \frac{V_0}{V_i}$ which cannot be more than 1 because of the equal ratio between t_{on} and time period T.

PROPOSED METHODOLOGY

Fuzzy logic is a method of reasoning that resembles human reasoning. The approach imitates the way of decision making in humans that involves all intermediate possibilities between digital values YES and NO. Fuzzy Logic (FL) is useful though it may not give accurate reasoning, but acceptable reasoning. The architecture of the FL is divided in to parts, module which transfer the system inputs in to fuzzy sets. Another module which stores IF-THEN rules provided by the use. An interference engine which simulates the human reasoning process by fuzzy inference on the inputs and IF-THEN rules. Another module called defuzzification which transforms the fuzzy set obtained by the interference engine in to a crisp value. The membership function work on fuzzy sets of variables. Membership function allow you to quantify linguistic term and represent a fuzzy set graphically. Simple membership functions can be used as complex functions does not add more precision in the output. The triangular membership function shapes are most common among various other membership functions shapes such as trapezoidal, singleton, and Gaussian. Mathematical concepts within fuzzy reasoning are very simple.

- You can modify a FLS by just adding or deleting rules due to flexibility of fuzzy logic.
- Fuzzy logic Systems can take imprecise, distorted, noisy input information.
- FLSs are easy to construct and understand.
- Fuzzy logic is a solution to complex problems in all fields of life, including medicine, as it resembles human reasoning and decision making.

A proportional integral derivative controller (PID Controller) is control loop feedback mechanism commonly used in industrial control systems. A PID controller continuously calculates an error value as the difference between a desired set point and a measured process variable and applies a correction based on proportional (K_p), integral (K_i), and derivative(K_d) terms respectively.

(i) Fuzzy Logic Controller:

Step 1: Define linguistic variables and terms

To design the system we took the initial parameters v_i = 10 v, v_{o_ref} =5v, L = 0.5mH, C = 0.5 mF. Voltage sources = {very low, low, normal, high, very high}

Step 2: Construct membership functions for them

In this section, the FLC is designed systematically to control the buck converter. The designed FLC has two input signals that are the error speed (E) and the derivation of error speed (DE). Using such input signals, FLC generates one output that is duty cycle of power converter. Figure 3, Figure 4, and Figure 5 shows the membership function for input variable E, DE and output duty cycle V_o respectively.

Step 3: Construct knowledge base rules

Create a matrix of target values and the expected values, which will be further applied to construct the IF-THEN-ELSE rules. Table 1 displays the set of constructed knowledge based rules constructed.

Due to one input signal containing five variables, therefore the fuzzy rule has 25 rules totally. Figure 6 displays the rules in 3-D view.

Step 4: Obtain fuzzy value

Fuzzy set operation perform evaluation of rules. The operations used for OR and AND are Max and Min respectively. Combine all results of evaluation to forma final result. The result is fuzzy value.

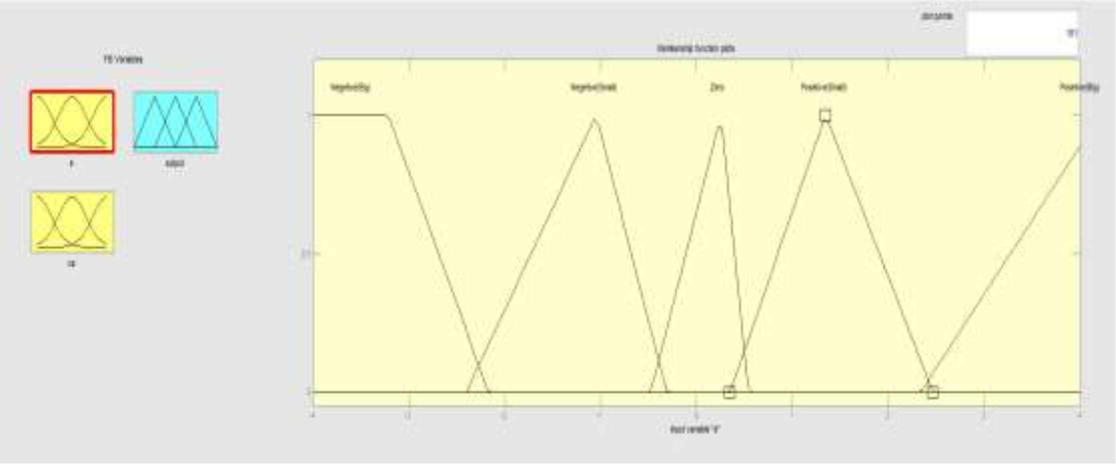
Step 5: Perform defuzzification

It is performed according to membership function for output variable.

Note: To unify the input and output value of the FLC, the value of E and DE are multiplied by the gain 100.0 and 0.01

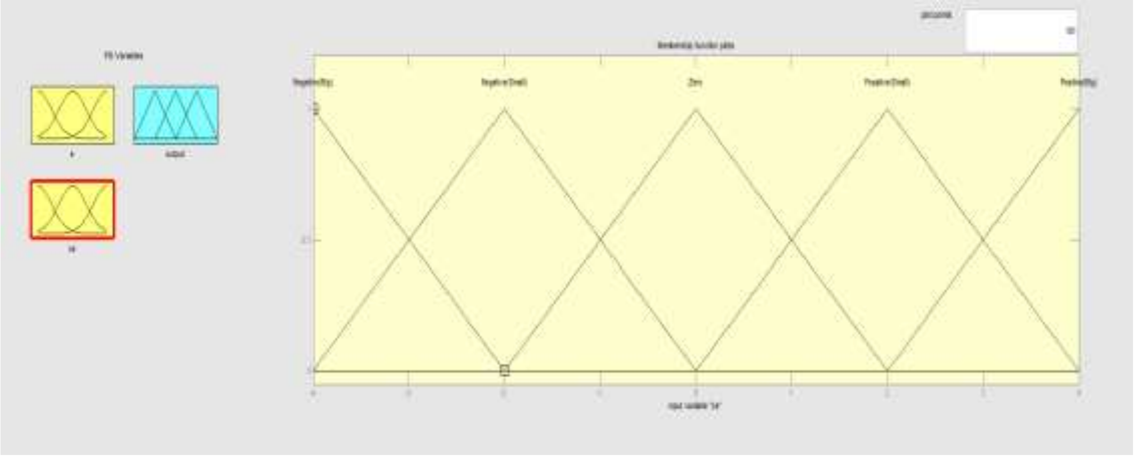
(ii) Self-tuning Fuzzy PID to Control Step Down Power Converter

Figure 7 describes the overall Simulink environment. FLC is designed to generate parameters K_p, K_i and K_d of a conventional PID controller. The overall system is shown in Figure 8. Membership functions and fuzzy rule table are plotted out in Figure 9 and Table 2 respectively.



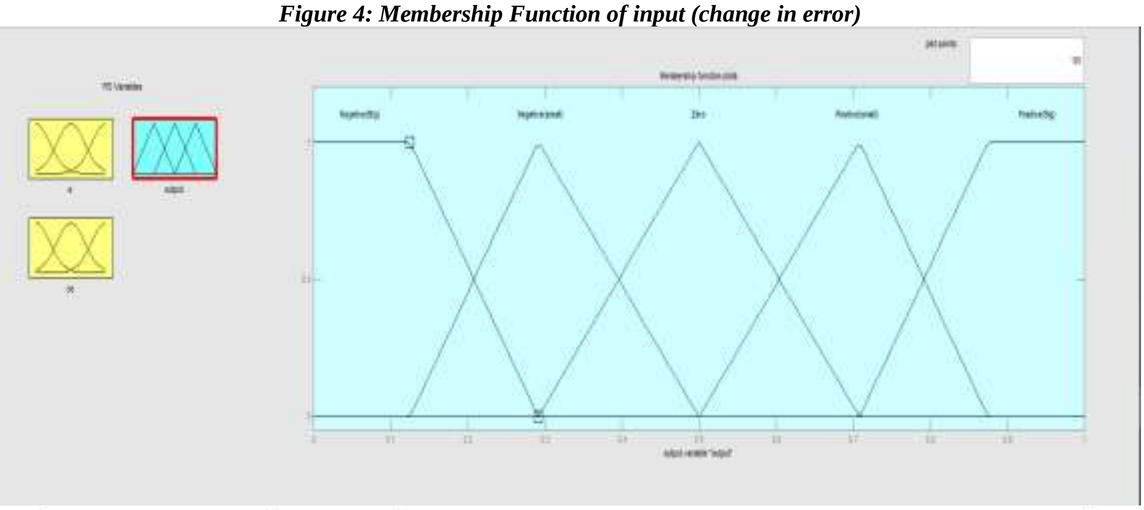
Input Variable	Range	Membership Function		
		Name	Type	Params
e	[-4 -4]	Negative(Big)	trapmf	[-10, -6, -4, -3.2]
		Negative(small)	trimf	[-3.2 , -1 , -0.5]
		Zero	trimf	[-0.5, 0.699, 0.709]
		Positive(small)	trimf	[0.48, 1.5, 2.25]
		Positive(Big)	trimf	[2.169, 4.21, 10.2]

Figure 3: Membership Function of input (error)



Input Variable	Range	Membership Function		
		Name	Type	Params
ce	[-4 -4]	Negative(Big)	trimf	[-20, -4, -2]
		Negative(small)	trimf	[-4 , -2 , 0]
		Zero	trimf	[-2, 0, 2]
		Positive(small)	trimf	[0, 2, 4]
		Positive(Big)	trimf	[2, 4, 20]

Figure 4: Membership Function of input (change in error)



Input Variable	Range	Membership Function		
		Name	Type	Params
Output	[0 1]	Negative(Big)	trapmf	[-0.333, -0.1667, 0.125, 0.2917]
		Negative(small)	trimf	[0.125, 0.3, 0.5]
		Zero	trimf	[0.3, 0.5, 0.7]
		Positive(small)	trimf	[0.5, 0.7, 0.875]
		Positive(Big)	trapmf	[0.708, 0.875, 1.167, 1.33]

Figure 5: Membership function for output duty cycle

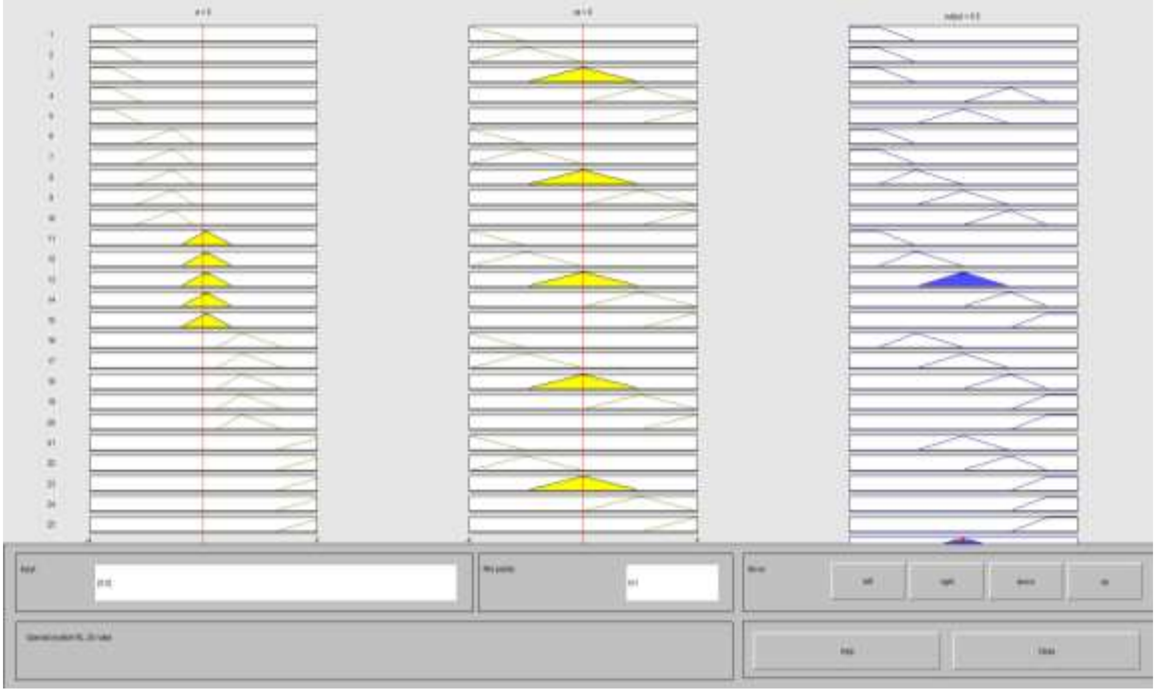
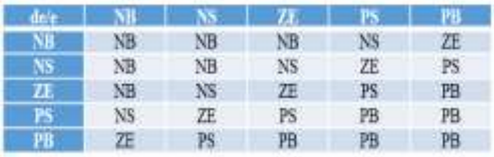


Figure. 6: Rule View of Fuzzy Controller

Table 1. Knowledge based rules



de/e	NB	NS	ZE	PS	PB
NB	NB	NB	NB	NS	ZE
NS	NB	NB	NS	ZE	PS
ZE	NB	NS	ZE	PS	PB
PS	NS	ZE	PS	PB	PB
PB	ZE	PS	PB	PB	PB

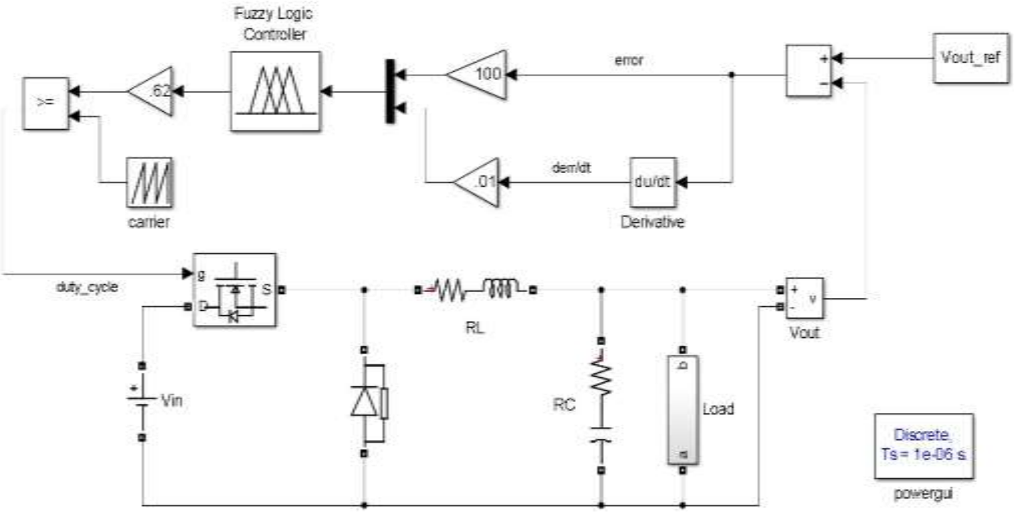


Figure 7: Overall system in Simulink with conventional PI controller.

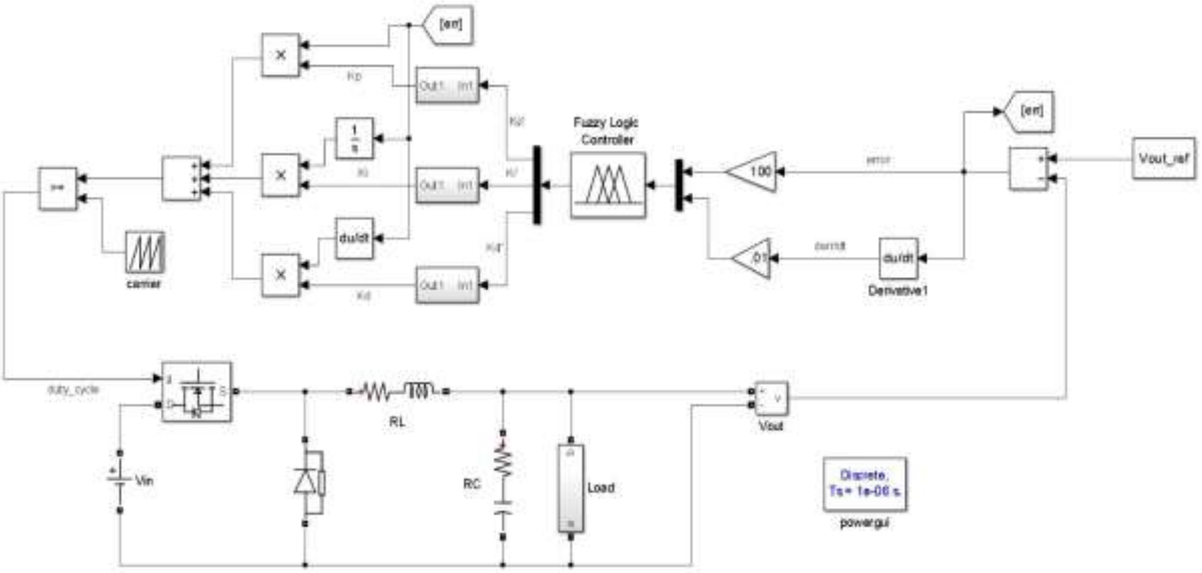


Figure 8: Overall system in Simulink environment with PID controller

FLC is designed to generate parameters K_p, K_i and K_d of a conventional PID controller. The overall system is shown in Figure 8. Membership functions and fuzzy rule table are plotted out in Figure 9 and Table 2 respectively.

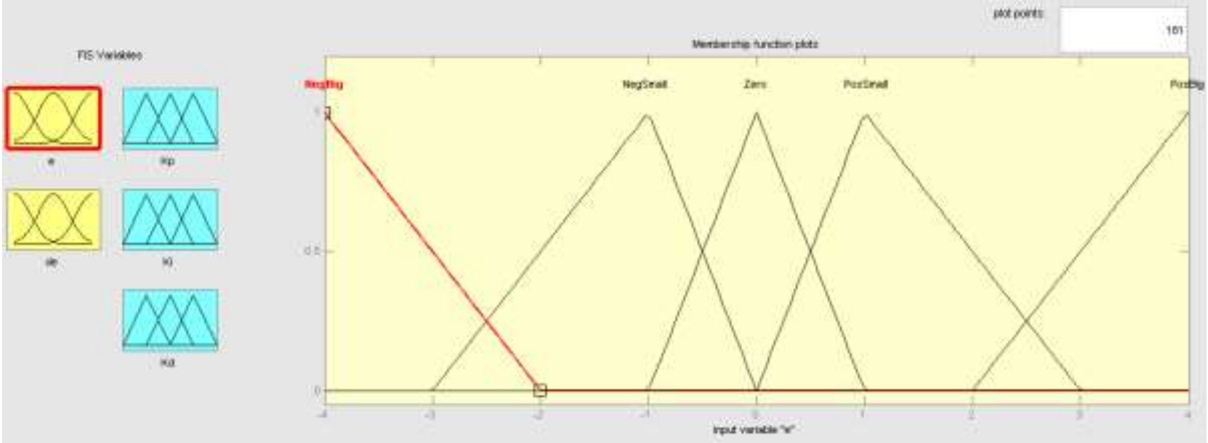


Figure 9 (A): Membership Function of input (error)

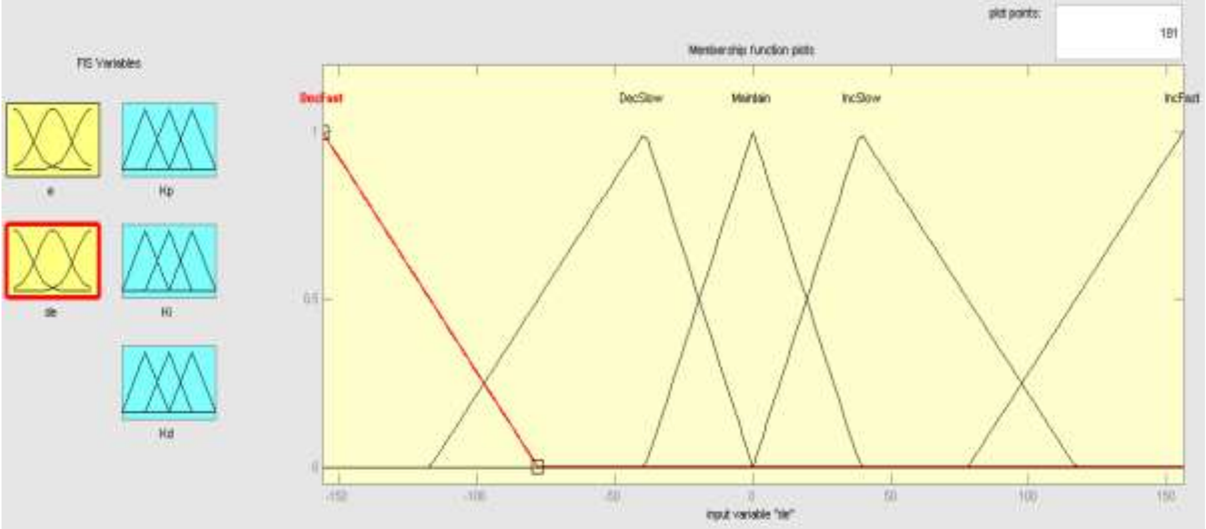


Figure 9 (B): Membership Function of input (change of error)

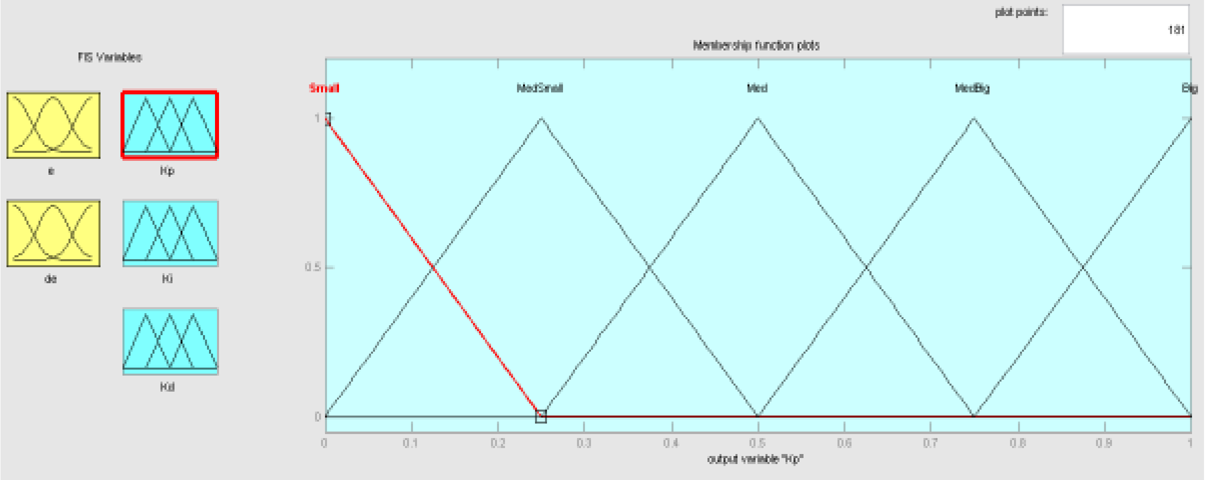


Figure 9 (C): Membership function of output K_d

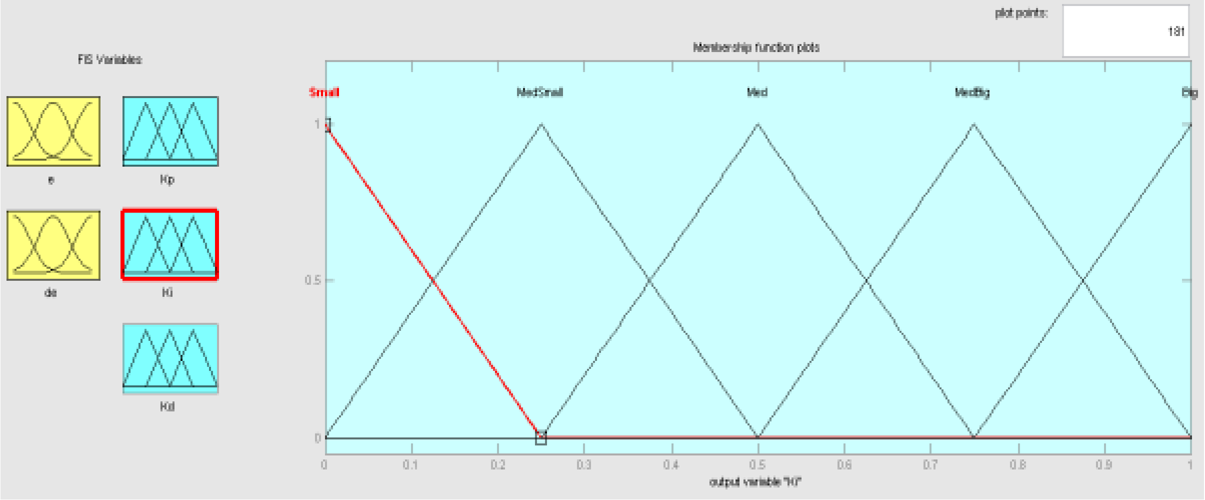


Figure 9 (D): Membership function of output K_i

Table 2.A. Fuzzy rule base of proportional gain (K_p)

de/e	NB	NS	ZE	PS	PB
NB	S	S	MS	MS	ME
NS	S	MS	MS	ME	MB
ZE	MS	MS	ME	MB	MB
PS	MS	ME	MB	MB	B
PB	ME	MB	MB	B	B

Table 2.B. Fuzzy rule based of integral gain (K_i)

de/e	NB	NS	ZE	PS	PB
NB	S	S	MS	MS	ME
NS	S	MS	MS	ME	MB
ZE	MS	MS	ME	MB	MB
PS	MS	ME	MB	MB	B
PB	ME	MB	MB	B	B

Table 2.C. Fuzzy rule based of derivative gain (K_d)

de/e	NB	NS	ZE	PS	PB
NB	S	S	MS	MS	ME
NS	S	MS	MS	ME	MB
ZE	MS	MS	ME	MB	MB
PS	MS	ME	MB	MB	B
PB	ME	MB	MB	B	B

RESULTS AND DISCUSSION

Figure 10 shows the surface view plot of the fuzzy rules**.** Figure 11 shows the overall simulation results for conventional PI controller and we can observe that there is small percentage of overshoot which we are trying to overcome. Figure 12 describes the self-tuning Fuzzy PID DC-DC converter which justifying the obtained results are given with a better performance.

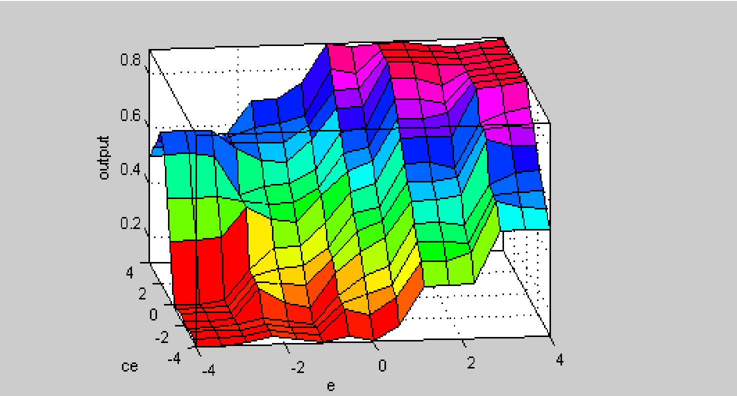


Figure 10: Surface view of plot of fuzzy rules applied.

Small Overshoot

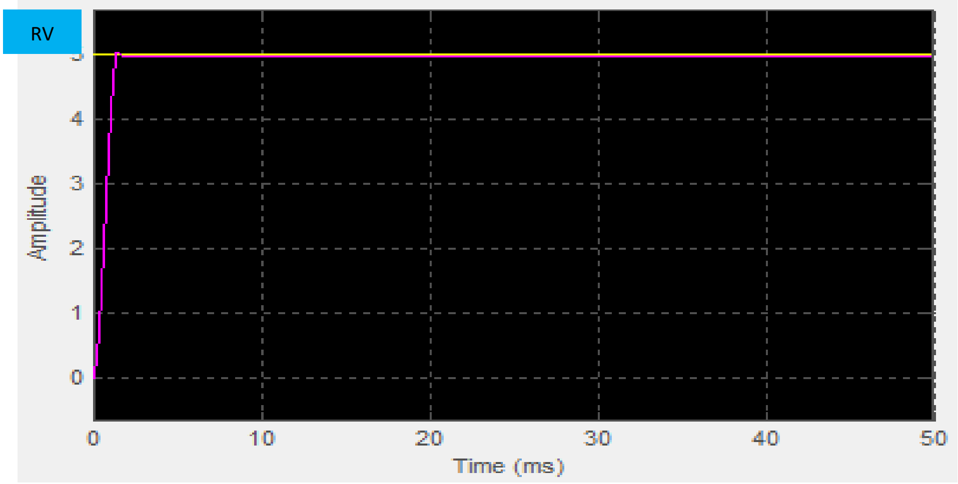


Figure 11: Simulation results of PI controller.

CONCLUSION

This report explained detail step by step how to design FLCs to control a DC-DC power converter successfully. Two intelligent control methods, including fuzzy logic control and self-tuning fuzzy PI reveal better performances than the PI conventional controller. Based on simulation results, the fuzzy controller seems to be an appropriate controller in transient time, and the self-tuning fuzzy-PI is the best controller in the steady state.

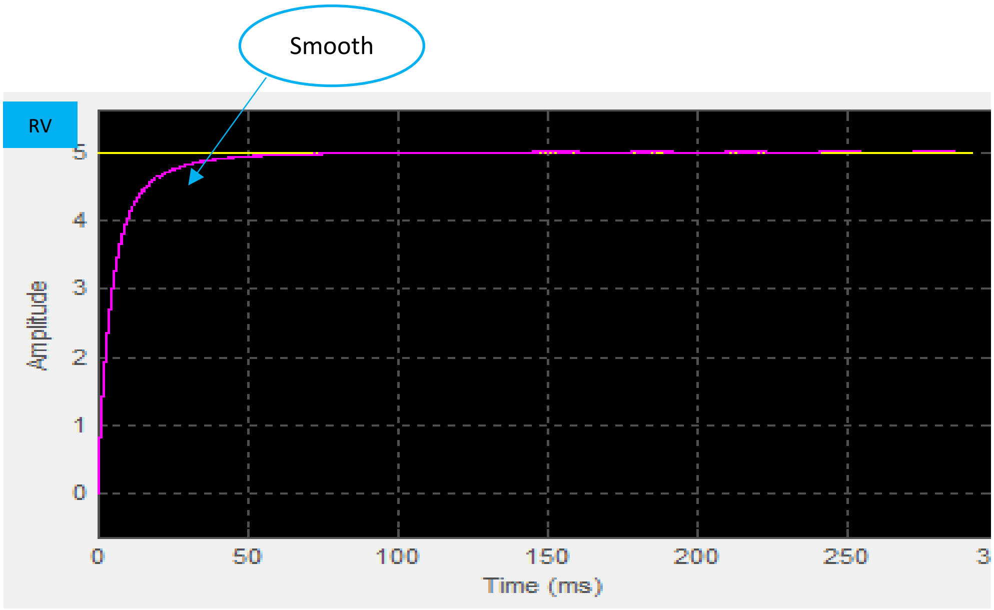

Smooth

Figure 12: self-tuning Fuzzy PID DC-DC Converter

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