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Analysis of Different Controllers for Controlling Buck Converter

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Abstract

In this paper a Hybrid Controller is introduced i.e. PID-NN Controller (PID with neural network) for improving the output response of buck converter. Hybridization is somewhat, combining the advantageous part of both controllers together. Here, Buck converter's Output voltage is controlled by different controllers and comparing results obtained from Controllers. Classical linear techniques have stability around the operating point. This Paper shows comparison of different controller's response in order to control buck converter. The output response of Buck Converter is tested with different controllers individually and results are shown. Neural network technique used as gain scheduler that computes the values of Proportion (Kp), Derivative (Kd),and integral constant (Ki) values for PID Controller. PID output provides the change in duty ratio and then it applied to PWM block to produce the required duty cycle for Switch of Buck Converter. The objective is to improve the System's output response under different load variations and also to use advantage of neural network such as strong learning ability and adaptability. All simulation are done at MATLAB/SIMULINK

Keywords: Buck Converter, PID-Neural network based Hybrid Controller, Fuzzy Logic Controller, PID Controller, MATLAB/Simulink.

Introduction

Buck converter is a DC-DC converter whose objective is to provide low output voltage level from high voltage level. In industries, various types of loads which may have non-linear effects received at the output thus there is a chance of receiving undesired voltage at load, which may reduce the efficiency of converter.

Conventional control techniques used for dc-dc converters are PID controllers which tend to provide linear characteristics[1].

There are both linear as well as non-linear control methods are available. Conventional PID controllers are based on precise mathematical models that have assured stability, reliability, and controllability, despite their effectiveness for linear systems, conventional PID controllers are not suitable for nonlinear systems and higher-order and time delayed systems[2].

For controlling buck converter, fuzzy based system is a non-linear control method. In fuzzy, if the designer has the complete idea of whole process, he can easily design the control system, but the problem with fuzzy controllers is that they are applied to system based on the experience of designer, not on any theoretical methods, that affects stability and controllability issues of these fuzzy controllers.

Fuzzy logic, which is the logic on which fuzzy control is based, is much closer in spirit to human thinking and natural language than the traditional logical systems. Basically, it provides an effective means of capturing the approximate, inexact nature of the real world[3].

Hybrid system is somewhat, combining the advantageous quality of different control techniques and that makes it more powerful. A conventional PID controller for regulating Buck converter with a neural network based system is proposed which calculates the values of different parameters of PID controller and in this way controlling action takes place.

The implemented ANN controller is trained offline using the data obtained from the experiments performed by the system.Artificial neural network is a model consists of artificial neurons which process the information from input and provides controlled output. Here, ANN is used for computing the gains values of PID controller so that change in duty cycle is produced.

Buck converter circuit: The circuit diagram of Buck Converter is as shown in Figure-1, where the switch movement i.e. on or off depends on duty ratio obtained from controller. Many control methods are used for control of switch mode DC-DC Converter and the simple and low cost controller structure is always in demand for most industrial and high performance applications[4].

It consists of input voltage (DC), a switch, Diode, Inductor, Capacitor and load resistance Ro. Buck converter operates in two states: State 1 (Switched closed), State 2 (Switch open)

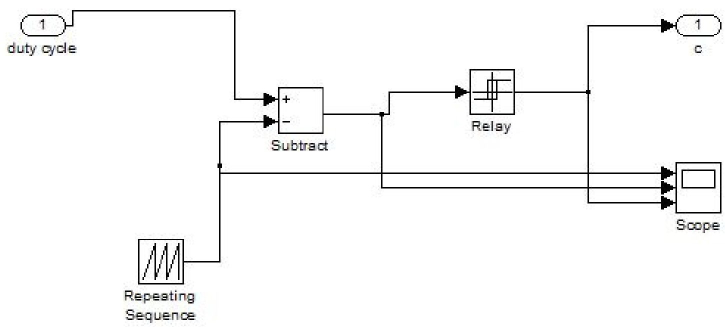

Figure-1
Buck Converter Circuit Diagram

State 1: The switch is at close position, Diode becomes reversed biased and therefore does not conducts. At that time, voltage at Inductor is (Vin–Vo). From the inductor equations, the inductor's current will increase at a rate of (Vin –Vo)/L.

State 2: The switch is at open position. The inductor current tries to flow in same direction as inductor opposes sudden change of current. When inductor's current discharges, a negative voltage drop appears at inductor and thus Diode gets forward biased and conducts.

Methodology

Buck Converter Subsystem: This block provides the output voltage and inductor current waveform at output. Inputs to this block are duty cycle, input voltage, and load current as shown in Figure-2.

The inductor's current can be computed from the first loop when differential equation is solved by applying KVL to the basic circuit of buck converter:

$$VinD = L\frac{d\,iL}{dt} + iLRL + Vo \quad (1)$$

$$L\frac{d\,iL}{dt} = V_{in}D - iLRL - Vo \quad (2)$$

$$iL = \frac{1}{L}\int Vin\,D - iL\,RL - Vo\ldots \quad (3)$$

Where: Vin= Input Voltage, iL=Inductor's Current, RL=Effective Series Resistance of Inductor, Vo=Output Voltage, L=Inductor.

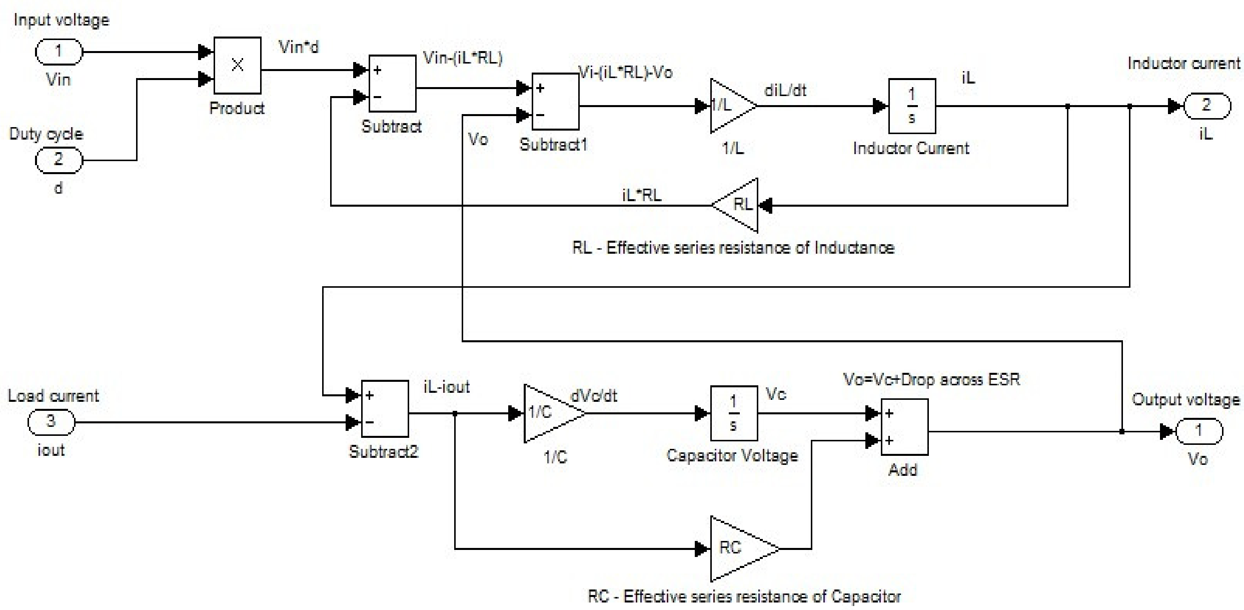

Figure-2
Subsystem for Buck Converter

The output voltage can be computed from second loop which is the addition of the voltage at capacitor and voltage drop across the Capacitor's Effective Series Resistance (Rc). From KCL at the capacitor node we get:

$$C\frac{d\,Vc}{dt} = iL - iout \quad (4)$$

$$Vc = \frac{1}{C}\int (iL - iout)dt \quad (5)$$

$Vo = Vc + DropacrossESR$ of Capacitor

$$Vo = Vc + Rc\,(iL\ - iout) \quad (6)$$

Where: Iout=Current at load, C=Capacitor (Farad), Vc= Capacitor voltage, RC=Capacitor's Effective Series Resistance

PWM Waveform Generator Subsystem: As name suggests that this block has an objective of providing series of PWM (pulse-width modulated) pulses based on varying duty cycle. As explained above, that buck converter has two modes of operation i.e. when converter's switch is on (Ton) and when converter's switch is off (Toff).

The block consist of two inputs are: From the controller, change in duty cycle. Switching Frequency Fs, as shown in Figure-3.

PID Controller: In Simulink the default PID controller available is used to generate change in duty cycle, according to the error signal provided by comparator. The PID's parameter can be provided either manually or by auto tuning concept provided by mat lab. Due to PWM logic, linearization error occurs because the forward path linearizes to zero. PID Controllers are most commonly used controllers in process industries, about 90% of industrial loops use PID controller. This is because of its simple structure, easy implementation, robust nature and less number of tunning parameters[5].

For using the auto tuning feature of PID controller, one needs to model Buck Converter as a transfer function, we get:

$$Vin\ D = L\ iL\ S + iL\ RL + Vo \quad (7)$$

On neglecting the drop across Rc,

$$iL = \frac{Vo}{R} + C\ Vo\ s \quad (8)$$

From above equation, substituting values, thus we get Buck converter's open loop transfer function model.

$$\frac{Vo}{D} = \frac{\frac{Vin}{L\,C}}{S^2 + S\left(\frac{1}{RoC} + \frac{RL}{L}\right) + \left(\frac{1}{LC} + \frac{RL}{RoLC}\right)} \quad (9)$$

Where: Vo=Output Voltage, Vin = Input Voltage, Ro = Resistance at load (Ω), L = Inductor (H), C = Capacitor (F), RL = Effective Series Resistance of Inductor (Ω).The buck converter in a transfer function model as shown in Figure-4.

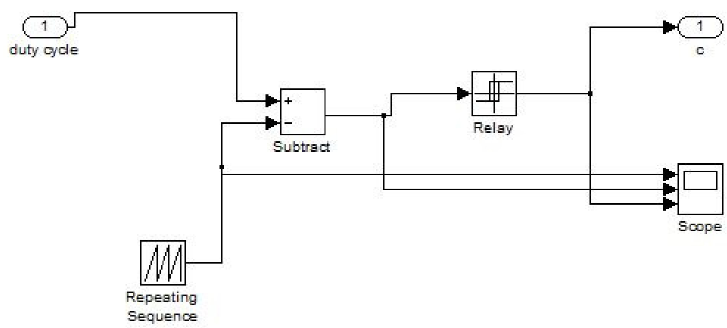

Figure-3
Subsystem for PWM Block

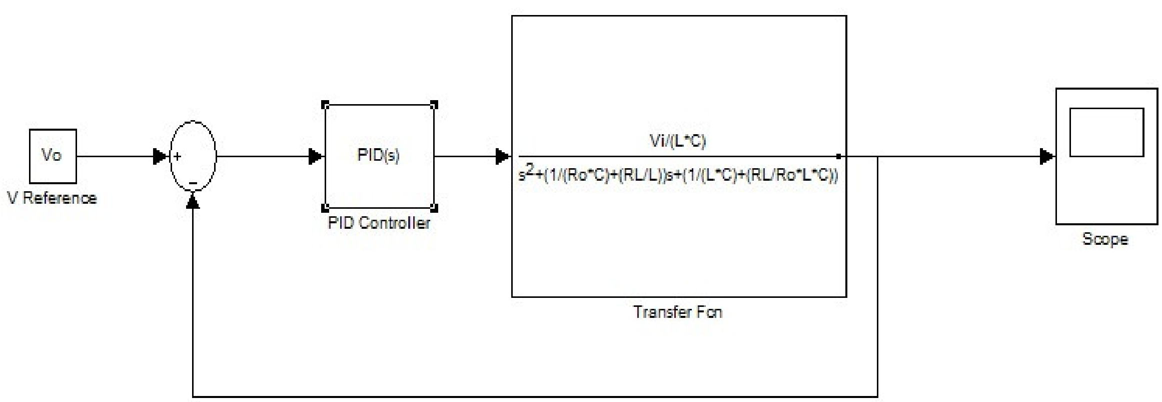

Figure-4
Transfer Function Model with PID Controller

Ordinary Fuzzy logic controller: The controlling process can be achieved through fuzzy controller by using sets of Linguistic rules. It does not require any mathematical model. Rules can be easily developed, if the process to be controlled is well known. Fuzzy controller consist of 4 units: Fuzzification: Here, input data is classified into linguistic sets. Knowledge base: Here, in this block rules are written in If then format. Inference engine: Decision making is performed in this block. Defuzzification: In this block, crisp signal is produced from fuzzy control action available. Fuzzy control rules can be derived easily, as it completely based on designer's experience such as what to do if system's output is higher or lower and based on following criteria:

If the Converter's actual output is not reference value and also actual output is distant from reference point the change in Duty cycle must be large, so that the actual output moves rapidly towards reference point. If the Converter's actual output is less than desired value then change in Duty cycle must be higher. If the Converter's actual output is more than desired value then change in Duty cycle must be lower. For Designing fuzzy logic controller, here two inputs are used i.e. error and change in error, While a single controlled output.

Error = Reference value – Actual value.

During fuzzification, five-membership functions for inputs and outputs are assigned they are BP, SP, ZO, SN, BN. Where BN=Big Negative, SN=Small Negative, ZO=Zero equal, SP=small Positive, BP=Big Positive. Fuzzy control rule for an ordinary fuzzy logic controller is shown on Table-1.

Fuzzy Logic for FUZZY-PID Controller: As the name suggests, it is one of hybrid controller, which is designed to utilize the characteristics or qualities of two or more techniques together. Conventional PID controller does not give acceptable performance for systems with uncertain dynamics, time delays and non-linearity[6].

Here, fuzzy system is used for calculating the parameter's values for PID controller such as Proportional, Integral and Derivative gain. The fuzzy module used is different as taking two inputs i.e. error and change in error while providing 3 different output. These 3 controlled output is nothing but the parameter's value that is to be given to PID controller. The structure of Module is shown in Figure-5.

Table-1
Fuzzy Control Rules for an Ordinary Fuzzy Logic Controller

Error/ Change in Error	BN	SN	ZO	SP	BP
BP	ZO	SP	BP	BP	BP
SP	SN	ZO	SP	BP	BP
ZO	BN	SN	ZO	SP	BP
SN	BN	BN	SN	ZO	SP
BN	BN	BN	BN	SN	ZO

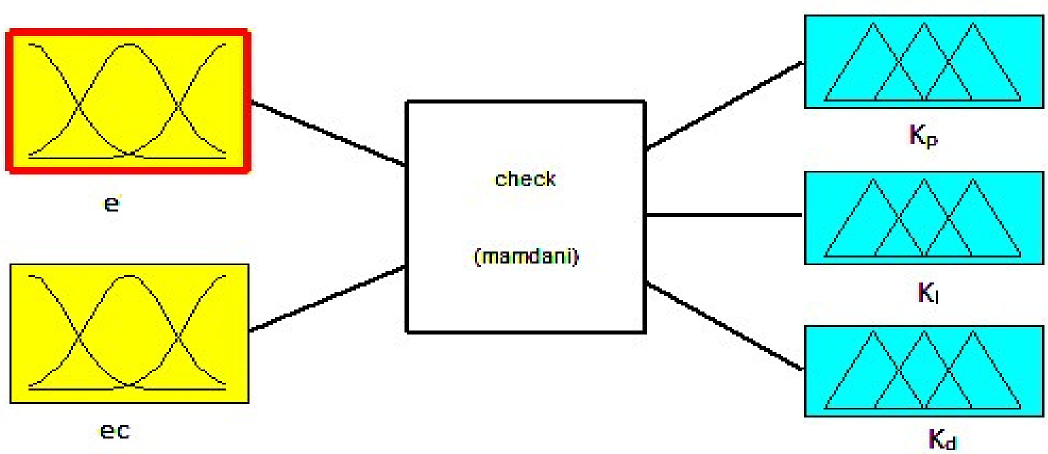

Figure-5
Two-input, three output Fuzzy logic Controller Structure

For Error and change in Error signals 5-Guassian membership functions is used and linguistic variables as :{ BP, SP, ZO, SN, BN} and range is limited between {-1 TO +1}.Where BN=Big Negative, SN=Small Negative, ZO=Zeroequal, SP=small Positive, BP=Big Positive.

While the output signals also consist of 5- Gaussian membership function and linguistic variables as :{ ZO, SM, EM, BM, VL} and range is different for all 3 outputs.

Individually fuzzy control rules for calculating proportional gain, Integral gain and Derivative gain respectively are obtained and shown on Tables-2, 3, 4 respectively.

Table-2
Fuzzy Control Rules for calculating Proportional gain

			Error			
		BN	SN	ZO	SP	BP
Change in	BN	VL	VL	BM	BM	EM
Error	SN	VL	BM	BM	EM	SM
	ZO	BM	BM	EM	SM	SM
	SP	BM	EM	SM	SM	ZO
	BP	EM	SM	SM	SM	ZO

Table-3
Fuzzy Control Rules for calculating Integral gain

			Error			
		BN	SN	ZO	SP	BP
Change in	BN	ZO	ZO	SM	SM	EM
Error	SN	ZO	SM	SM	EM	BM
	ZO	SM	SM	EM	BM	BM
	SP	SM	EM	BM	BM	VL
	BP	EM	BM	BM	VL	VL

Table-4
Fuzzy Control Rules for calculating Derivative gain

			Error			
		BN	SN	ZO	SP	BP
Change in	BN	BM	ZO	ZO	ZO	BM
Error	SN	EM	ZO	SM	SM	EM
	ZO	EM	SM	SM	SM	EM
	SP	EM	EM	EM	EM	EM
	BP	VL	BM	BM	BM	VL

Artificial Neural Networks with PID Controller: Artificial neural network is a model consist of artificial neurons which process the information from input and provides controlled output. Here, ANN is used for computing the gains values of PID controller so that change in duty cycle is produced. The ANN structure in a closed loop with a single neuron is shown in Figure-6. Weights w1, w2, w3 will acts as a PID controllers gains. The weights are modified by the help of learning algorithms to achieve desired value.

$$x_1(k)=e(k)-e(k-1) \quad (10)$$

$$x_2(k)=e(k) \quad (11)$$

$$x_3(k)=e(k)-2e(k-1)-e(k-1) \quad (12)$$

Now, weights are multiplied with these error signals and input given to single neuron. Output of Neuron is given by:

$$u(k)= \quad u(k-1)+K\sum_{i=1}^{3}w_i(k)x_i(k) \quad (13)$$

Where: K is constant from which we can increase or decrease the speed of system's response. Tuning a PID controller by ANN involves steps such as: Step-1: For the weights, select any Random values. Step-2: Now Error is calculated which is the Difference of Reference value and Actual value. Step3: The Error signal can be used for calculating gain of PID controller which in turn decided by Supervised Data Learning Algorithm. Step 4: Single Neuron's output i.e. Δu for obtaining better response must be multiplied with a gain k. Step5: Proportionalgain, Integral gain and Derivative gain respectively are obtained by updating the weights.

Results and Discussion

For finding the proposed controller i.e. PID-NN (PID controller with neural network) accuracy, its needs to be investigate by using mat lab/Simulink software. Different controllers are tested with Buck Converter individually and results are shown in a comparison table from that we could easily find the merits and demerits of every controller's proposed.

In this Paper, a Buck Converter is controlled by different controllers such as Conventional PID controller, an ordinary Fuzzy Logic Controller, a hybrid Fuzzy-PID controller and a hybrid PID-NN controller are simulated separately. Also, output voltage waveform regarding with different controllers are shown in Figure-7, Figure-8, and Figure-9 respectively.

In the next step, we have proposed NN-PID controller shown in Figure-10 and its output voltage waveform in Figure-11 shown. The desired output voltage is equal to 10 Volt. Firstly, voltage at output is compared with the reference voltage thereby error and change in error are obtained. A single neuron ANN structure is used for tuning of PID and corresponding duty ratio command is obtained. The comparison of all controllers magnified view as shown in Figure-12 from the comparison Table-5 and Figure-12, the proposed NN-PID controllers provides lower Steady state Error and overshoot but having higher rise time and settling time.

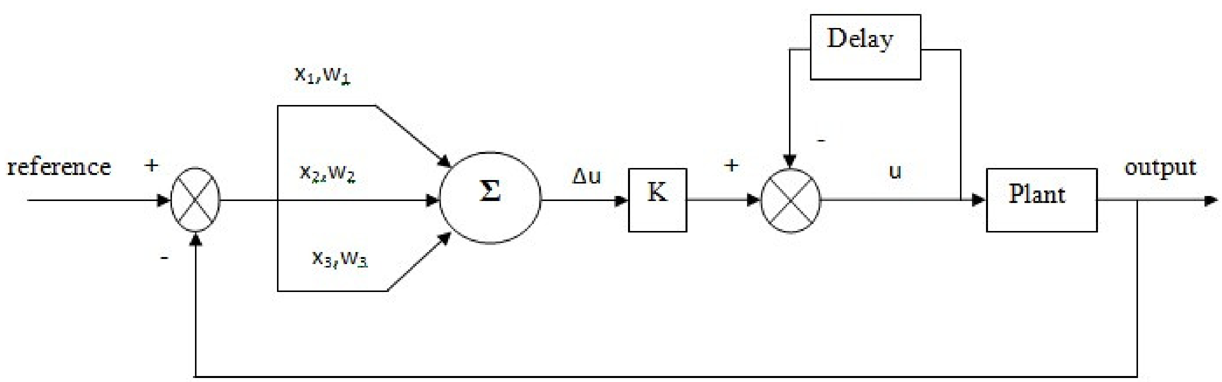

Figure-6
Single neuron ANN structure

Table-5
Comparisons of responses of various controllers

Types of Controller's	Rise time	Settling time	overshoot	Steady state error
PID	0.67 sec	5 sec	10.5 %	< 2.5%
FUZZY	1.2 sec	2 sec	10%	<3%
FUZZY-PID	0.6 sec	1.5 sec	0.5 %	< 0.2%
PID-NN	0.8 sec	2 sec	0.2%	< 0.1%

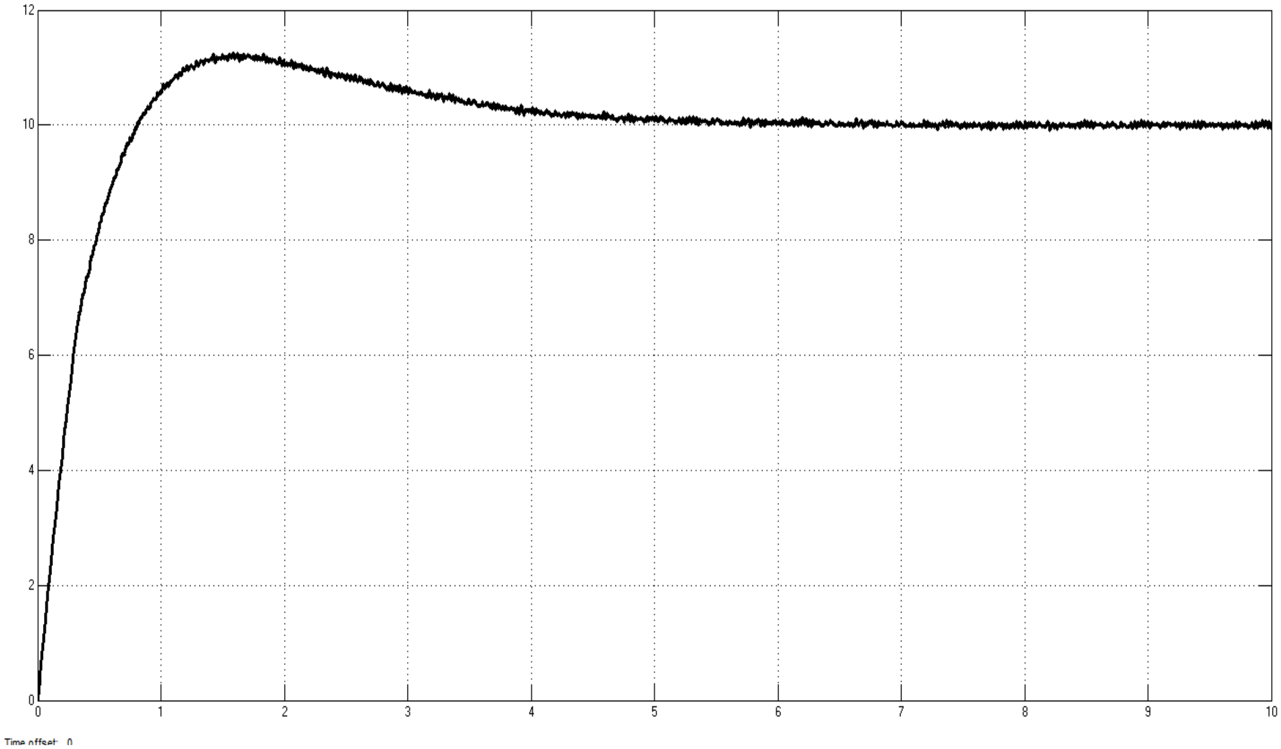

Figure-7
Output voltage waveform of conventional PID controller

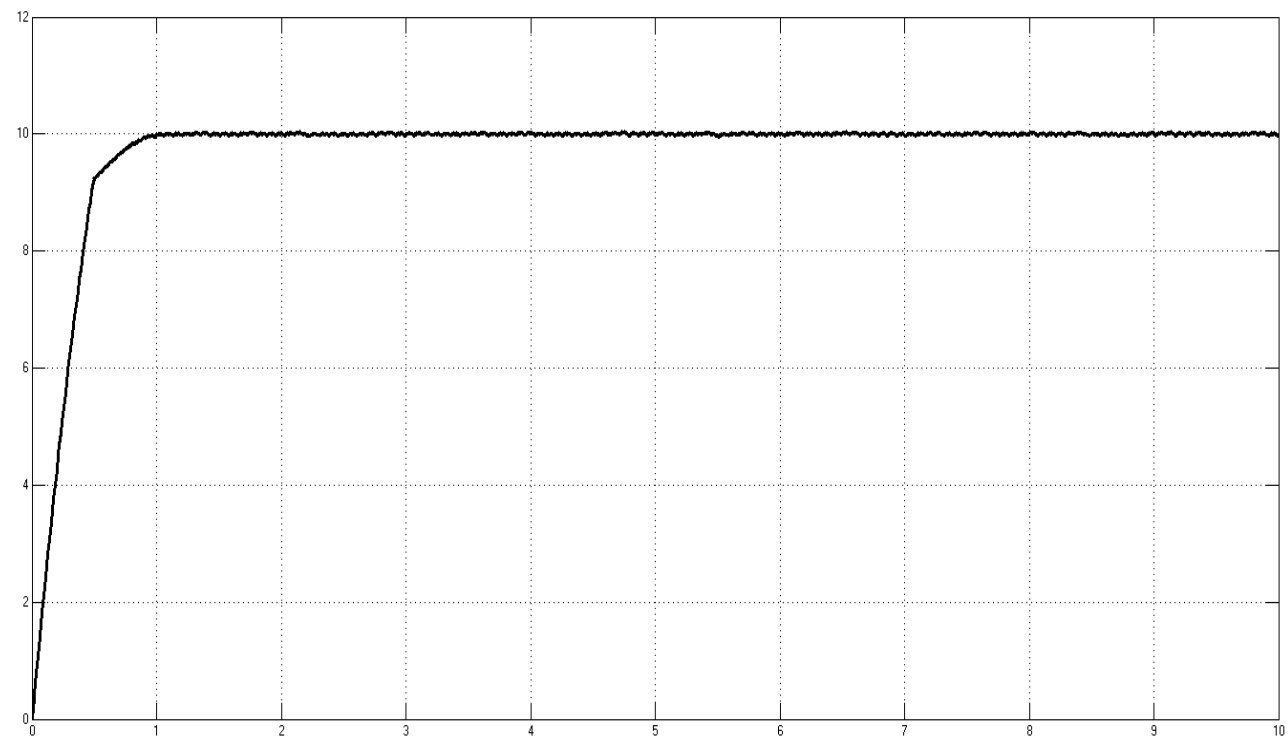

Figure 8
Output voltage waveform of an ordinary Fuzzy Logic Controller

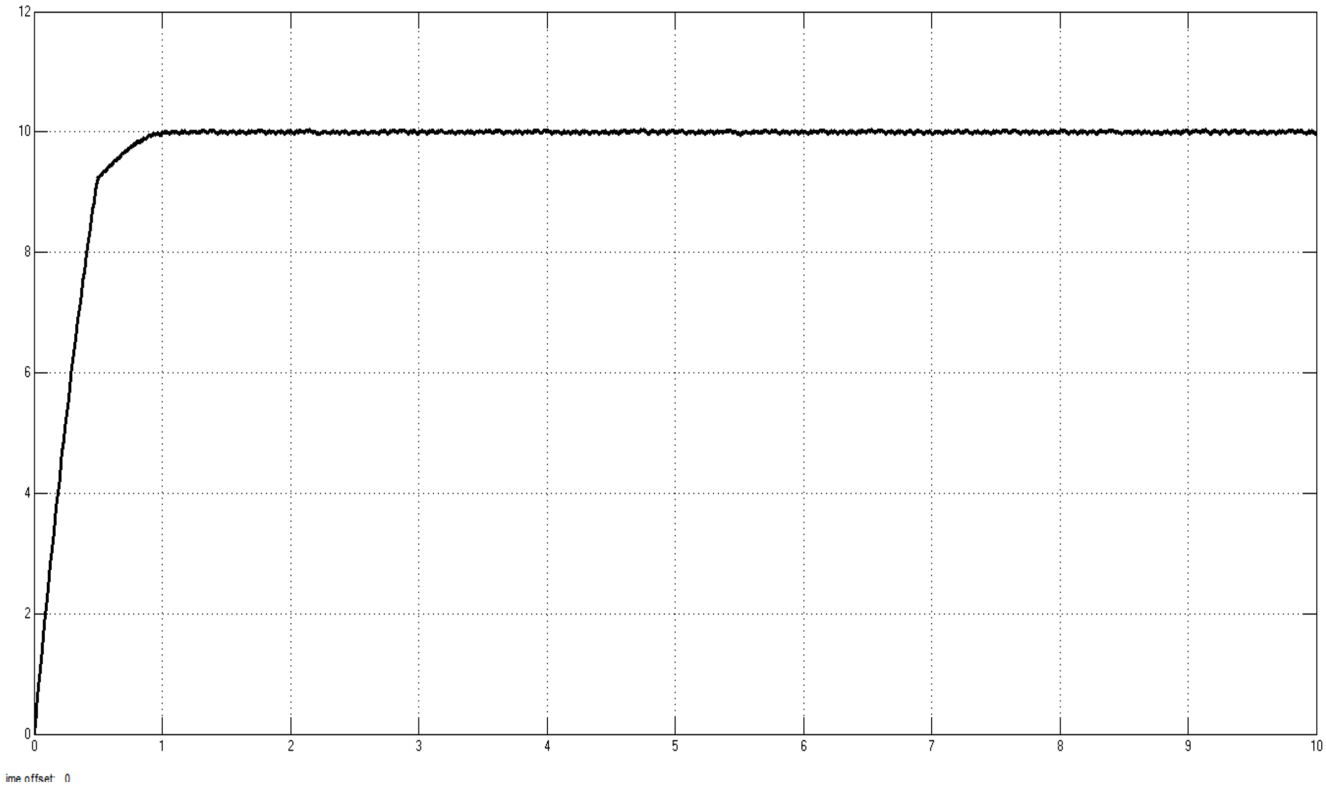

Figure-9
Output voltage Waveform of FUZZY-PID controller

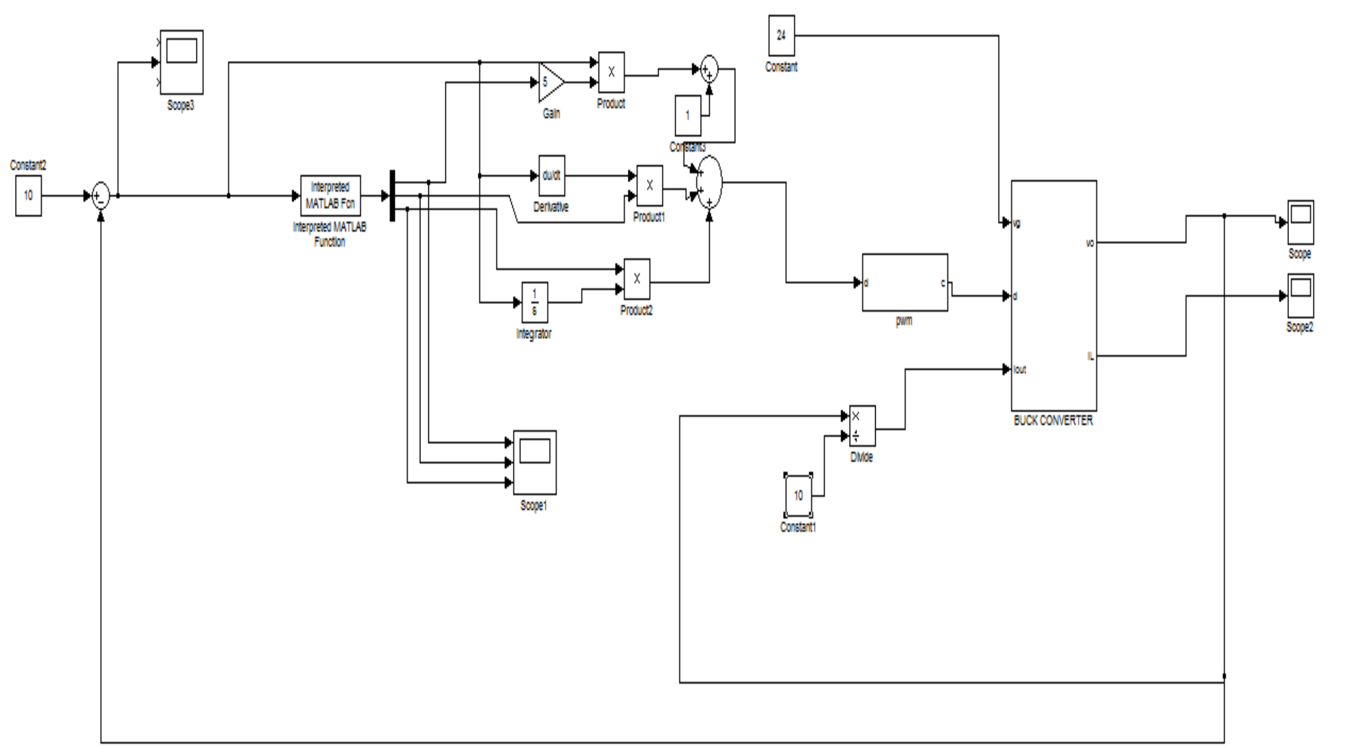

Figure-10
Simulated model of NN-PID Controller for Controlling Buck Converter

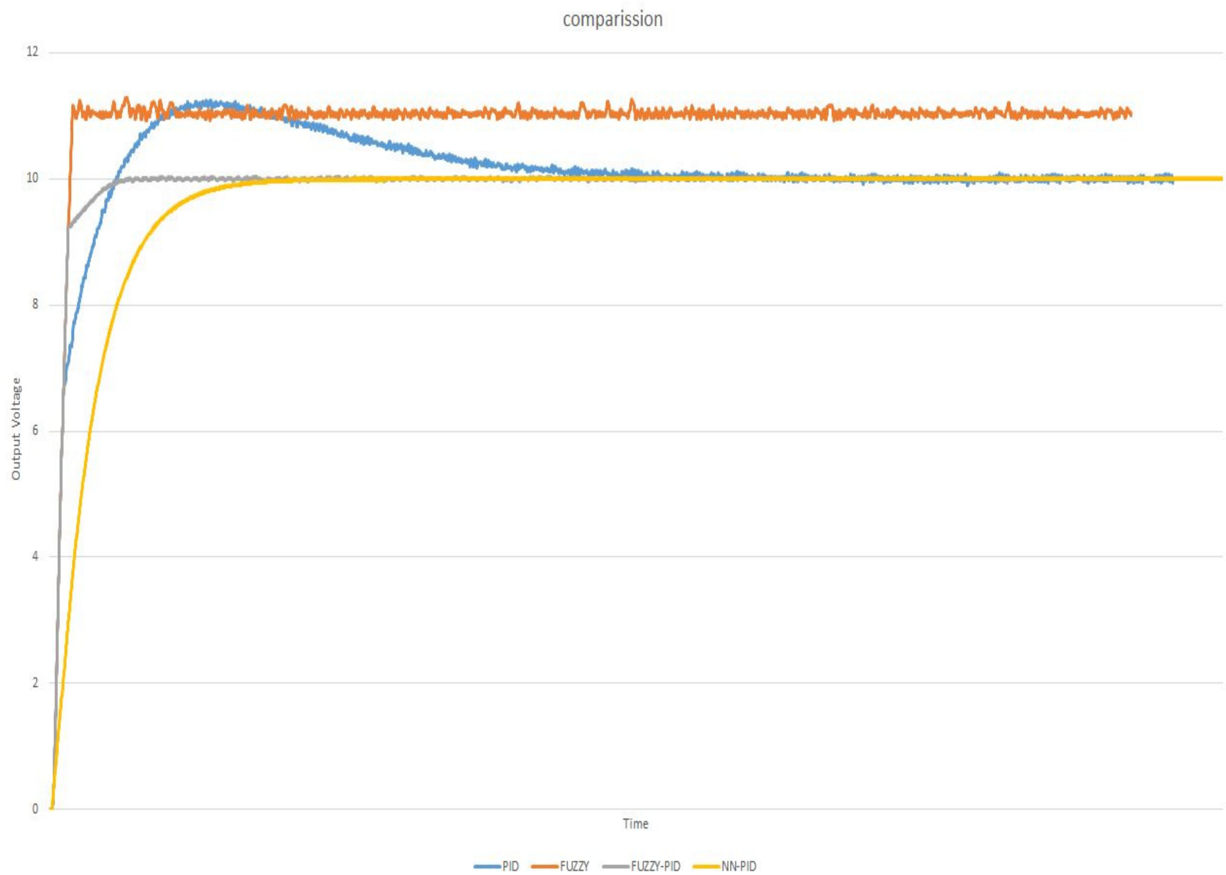

Figure-11
Output voltage Waveform for NN-PID controller

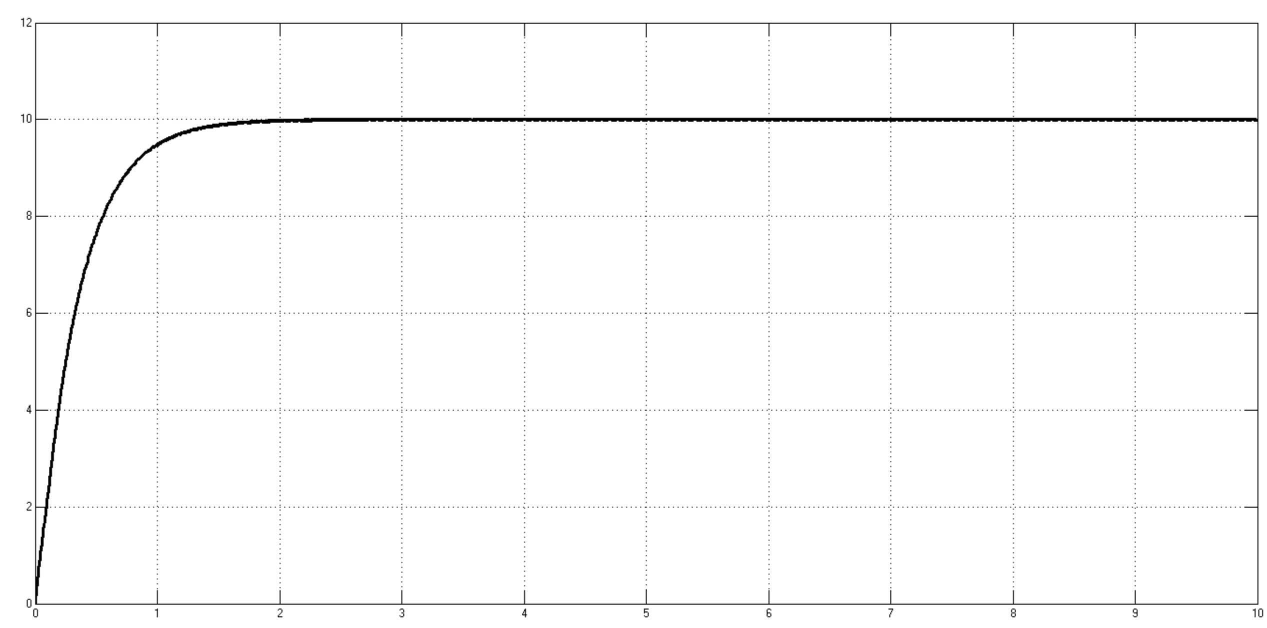

Figure 12
Responses of different controllers

Conclusion

PID controllers are the most suitable controller that are extensively used in industries process. The objective of proposed controller i.e. PID-NN controller to provide more accuracy with less error to the system's response. Here, the neural network with its adaptability and strong learning ability calculates the different parameters gain of PID controller and hence, output response of system is improved.

After Analyzing the output voltage waveform with different controllers, a comparison table is prepared and from that we can conclude that the proposed controller have less Error i.e. highly accurate but response is little slow.

Scope of Further Work: In order to use the advantages of fuzzy logic it may combine with neural network for improving rise time and peak time and also many algorithms can be used for improving the transient response of system such as ANFIS, Genetic Algorithms, soft computing technics etc.

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