Simulation Based comparative study of AI (ANN) based voltage regulation of Buck - Boost converter with PI based Buck-Boost converter.

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Abstract— **This paper proposes a neural network control scheme of a DC-DC buck-boost converter using model reference control. In this technique, a dynamic back propagation algorithm is used. The controller is designed to stabilize the output voltage of the DC-DC converter and to improve performance of the Buck-Boost converter during transient operations. The general idea behind Model Reference Adaptive Control is to create a closed loop controller with parameters that can be updated to change the response of the system. The output of the system is compared to a desired response from a reference model. The numerical simulation results show that the proposed controller has a better performance compare to the conventional PI-Controller method.**

Keywords— **Buck-Boost converter, Model reference control, Neural Network, Levenberg-Marquardt Backpropagation**

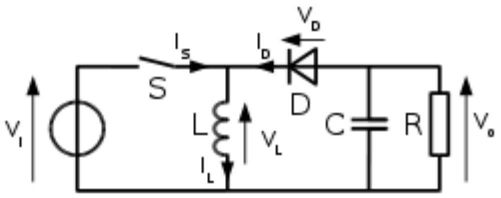
I. INTRODUCTION

DC power supplies are often utilized to provide electric power supply not only for portable electronic devices such as notebook computers, but also for electric vehicle and aerospace applications. To provide the DC voltage source level requirements of the load to the DC power supply, the DC-DC converter is widely used. Basically, the DC-DC converter consists of power semiconductor devices which are operated as electronic switches. Operation of the switching devices causes the inherently nonlinear characteristic of the dc-dc converters including one known as the Buck-Boost converter. Consequently, this converter requires a controller with a high degree of dynamic response. Proportional-Integral Differential (PID) controllers have been usually applied to the converters because of their simplicity. In general, PID controller produces long rise time when the overshoot in output voltage decreases. In order to improve dynamic response of DC-DC converters, several intelligence controllers such as fuzzy logic control, neural network control and hybrid neuro-fuzzy control methods for DC-DC converter have been reported. As another option of intelligence controls, based on their ability to update the internal controller parameters, the neural network controls [NNC] are suitable for nonlinear system. Implementation of the NNC for DC-DC converter in computer simulation model has been proposed. This paper proposes a neural network control scheme of a DC-DC buck-Boost converter using model reference control. The organization of this paper is as follows: Section II discusses basic concept of a Buck Boost converter as a stepup and step-down of a DC-DC Buck-Boost converter. In section III, the design of neural network control is described. PI controller is described in section IV. Simulation results are carried out in section V. Finally, conclusions are summarized in Section VI.

II. BUCK-BOOST CONVERTER

The buck-boost converter is a type of DC to DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. Output of the Buck-Boost converter is regulated according to the duty cycle of the Pulse Width Modulation (PWM) input at fixed frequency. When the duty cycle (d) is less than 0.5, the output voltage of converter is lower than the input voltage. However, when the duty cycle is more than 0.5 the output voltage of converter is higher than the input voltage.

Fig 1 : Circuit Diagram of a buck-boost converter



$$\frac{dI_L}{dt} = \frac{V_i}{L}$$

$$\Delta I_{L_{On}} = \int_0^{DT} dI_L = \int_0^{DT} \frac{V_i}{L} dt = \frac{V_i DT}{L}$$

$$\frac{dI_L}{dt} = \frac{V_o}{L}$$

$$\Delta I_{L_{Off}} = \int_0^{(1-D)T} dI_L = \int_0^{(1-D)T} \frac{V_o}{L} dt$$

$$= \frac{V_o(1-D)T}{L}$$

$$\Delta I_{L_{On}} + \Delta I_{L_{Off}} = 0$$

$$\Delta I_{L_{On}} + \Delta I_{L_{Off}} = \frac{V_i DT}{L} + \frac{V_o(1-D)T}{L}$$

$$\frac{V_o}{V_i} = \frac{-D}{1-D}$$

Depending upon the value of D, the circuit can act as a step-up or a step-down converter

III. NEURAL NETWORK CONTROLLER

To design the neural network control, some information about the plant is required. Basically, the numbers of input and output neuron at each layer are equal to the number of input and output signals of the system respectively. The structure of the proposed neural network control of a buck boost converter is 1-7-1 and is shown in Fig. 2.

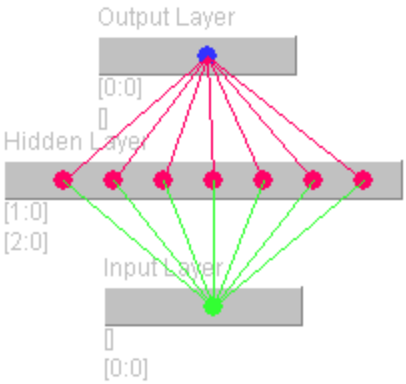


Fig 2 : Neural Network Architecture (1-7-1 design)

Model Reference controller has been used to construct the neural network. The neural model reference control architecture uses two neural networks: a controller network and a plant model network, as shown in the figure below. The plant model is identified first, and then the controller is trained so that the plant output follows the reference model output.

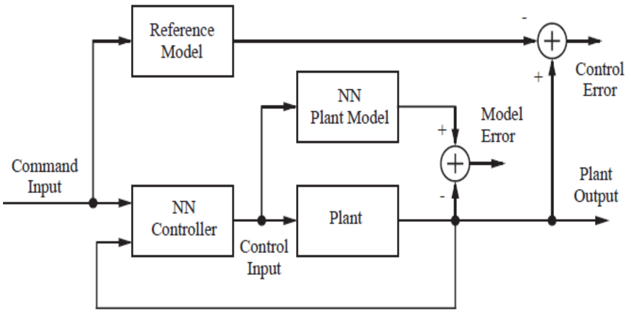


Fig 3 : Model Reference Control Architecture

The plant multiplies the input voltage value with D/1-D. Hence, plant is a non-linear model with respect to D.

Figure 4 shows the plant model. As we can see, the input voltage is taken using the 'random reference' block in simulink library. The input voltage is set to vary between 8 to 14 V. This is done because our aim is to stabilize the output voltage with respect to variations in input voltage.

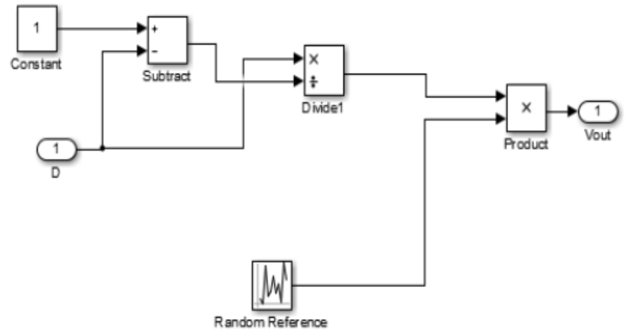


Fig 3 : Buck-Boost plant model

Next step is to choose the reference model. In the plant model, we have chosen 'Random Reference' as the input voltage to the buck boost converter model, but in reference model, we need to use the input that will be the actual input to the converter under ideal conditions. For our case, we have assumed it to be 12 V.

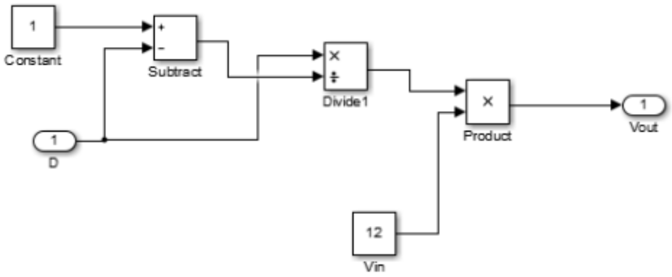


Fig 4 : Buck-Boost reference model

Figure 5 shows the complete Reference model based neural network control of buck boost converter.

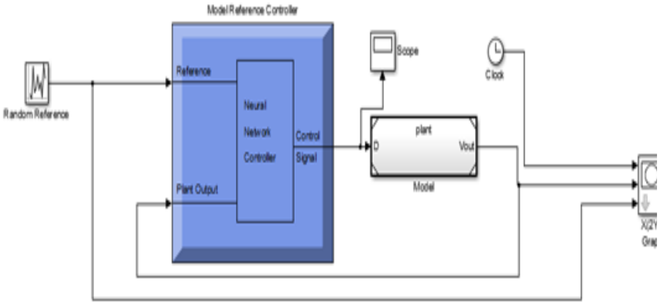


Fig 5 : Buck-Boost converter with NN Controller (MRAC)

IV. PI CONTROLLER

A proportional–integral controller (PI controller or two term controller) is a control loop feedback mechanism widely used in industrial control systems and a variety of other applications requiring continuously modulated control. A PI controller continuously calculates an error value e(t) as the difference between a desired setpoint (SP) and a measured process variable (PV) and applies a correction based on proportional, and integral terms (denoted P, and I respectively) which give the controller its name. The proportional term acts on the current error and thus improves the system dynamics, while the integral term sums up the errors upto a certain time and then acts on them.

The block diagram shown in Figure 6 explains the implementation of the PI controller for buck-boost converter. The actual output voltage of the buck-boost converter and the constant reference voltage are compared, to form the error signal. The error signal given to the PI controller. The PI controller generates the control signal based on the error signal for varying the turn on and turn off time (also referred to as duty cycle, D) of the regulator switch of the buck-boost converter, to maintain the constant output voltage (Vo) irrespective of the input voltage and load variations

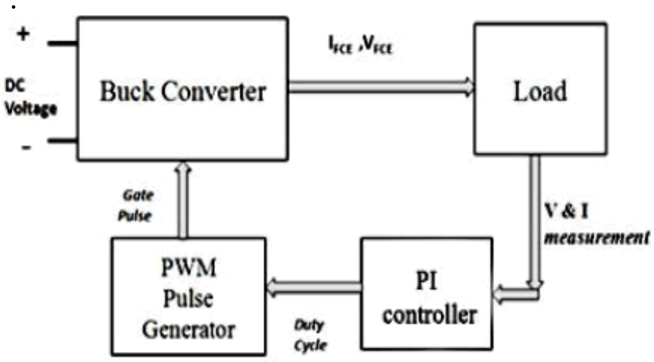


Fig 6 : PI controller for buck-boost model

Fig 7 shows the simulink model for PI based buck-boost controller.

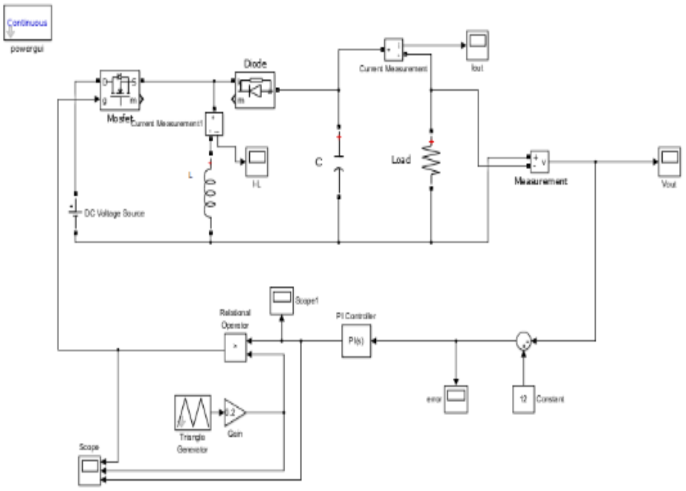


Fig 7 : Simulink model for PI based buck-boost converter

V. SIMULATION RESULTS & DISCUSSION

To investigate the comparative effectiveness of both the proposed controllers (MRAC & PI),computer simulations using Simulink-MATLAB have been conducted. The Buck-Boost converter parameters are shown in Table 1.

Symbol	**Parameter**	**Value**
L	Inductance	1 mH
C	Capacitance	100 mF
Vi	Input Voltage	12V
R	Resistance	100 ohm
F	PWM Generation Frequency	1 kHz

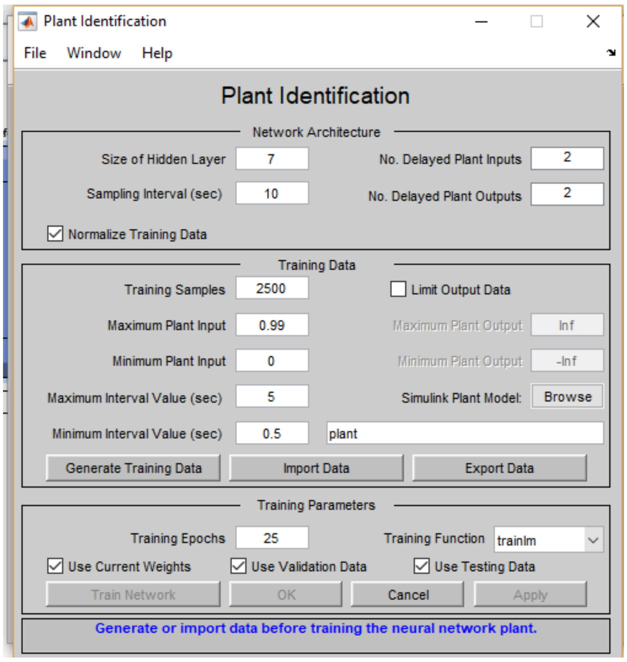
Table 1 : Buck-Boost converter parameters

The PI controller parameters are given in Table 2 below.

Parameter	**Value**
Kp	0.012
Ki	0.001

Table 2 : PI controller parameters

Figure 8 and 9 show the Neural network training parameters for both plant identification as well as Model reference control.



Plant Identification

Network Architecture

Size of Hidden Layer: 7
No. Delayed Plant Inputs: 2
Sampling Interval (sec): 10
No. Delayed Plant Outputs: 2
☑ Normalize Training Data

Training Data

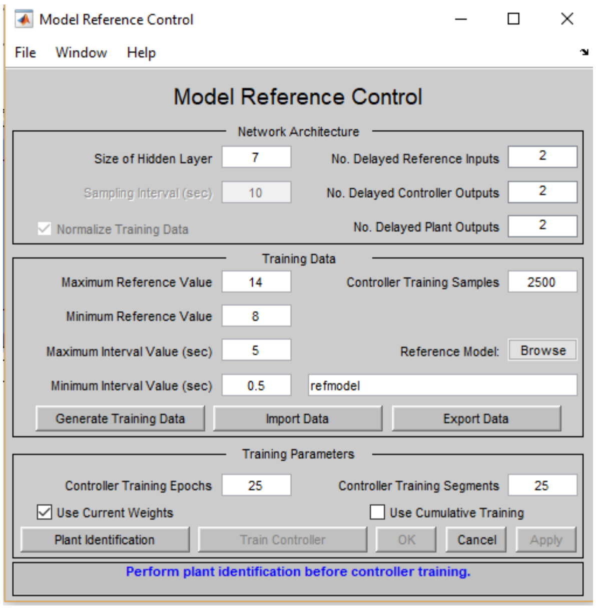
Training Samples: 2500
☐ Limit Output Data
Maximum Plant Input: 0.99
Maximum Plant Output: Inf
Minimum Plant Input: 0
Minimum Plant Output: -Inf
Maximum Interval Value (sec): 5
Simulink Plant Model: Browse
Minimum Interval Value (sec): 0.5
plant

Training Parameters

Training Epochs: 25
Training Function: trainlm
☑ Use Current Weights
☑ Use Validation Data
☑ Use Testing Data

Generate or import data before training the neural network plant.

Fig 8 : Plant identification parameters for MRAC.



Model Reference Control

Network Architecture

Size of Hidden Layer: 7
No. Delayed Reference Inputs: 2
Sampling Interval (sec): 10
No. Delayed Controller Outputs: 2
☑ Normalize Training Data
No. Delayed Plant Outputs: 2

Training Data

Maximum Reference Value: 14
Controller Training Samples: 2500
Minimum Reference Value: 8
Maximum Interval Value (sec): 5
Reference Model: Browse
Minimum Interval Value (sec): 0.5
refmodel

Training Parameters

Controller Training Epochs: 25
Controller Training Segments: 25
☑ Use Current Weights
☐ Use Cumulative Training

Perform plant identification before controller training.

Fig 9 : Model Reference parameters for MRAC.

In this simulation, the conventional PI controller was compared to the model reference adaptive control (MRAC). Fig 10-12 show the error graphs of MRAC (plant identification stage) for the training, validation and testing phase respectively.

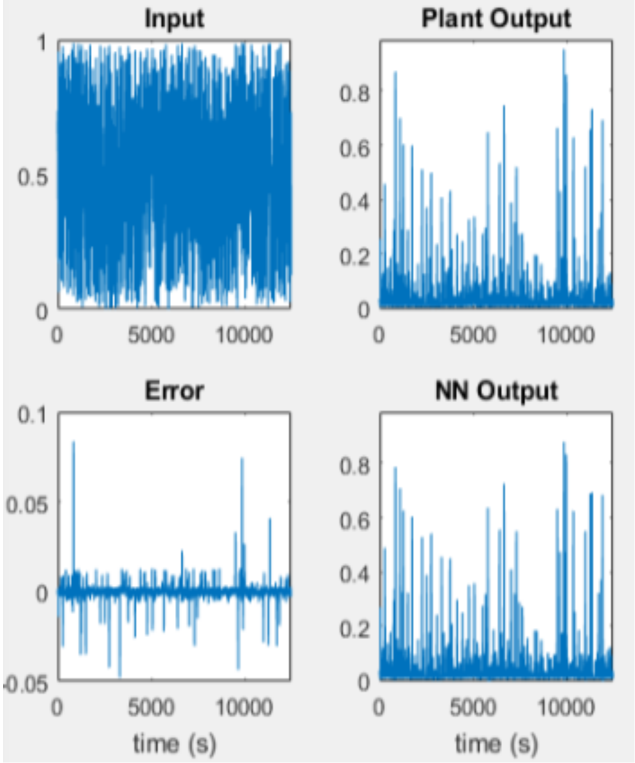


Fig 10 : Error graph for training data

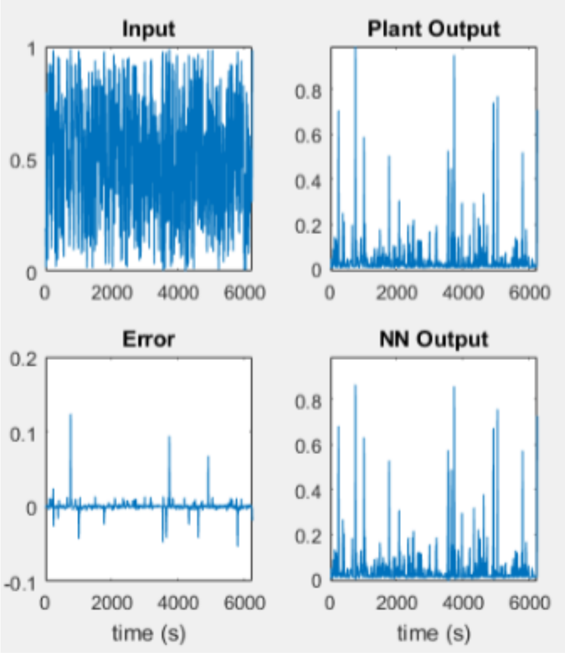


Fig 11 : Error graph for validation data

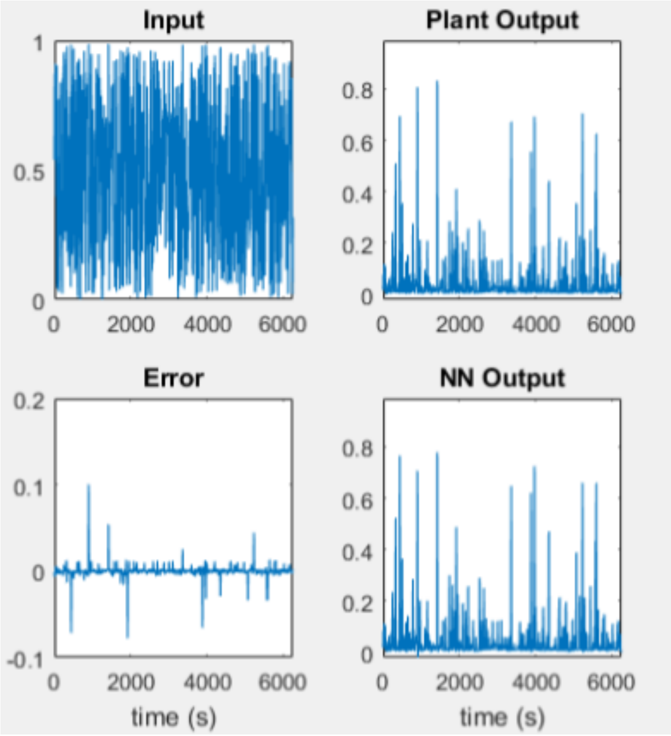


Fig 12 : Error graph for testing data

Figure 13 below shows the reference model input output variation for the model reference stage. As we can see, for input voltage variation between 8 to 14 V, output voltage is almost stable between 13 to 13.5 V, as desired.

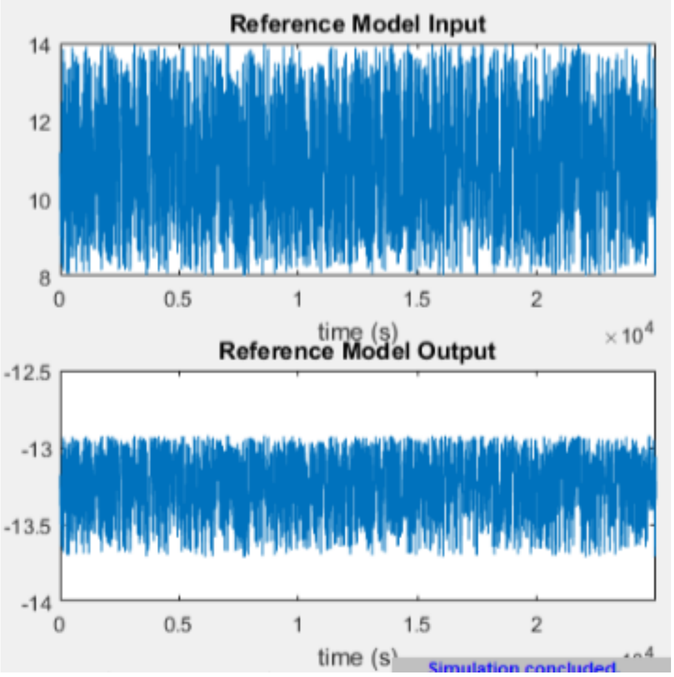


Fig 13 : Reference model input-output variation

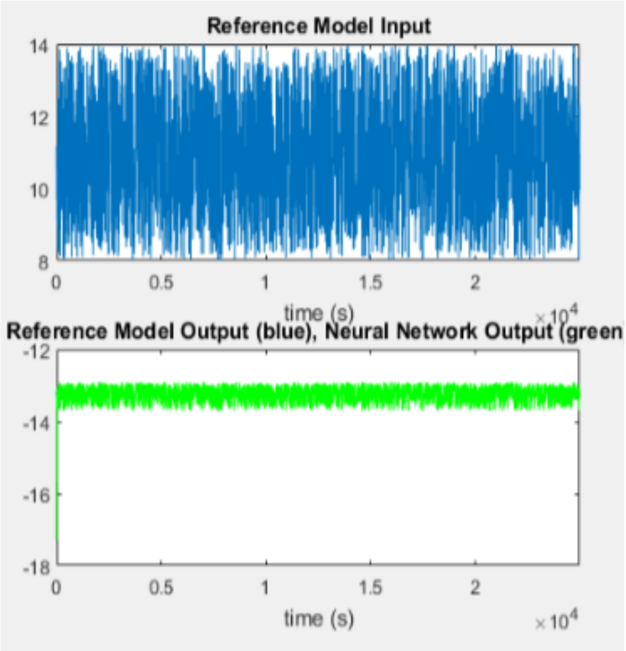


Fig 14 :Plant response for NN model reference control

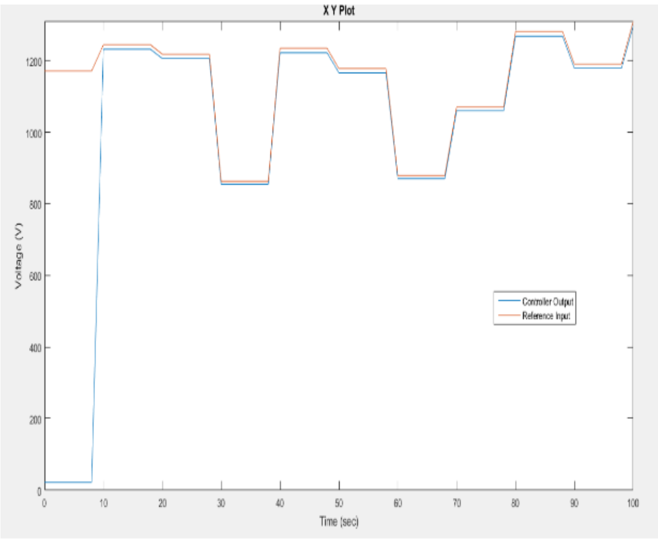


Fig 15 :Reference controller output

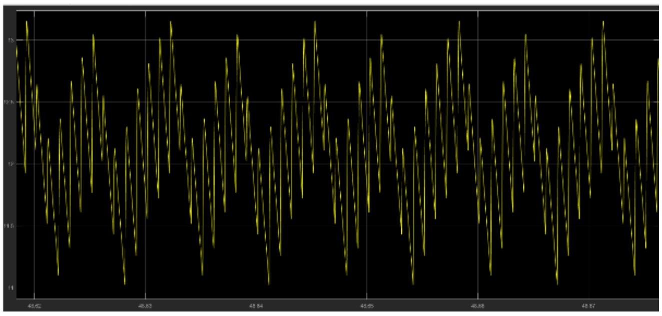


Fig 16 :PI controller output varies between 11- 13V.

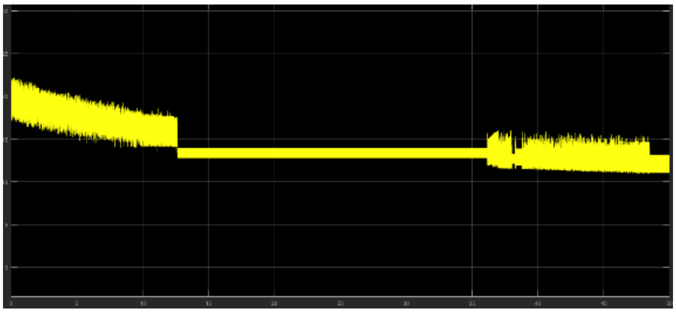


Fig 17 : PI controller Vout

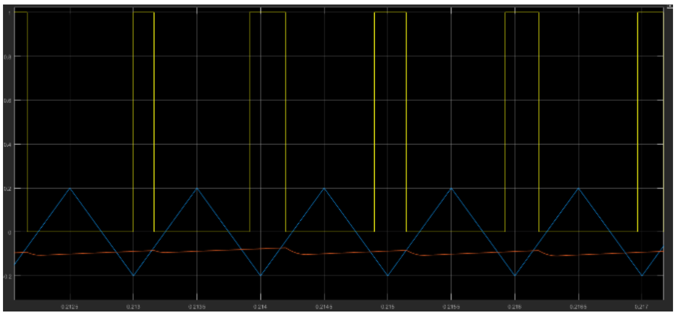


Fig 18 : PWM control using PI controller

Figure 15 shows the response of Buck Boost converter with MRAC to changes in reference voltage. As we can see, the model is able to exactly follow any variations in the reference and thus has a very good fit. If we compare this to figure 17 i.e. output variation of closed loop buck converter with PI controller in feedback, we can see that the fit in figure 17 is not as good. Figure 16 further shows that even after stabilizing, the converter with PI controller in feedback path is able to provide output voltage that varies between 11 V to 13 V (approx) compared to MRAC which is almost constant at around 13-13.5 V (refer Figure 14). Thus, we can say that Neural network controllers offer a much better fit as compared to traditional PI controller.

VI. CONCLUSION

A neural network controller for DC-DC Buck-Boost converter has been presented in this paper. To improve the performance of the ANN controller, an offline learning algorithm based on back propagation scheme is employed. The Simulation results shows that implementation of the online learning technique is feasible for the buck-boost converter. The ANN controller here mimics the operation of PI controller. The data required for training the ANN is obtained by running the above program for different line and load changes. ANN is trained such that any change in the source or load side does not affect the regulation. For training, all data are normalized and the controlled output from ANN is de-normalized and given to PWM modulator to change the pulses to switch.

VII. ACKNOWLEDGMENT

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