

# Neuro-Fuzzy Controller for a Non Linear Power Electronic Buck & Boost Converters

S. Joseph Jawhar<sup>1</sup>, N.S. Marimuthu<sup>2</sup>, S.K Pillai<sup>3</sup> and N. Albert Singh<sup>4</sup>

**Abstract** –This paper describes the design and development of a novel controller for a non-linear power electronic converter. Neuro-Fuzzy controller is proposed to improve the performance of the buck & boost converters. The duty cycle of the buck & boost converters are controlled by Neuro-Fuzzy controller. The conventional PI controllers for such converters, designed under the worst case condition of maximum load and minimum line condition, present a lower loop band width, and the system response is sluggish. The common bottleneck in fuzzy logic is the derivation of fuzzy rules and the parameter tuning for the controller. The Neural Networks have powerful learning abilities, optimization abilities and adaptation. The Fuzzy logic and Neural Networks can be integrated to form a connectionist adaptive network based Fuzzy logic controller. This integrated adaptive system modifies the characteristics of rules and the structure of the control system so that the proposed controller is adaptive for all operating conditions. This paper aims to establish the superior performance of Neuro-Fuzzy controller over the conventional PI controllers and Fuzzy controllers at various operating points of the buck & boost converters.

**Keywords** - ANFIS, DC-DC converter, FLC, ANN, AI.

## I. INTRODUCTION

Traditional frequency domain methods for design of controllers for power converters are based on small signal model of the converter. The small signal model of the converter has restricted validity and changes due to changes in operating point. Also the models are not sufficient to represent systems with strong non-linearity. Moreover the performance of the controllers designed by frequency domain methods is dependent on the operating point, the parasitic elements of the system, and the load and line conditions. Good large signal stability can be achieved only by decreasing the bandwidth, resulting in slow dynamics. A state space averaged model of the classical buck & boost DC/DC converters suffers from the well known problem of Right-Half-Plane zero in its control to output transfer function under continuous conduction mode. The movement of the zero on the complex S-plane as the operating point changes further compounds the problem.

Designers are generally forced to limit the overall closed loop bandwidth to be much less than the corner frequency due to the worst case right half plane zero location. As a result of this, the system has a sluggish small signal

response and a poor large signal response. There are two possible routes to achieve fast dynamic response. One way is to develop a more accurate non-linear model of the converter based on which the controller is designed. The other way is the artificial intelligence way of using human experience in decision-making. Among the various techniques of artificial intelligence, the most popular and widely used technique in control systems is the fuzzy logic. Such an intelligent controller designed may even work well with a system with an approximate model.

Several researchers have contributed in evolving such artificial intelligent (AI) controllers for the buck converters[1],[2]. Among the various techniques of artificial intelligence, the most popular and widely used technique in control systems is the Neuro-fuzzy logic. In recent years fuzzy logic control (FLC) has emerged as one of the practical solution when the process is too complex and non-linear for analysis by conventional quantitative techniques[3],[4]. However the development of a fuzzy controller has to rely on the experience of the experts for deriving effective fuzzy control rules. Recently there has been an increasing use of artificial neural networks (ANNs) for various applications particularly because of their capability for learning from examples and adaptation. This paper aims to establish the superior performance of Neuro-fuzzy controllers at various operating points of the buck & boost converters. The basic concept of Neuro-Fuzzy control method [5] is first to use structure-learning algorithm to find appropriate Fuzzy logic rules and then use parameter-learning algorithm to fine-tune the membership function and other parameters. The proposed controller reveals that it is adaptive for all operating conditions. Simulation results are shown and settling time and peak overshoot have been used to measure the performance.

## II. LINEARIZED MODEL FOR BUCK CONVERTER

Rigorous determination of the stability and the control characteristics of power electronic converters require solving the non-linear model. Linearization of the non-linear model greatly simplifies analysis. Linearized model approximately describe small deviations or perturbations from nominal operation of the system.

### A. Deriving the small signal model of the converter

The buck converter in Fig. 1, when operating in continuous conduction mode, switches between these two linear states, depending on the state of the switch 'S'[6]. The first step in the design of controller for such a bi-linear system is to obtain its control-to-output transfer function. Using the state space averaging technique, the control-to-output transfer function of the classical buck converter operating in continuous conduction mode can be obtained as in [7],[8]. The transfer function shows a right-

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<sup>1</sup>Prof. and Head, Dept. of EEE, Noorul Islam College of Engineering, Kumaracoil, India, Research Scholar, Anna University, Chennai, India.

<sup>2</sup>Prof. & Head, Dept. of EEE, Govt. College of Engineering, Tirunelveli, India

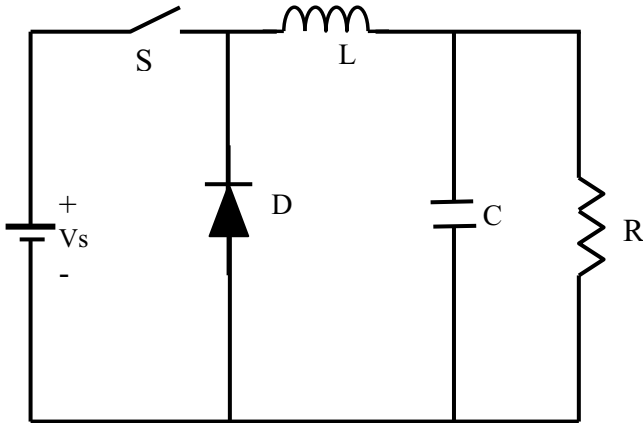
<sup>3</sup>Prof. Emeritus, Dept. of EEE, IIT, Mumbai, India

<sup>4</sup>Executive, Bharat Sanchar Nigam Limited, TamilNadu, India.

E-mail: hodfromnice@yahoo.co.uk

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half-plane zero, which moves with the operating point in the s-plane.



L – Inductance, S – Switch, D – Diode, R – Load Resistance, C – Capacitance

Fig.1:Circuit Diagram of buck converter

$$\frac{Vo(s)}{D(s)} = \frac{(Vs/LC)}{s^2 + s/RC + 1/LC} \quad (1)$$

where D = duty ratio at the operating point, Vs = supply voltage, L = filter inductor, C = filter (output) capacitor, Vo =output voltage, R = load resistor.

It can be seen from (1) that the control-to-output transfer function is dependent on the operating point and its validity is limited to in and around the operating point. As the operating region of the converter is wide, the conventional way of designing the controllers involves selecting the worst case operating point i.e. under the minimum line and maximum load conditions. The transfer function of the converter under the worse case conditions is taken as the base in the design of the controller.

*B. Control requirements*

The control specifications of the converter are

1. Steady state error
  2. Settling time and allowable transient overshoot
- In frequency domain terms, the steady state error is related to the dc loop gain. Thus the higher the open loop dc gain, the lower will be the steady state error.

This section gives a general background and review of the paper or work done by other engineers in the field. It should be well supported by citations. Moreover, the citations are served as a guide for those who want to learn more about the field.

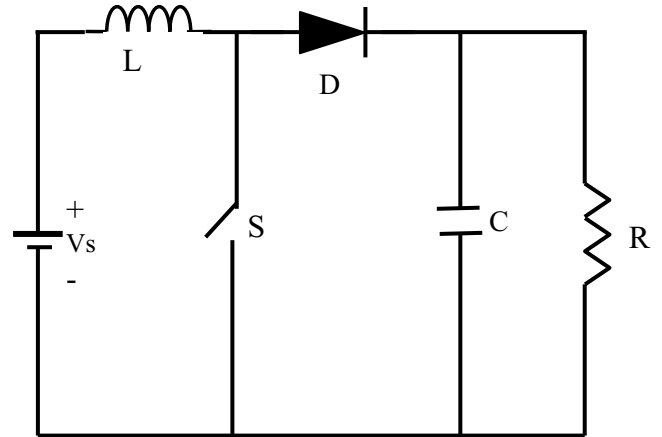
III LINEARIZED MODEL FOR BOOST CONVERTER

Rigorous determination of the stability and the control characteristics of power electronic converters require solving the non-linear model. Linearization of the non-linear model greatly simplifies analysis. Linearized model approximately describe small deviations or perturbations from nominal operation of the system.

*A. Deriving the small signal model of the converter*

The boost converter in Fig. 2, when operating in

continuous conduction mode, switches between these two



L – Inductance, S – Switch, D – Diode, R – Load Resistance, C – Capacitance

Fig.2:Circuit Diagram of boost converter

linear states, depending on the state of the switch ‘S’. The first step in the design of controller for such a bi-linear system is to obtain its control-to-output transfer function. Using the state space averaging technique, the control-to-output transfer function of the classical boost converter operating in continuous conduction mode can be obtained as in [7],[8]. The transfer function shows a right-half-plane zero, which moves with the operating point in the s-plane.

$$\frac{Vo(s)}{D(s)} = \frac{Vs}{(1-D)^2} \frac{\left(1 - s \frac{L}{R(1-D)^2}\right)}{1 + s \frac{L}{R(1-D)^2} + s^2 \frac{LC}{(1-D)^2}} \quad (2)$$

where D = duty ratio at the operating point, Vs = supply voltage, L = filter inductor, C = filter (output) capacitor, Vo =output voltage, R = load resistor.

It can be seen from (2) that the control-to-output transfer function is dependent on the operating point and its validity is limited to in and around the operating point. As the operating region of the converter is wide, the conventional way of designing the controllers involves selecting the worst case operating point i.e. under the minimum line and maximum load conditions[9]. The transfer function of the converter under the worse case conditions is taken as the base in the design of the controller.

*B. Control requirements*

The control specifications of the converter are

1. Steady state error
  2. Settling time and allowable transient overshoot
- In frequency domain terms, the steady state error is related to the dc loop gain. Thus the higher the open loop dc gain, the lower will be the steady state error.

IV. DESIGN PROCEDURE

Neuro-Fuzzy controller is designed based on an average state space model of the classical buck & boost DC-DC

converters. The design of Neuro Fuzzy controller needs a good knowledge of the system operation (fig.4). The various steps involved in the design of Neuro Fuzzy controller for power converter are stated below. A universal Sugeno type Neuro Fuzzy controller has been simulated for the buck converter.

*A. Identification of inputs and outputs:*

This step in the design identifies the key inputs that affect the system performance. The goal of the designer is to ensure that the output voltage matches the reference voltage. The inputs to the Neuro Fuzzy controller are  
 i. The voltage error.  
 ii. The change of voltage error.

Some controllers even may use more information in the form of inductor current. The voltage error input is sampled once in every cycle.

The output of the controller is the incremental control action i.e. the incremental duty ratio.

*B. Fuzzifying the inputs and outputs:*

The universe of discourse of the inputs is divided into seven fuzzy sets of triangular shapes (fig.3). Outputs are also mapped into several fuzzy regions of several singletons.

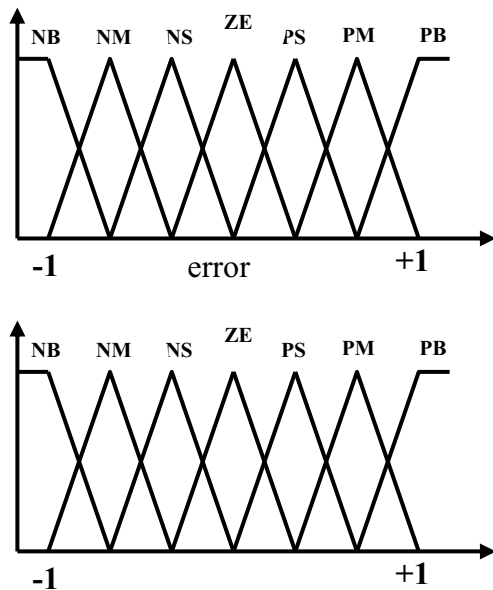


Fig.3 Membership function for inputs

*C. Development of rule base:*

The rules connecting the inputs and the output singletons are based on the understanding of the system. Normally the fuzzy rules have if...then... structure. The inputs are combined by AND operator. The rule-base contains the fuzzy IF-THEN rules of sugeno's first order type.

*D. Defuzzification:*

The output space with the 'fired' singletons is 'defuzzified' to get a final crisp value of the incremental

control, in which the output of each rule is a linear combination of input variables plus a constant term.

*Layer 1:*

Each node in this layer performs a Triangular membership function.

$$O_{1,i} = \max(\min(x-a/b-a, c-x/c-b), 0), i=1 \dots 7. \quad (3)$$

where the parameters a and c locate the "feet" of the triangle and the parameter b locates the peak of the fuzzy set,  $x_i$  is the input to the node i.

*Layer 2:*

Every node in this layer (fig.3) represents the firing strength of the rule.

$$O_{2,i} = w_i = \min(u_{Ai}(x), u_{Bi}(y)), i=1 \dots 7. \quad (4)$$

Eventually the nodes of this layer perform fuzzy AND operation.

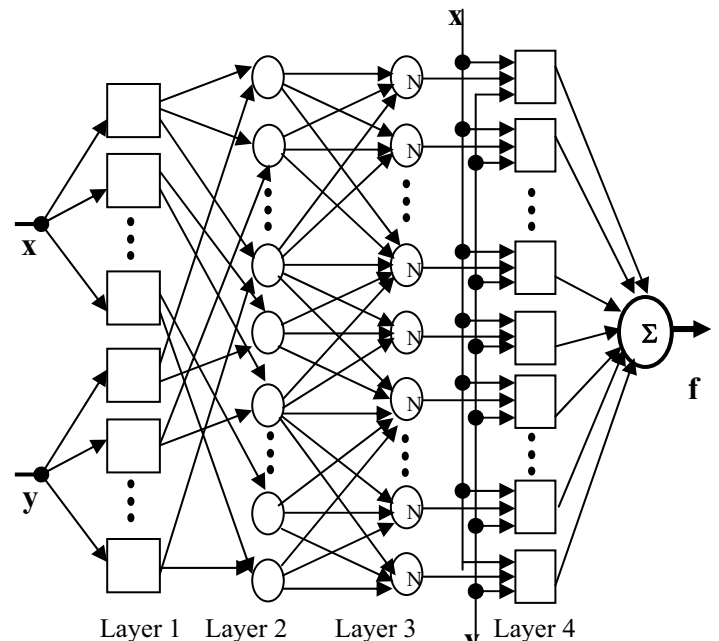


Fig.4. Structure of Adaptive Network Based Fuzzy Inference Systems (ANFIS)

*Layer 3:*

The nodes of this layer calculate the normalized firing strength of each rule.

$$O_{3,i} = w_i = w_i / \sum w_i, i=1 \dots 7. \quad (5)$$

$w_i$  – firing strength of a rule.

*Layer 4:*

The nodes in this layer output the weighted consequent part of the rule table.

$$O_{4,i} = w_i f_i = w_i(p_i x + q_i y + r_i), i=1 \dots 7. \quad (6)$$

where  $\{p_i, q_i, r_i\}$  is the parameter set of this node.

*Layer 5:*

The single node in this layer computes the overall output as the summation of all the incoming signals.

$$O_{5,i} = E w_i f_i / E w_i, i=1 \dots 7. \quad (7)$$

where  $O_{5,i}$  denote the output of the 'i'th node in layer 5.

The Adaptive Neuro-Fuzzy Inference System (ANFIS) training is done assuming that no expert available and the initial values of the membership functions parameters are equally distributed along the universe of discourse and all

consequent parts of the rule table set to zero. The ANFIS starts from zero output and during training it gradually learns the rules and functions as close to the desired controller. Thus during training the network structure update membership functions and rule base parameters according to the gradient descent update procedure.

V. TEST RESULTS

A. Buck Converter

The Neuro-fuzzy control algorithm is now verified by simulation. The simulation is performed in the time domain for the load regulation and line regulation of buck converter [10]. The specification for the 54V, 200 W bench mark converter used is given in Table I. The switching frequency of the converter is taken as 50 kHz.

Table.1 Converter Specifications

Input Voltage	L	C	R	Output
120-150V	1mH	100 $\mu$ F	11-100 $\Omega$	54V

L – Inductance, C – Capacitance, R – Load Resistance

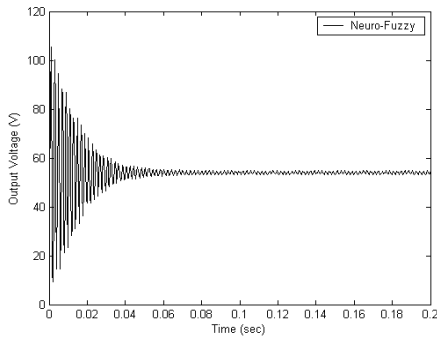


Fig. 5 Output voltage for a minimum line and load condition Vs=130 V, R=100 $\Omega$

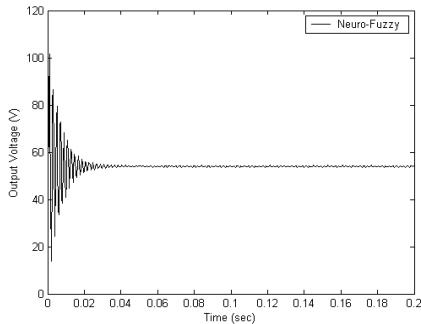


Fig. 6 Output voltage for a midrange line and load condition Vs=135 V, R=40 $\Omega$

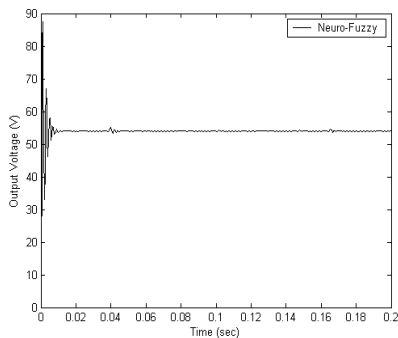


Fig. 7 Output voltage for a maximum line and load condition Vs=140 V, R=11 $\Omega$

The above figs. 5 - 7 demonstrate the effectiveness of the

proposed Neuro-fuzzy controller for output voltage regulation in the closed loop control of buck converter.

B. Boost Converter

The Neuro-fuzzy control algorithm is now verified by simulation. The simulation is performed in time domain for load regulation and line regulation of boost converter [10]. The specification for the 25V, 50 W bench mark converter used is given in Table 2. The switching frequency of the converter is taken as 50 kHz.

Table.2 Converter Specifications

Input Voltage	L	C	R	Output
10-20V	275 $\mu$ H	540 $\mu$ F	12.5-100 $\Omega$	25V 50W

L – Inductance, C – Capacitance, R – Load Resistance

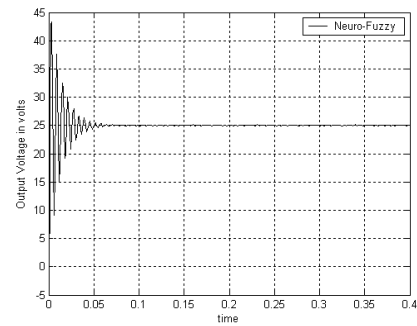


Fig. 8 Output voltage for a minimum line and maximum load condition Vs=10 V, Io=2A

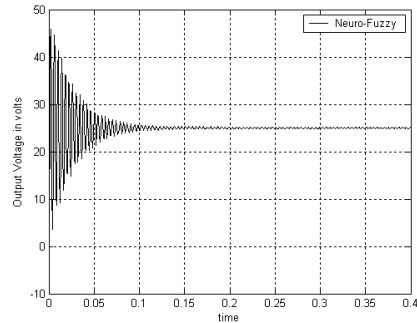


Fig. 9 Output voltage for a midrange line and load condition Vs=15 V, Io=1A

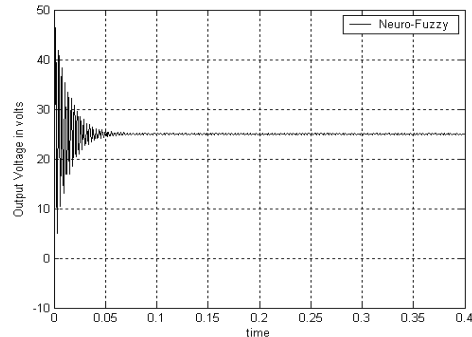


Fig. 10 Output voltage for a maximum line and load condition Vs=140 V, R=11 $\Omega$

The above figs.8 - 10 demonstrate the effectiveness of the proposed Neuro-fuzzy controller for output voltage regulation in the closed loop control of boost converter.

## VI. CONCLUSION

The buck & boost converters are subjected to various disturbances of input voltage and load changes is performed to demonstrate the effectiveness of the proposed controller.

The conclusions drawn from the results are

i. The proposed novel controller gives small overshoots and has much superior performance compared to the local PI controllers.

ii. The Neuro-Fuzzy controller behaves effectively like an adaptive local tuned controller designed for each operating point and gives an improved performance compared to the conventional PI controller.

iii. The proposed Neuro-Fuzzy controller is adaptive for all the operating point as compared to Fuzzy controller.

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India.

S. Joseph Jawhar obtained the B.E. degree from Madurai Kamaraj University, Tamilnadu, India in 1990, the M.Tech. degree from Bharthiyar University, Tamilnadu, India in 1993. He is working as part time toward the Ph.D. degree at Anna University, Chennai, Tamilnadu, India. His present research interests are Soft Computing Techniques and Power Electronics. He is now Professor and Head, Department of EEE, Noorul Islam College of Engineering, Kumaracoil, Tamilnadu,