Voltage Regulation of Buck Boost Converter Using Non Linear Current Control

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Abstract: In this paper, an adaptive non-linear controller is designed for DC–DC buck/boost converter which is stable against converter load changes, input voltage variations and inductor current variations. The proposed controller is developed based on input–output linearization using an adaptive back stepping approach. Owing to non-minimum phase nature of buck/boost converter, the output voltage of this converter is indirectly controlled by tracking the inductor reference current. The inductor reference current is generated by a conventional PI controller. Some simulations and practical results are presented to verify the capability and effectiveness of the proposed control approach.

1. Introduction

DC–DC converters recently have a great impact in the power electronics and in automatic control system. This is due to their application over wide ranges in communication systems. It has some of the application which is as follows: used in computers, industrial electronics, battery-operated portable equipment and uninterruptible power supply. When considering the automatic control, these closed-loop power converters are inherently non-linear systems which include the switching and interaction of controllers. With these non linearity's, the small signal analysis is not enough to analyze the steady state performance of the converter and the transient analysis accurately. To solve these problems, there were different non linear control methodologies which are as follows: sliding mode, fuzzy and adaptive control approaches.

There were different switching control methods such as pulse width modulation (PWM) based on fast switching and duty ratio control extensively used. At the same time, one of the parameter: magnetic saturation of the converter is also a major consideration which also causes non linearity which makes the converter unstable with the load disturbances and variation in input voltage. Because of non-minimum phase nature of boost and buck/boost converters, it is difficult to regulate the converter output voltage directly.

In some of the existing paper the indirect voltage regulation is discussed which are having their own drawbacks are reported for the control of buck/boost controller.

The FLC approach is general in the sense that almost the same control rules can be applied to several converters. However, some scale factors must be tuned according to converter topology and parameters. The fuzzy controller requires only sensing of one inductor current and the output voltage, and its implementation is relatively simple. Standard discrete electronic circuitry can be used, resulting in a control speed similar to that of other standard regulators.

Fuzzy controllers cannot provide better small signal response than standard regulators. Since fuzzy logic control is based on defining rules, application of nonlinear control to face the nonlinear nature of converters is easy.

Integral-variable-structure control (IVSC) schemes for parallel dc–dc converters. The choice of a VSC is logical for power converters because the control and plant are both discontinuous. All of the nonlinear controllers are not based on VSC, but relied on smooth averaged models of the power converters. Therefore, the control is valid only on a reduced-order.

Sliding-mode (SM) control is well-known for good stability and regulation properties in a wide range of operating conditions. It is also well known for its better choice than other non-linear controllers for its relative ease of implementation. In particular, the fixed frequency PWM-based sliding mode controllers, which amplify control signals from the controller. It is easy for the practical implementation of the converter. It is not obtained based on a Lyapunov function; as a result it cannot be robust against load changes, input voltage variations and converter parameter uncertainties. In it has been shown that when the load changes, a minimum steady-state error still exists in regulated output voltage.

The main drawback of the SM method described in is that it is applicable only for DCM operation and the converter duty cycle is obtained based on steady-state analysis of the converter. In addition, a high amount of SM chattering is seen in converter output voltage.

Current mode control algorithm for converters operating in DCM is applicable for power factor correctors (PFC), where more precision in power factor correction and faster dynamic response are required, compared to automatic current shapers. The basic idea of this control scheme is to estimate the value of the duty ratio based on the measured samples of the voltage signals in order to make the average value of the inductor current track the input control signal. This control scheme operates in a fixed frequency.

A two-loop microprocessor-based controller has been described for the DC to DC converter in CCM operation. The purpose of the inner loop is to control the inductor reference current based on variable band hysteresis current controller. The next loop provides a set point to the first control loop according to the output voltage error. Hysteresis current controller has some major disadvantages such as variable switching frequency, which makes converter implementation difficult.

A non-linear control strategy is described based on input–output feedback linearization to solve the non-linearity and unstable zero-dynamics problems of the DC–DC boost converter operating in CCM. This non-linear controller requires an exact model of the converter. The controller reported is not robust against load changes, input voltage variations and parameter uncertainties. It can be said that the developed controller described is similar to a non-adaptive version of the back stepping controller proposed. Note that the DCM operation of the DC–DC boost converter has not been considered.

An adaptive back stepping control approach has been developed in order to control the DC–DC boost converter in CCM. It is assumed that the load resistance is uncertain and its value is estimated based on a suitable Lyapunov function. Also, a backstepping control of the DC–DC boost converter in the presence of coil magnetic saturation has been reported.

Indirect output voltage regulation is accomplished through the regulation of inductor reference current, considering steady-state analysis of the converter. This method has been supported only by computer simulation results. Also, these approaches are not robust and stable with reference to converter parameter uncertainties and input voltage variations. In addition, these proposed methods are only applicable for CCM operation of the converter. Moreover, the output voltage of the converter is controlled indirectly based

ISSN 2229-5518

on steady-state analysis with no closed-loop voltage control. For these reasons, some steady-state error in converter output voltage is necessary.

This controller is based on steady-state analysis of the DC–DC buck converter in CCM and DCM operations. As a result it cannot guarantee controller stability and robustness against load disturbances, input voltage variations as well as with reference to converter parameter uncertainties. In minimum and maximum duty ratios are assumed for converter CCM and DCM operations, which are obtained based on steady-state analysis of the converter. Note that during a load disturbance, the duty ratio of the converter is not predictable especially in DCM operation.

A conventional PI and sliding mode double-loop controller have been proposed for a buck/boost converter with wide range of load resistance and reference voltage which is not valid for the DCM operation. The controller has been verified only by computer simulation.

In this paper, an adaptive non-linear current controller is developed for the buck/boost converter which is robust and stable with respect to converter parameter uncertainties and variations in input voltage. Due to the non-minimum phase nature of the buck/boost converter, the output voltage of this converter is indirectly controlled by tracking the inductor reference current.

The inductor reference current is generated by a conventional PI controller. The proposed control technique is applicable to both CCM and DCM operations. In the DCM operating mode, the duration in which the inductor current is zero, is assumed to be constant but has an unknown parameter similar to other converter parameters. The capability and effectiveness of the developed adaptive non-linear control approach is supported by simulation and experimental results.

2 Averaged state space modeling of the DC–DC buck/boost converter:

Considering averaged state-space modeling, the DC–DC buck/boost converter in DCM can be modeled as follows

$$X_1 = \theta_1 (1\text{-}u)\, x_2 + \theta_5 x_2 + \theta_4 u + \theta_7 x_1 \quad (1)$$

$$X_2 = \theta_2 (1\text{-}u)\, x_1 + \theta_6 x_1 + \theta_3 x_2 \quad (2)$$

where u (duty ratio) is the control input of the converter and Note that, if it is equated to zero, the converter model for CCM operation will be obtained.

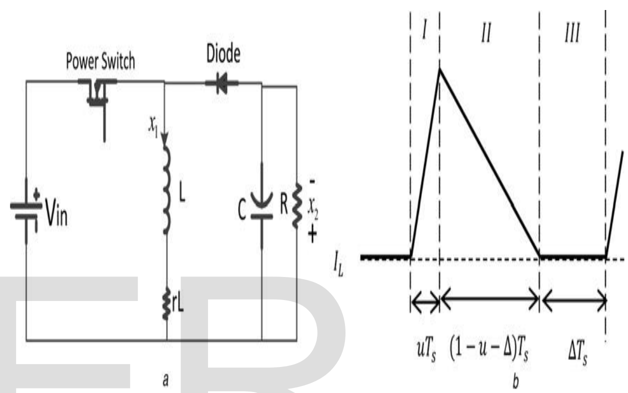

Fig1. Inductor current of a DC–DC buck/boost converter operating in DCM

3. Adaptive non-linear controller design:

Block diagram of the developed two-loop controller is illustrated in diagram. To eliminate the steady-state error of the system, a convectional PI controller is used to generate.

Adaptive non-linear current controller is designed for DC–DC buck/boost converter in the following steps.

Step1: Considering (1), Converter output current error,

where, I_L is the inductor reference current.

Step 2: Since θL_1-I_1 and $C_1 Z_1$ may not be equal, the second error should be defined.

Using the same procedure as in the DCM operation an adaptive backstepping current

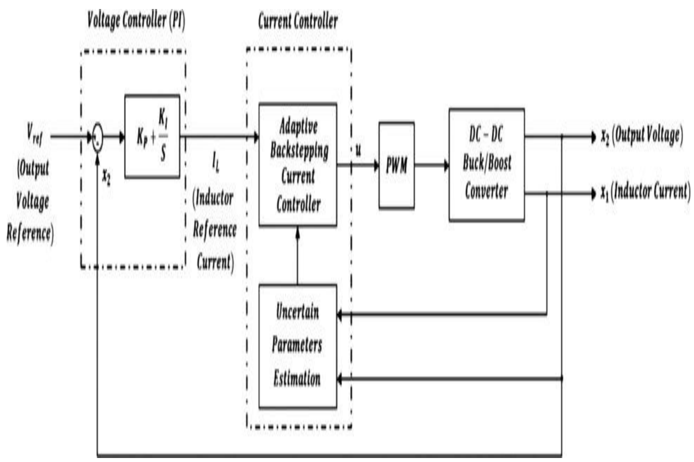

Fig2. Designed Two Loop Controller

Table-1

S.No	Nominal Specification	Ratings
1	Input Voltage	12V
2	Converter Inductor	550µH
3	Output Capacitor	330µF
4	Load Resistance	200Ω
5	Switching Frequency	9.25KHz
6	Inductor Series Resistance(R_L)	0.2 Ω
7	Capacitor Series Resistance(R_C)	0.05 Ω

4. Simulation and practical results:

Considering a DC–DC buck/boost converter with electrical circuit shown in Fig. 1a and nominal specifications given in Table 1, some simulation and practical results are obtained for DCM and CCM operations of this converter. An adaptive controller has been used for practical implementation of the proposed control approach. An IL300 voltage isolated sensor and Hall Effect current sensor are used to measure converter output voltage and inductor current. Choosing a sampling frequency of 130 kHz and a converter switching frequency of 9.25 kHz, it is possible to sample 14 points in each switching period. The processor is fast enough to update the controller and estimation rules after each sampling.

Simulation Diagram

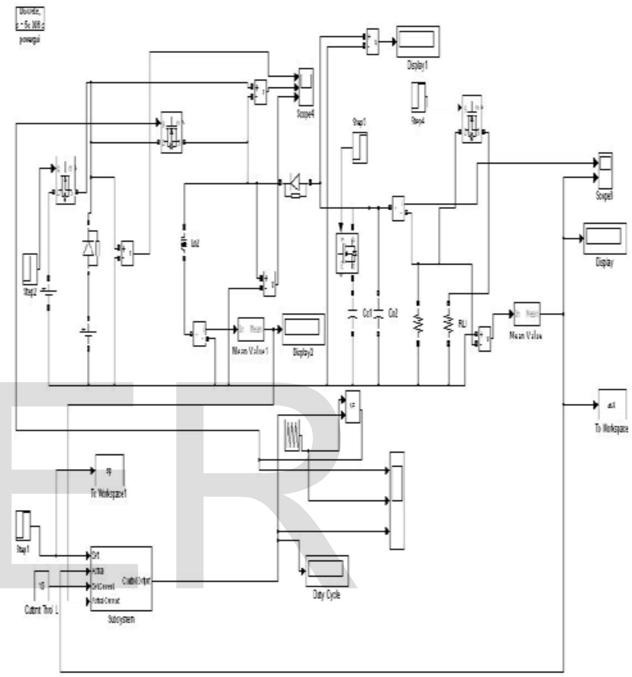

Fig3. Experimental Setup and Implemented Circuit

It provides the constant and stable output with respect to the change in the uncertain parameter which is consider here as inductor current and output voltage. Even though there is a wide change in those parameters, the trained neural network controller will regulate the output voltage to its desired value. In this the training algorithm used is, adaptive backstepping approach which is similar to that of the back propagation algorithm and the operation of the training is also similar to that approach.

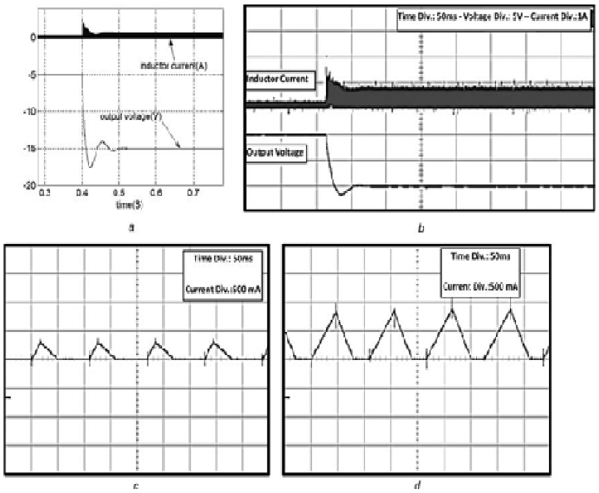

Fig4. Step response of the proposed controller. At t=0.4 s, reference voltage is stepped up from −5 V to −15 V

4.1 Buck operation

Test 1: Considering the nominal values of the power circuit given in Table 1, the converter output reference voltage is stepped up from V_{ref} = 5 V to V_{ref} = 15 V at t = 0.4 s. For this condition simulation and practical results obtained are demonstrated in fig4.

Test 2: Assume that the converter operates in a steady-state condition with R = 100 Ω and C = 660 μF and V_{ref} = −5 V. Considering a step change in load resistance and output capacitor to R = 200 Ω and C = 330 μF at t = 0.4 s and then back to primary values at t = 0.6 s, simulation and experimental results obtained for this condition are shown in fig5.

Test 3: Assuming an output reference voltage of V_{ref} = −5 V, simulation and experimental results of the DC–DC buck/ boost converter to step changes of input voltage are shown. In this test, at t = 0.4 s the input voltage is stepped up from +12 V to +17.

Test 4: Considering a steady-state DCM operation of the converter with V_{ref} = −5 V, R = 200 Ω, V_{in} = 12 V and C = 330 μF; these values are stepped up to R = 100 Ω, V_{in} = 17 V and C = 660 μF at t = 0.4 s. Simulation and experimental results obtained for this test are shown in fig6.

4.2 Boost operation

Some tests are repeated for boost operation of the converter. In these tests, the converter output voltage reference is chosen to be V_{ref} = −18 V.

Test 5: Assume that the converter operates in steady state with R = 100 Ω. Consider a step change in load resistance to R = 200 Ω at t = 0.2 s and then back to primary values at t = 0.4 s, simulation and experimental results obtained for this test are shown. Under these conditions, the converter operates in DCM.

Test 6: Considering a steady-state DCM operation of the converter that is achieved by R = 200 Ω, V_{in} = 27 V and C = 330 μF; these values are stepped up to R = 100 Ω, V_{in} = 17 V and C = 660 μF at t = 0.3 s and then back to primary values at t = 0.65 s. Simulation and experimental results obtained for this test are shown in fig8.

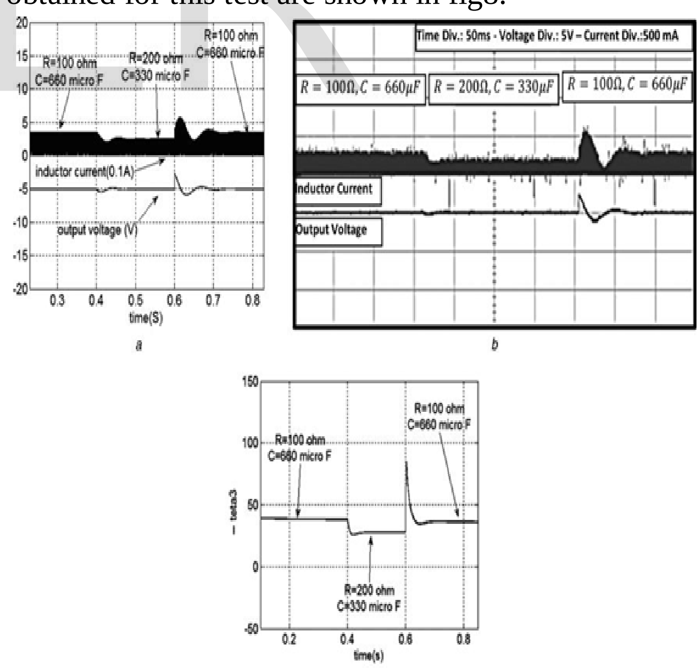

Fig5. Response of the controller to step changes of R and C in DCM

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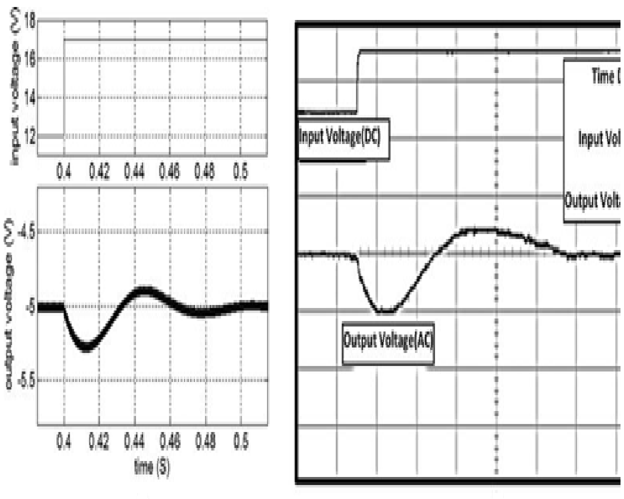

Fig6. Response of the controller to step changes of input voltage in DCM

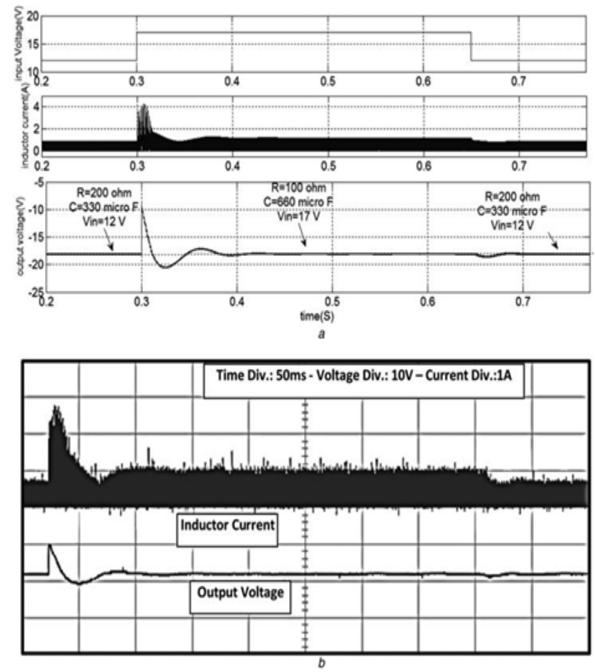

Fig8. Simulation and experimental response of the proposed controller to simultaneous variations in input voltage, load resistance and inductor current

a Simulation

b Practical

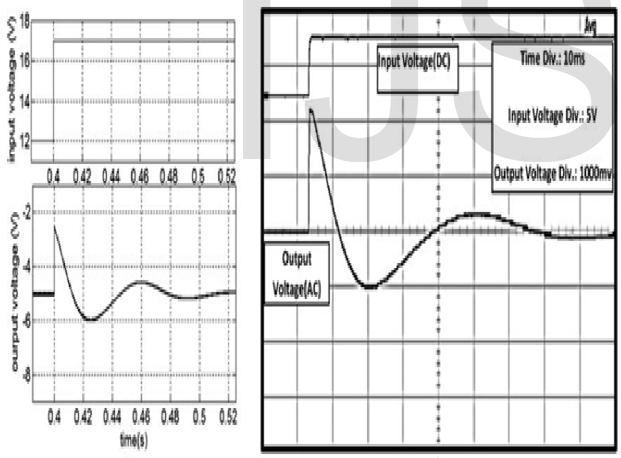

Fig7. Simulation and experimental response of the proposed controller to simultaneous variations in input voltage, load resistance and output capacitor

a Simulation

b Practical

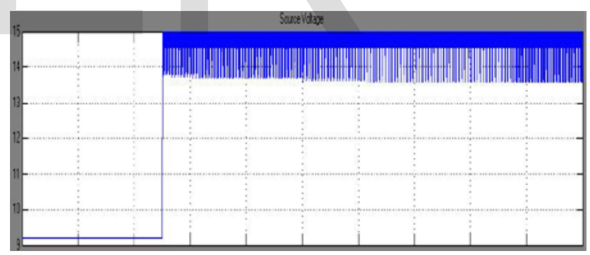

Fig9. Source Voltage

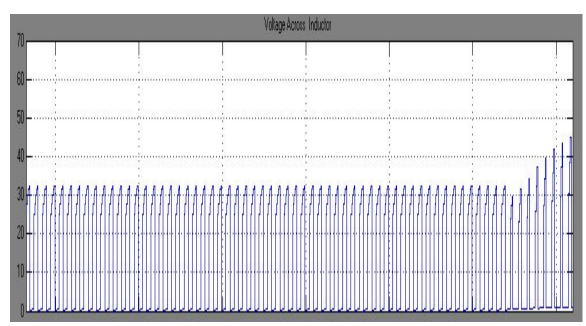

Fig10. Voltage across Inductor

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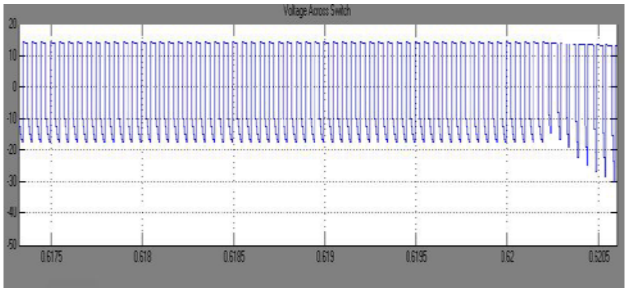

Fig11.Voltage across Switch

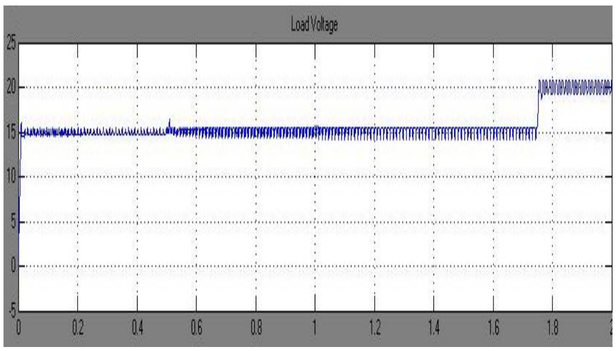

Fig12. Load Voltage

5. Hardware Projection:

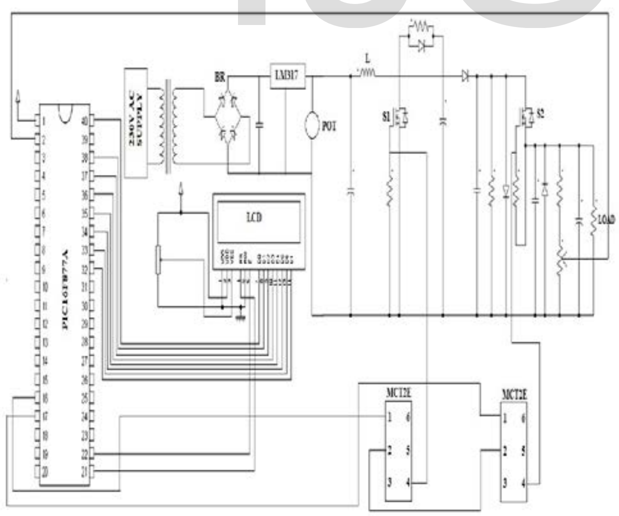

Fig9. Hardware Circuit Diagram

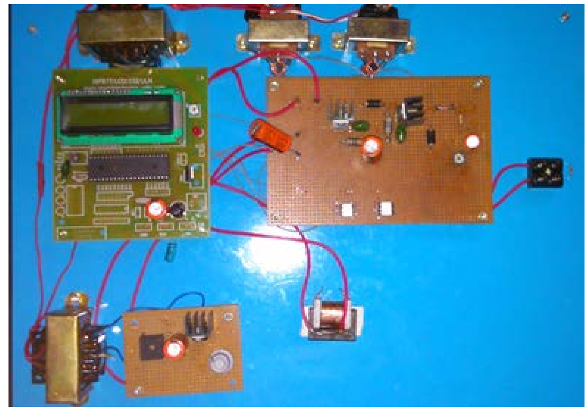

Fig10. Hardware Implementation

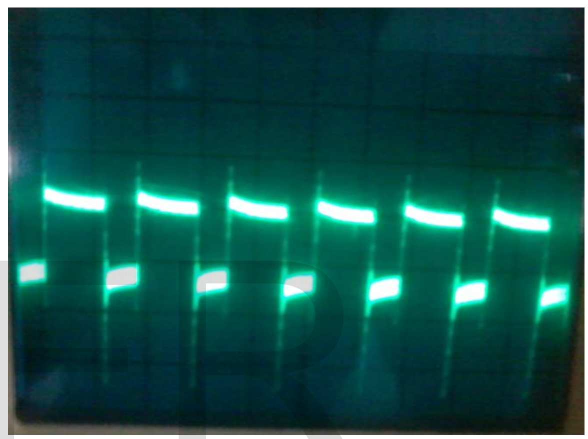

Fig11. PWM Signal for Boost operation

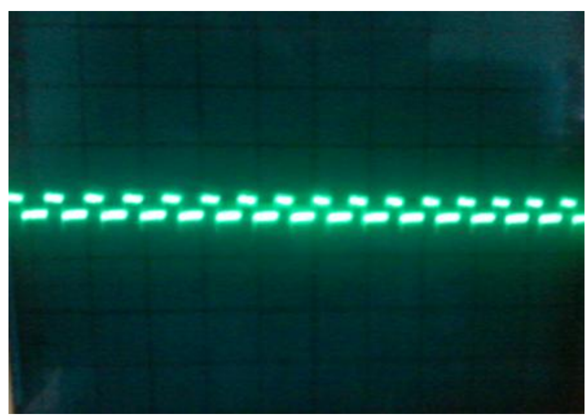

Fig11. PWM Signal for Buck operation

6. Conclusion:

In this paper, the CCM and DCM operations of a DC–DC buck/boost converter have been investigated. An adaptive non-linear current controller has been developed based on input–output feedback linearization using an adaptive backstepping control approach. Owing to non-minimum phase nature of the buck/boost converter, the output voltage of this converter is indirectly controlled by tracking inductor reference current. The inductor reference current is generated on-line by a conventional PI controller. The effectiveness and capability of the proposed control approach has been supported by simulation and experimental results. Simulation and experimental results have been obtained for some tests. These results are corresponding to the converter CCM and DCM operations. These results confirm that the proposed controller is stable and robust with reference to converter uncertainty parameters, load disturbances and input voltage variations.

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