A COMPARATIVE STUDY OF ADAPTIVE FEEDBACK AND FEEDFORWARD CONTROLLER SCHEME TO BOOST CONVERTER

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Abstract

Now a day, the uses of adaptive controller in various fields increase rapidly as it adapts all the changing environmental condition by designing a control law itself. Though the controller doesn't require any information for the time varying parameters such as inductor current and capacitor voltage, hence it can be preferable for using in converter circuits. The adaptive controller is designed always to give a good output voltage regulation regardless of system uncertainties and external load variations for some specific range. The boost converter is a non-minimum phase system so local stability can be achieved by the linearizing technique but better stability can be found by some non linear control technique under load variations. In this paper both adaptive feedback and feed forward controller schemes are applied to the non minimum phase boost converter and the results are analyzed in MATAB/ Simulink platform. Adaptive feed forward controller scheme reduces the output voltage oscillation very fast and adaptive feedback controller scheme tracks the output voltage very smoothly with minimum overshoot.

Keywords: *Boost converter; adaptive feed forward control; adaptive feedback control; Pulse width modulation; hysteresis modulation.*

1. INTRODUCTION

The switching frequency of a power electronic converter (PEC) plays a great role during the variation in input voltage and output load. So it is advised to keep the switching frequency constant irrespective of the perturbation in source voltage and output load. Pulse width modulation scheme [1] is used to generate gate pulse by comparing the carrier signal and reference signal for the operation of switch. The application of adaptive feed forward control scheme [2] [3] varies the hysteresis band limit for any change in the input voltage and the application of adaptive feedback controller [4] [5] varies the control parameters for any change in the output load.

In such cases, a controller needs to be designed for a DC-DC converter to stop the output voltage fluctuation under source voltage disturbances. The use of feed forward controllers [6] under disturbance conditions make the output voltages smooth but the output voltage is disturbed while there is an abrupt change in source voltage. Disturbance rejection and tracking performance is improved by the use of feedback control [7], developing two degree of freedom (2-DOF) design. In feed forward control scheme zero steady state error is obtained by properly adapting a gain [8]. This paper presents an investigation on variation of input voltage and load on system performance and also proposed solutions for mitigating the problem by choosing accurate control technique.

The PI controller along with the sliding mode controller used in [9] is widely used for power converter as it gives better output voltage regulation and large disturbance rejection; therefore it is a good candidature to perform the simulation with the proposed adaptive feedback controller [10]. The proposed controller forces the output voltage to track the reference voltage despite of the input voltage and load resistance variations.

In this paper performance analysis were carried out for a non minimum phase boost converter using different adaptive controller techniques [11]. Different controlling methods like adaptive feed forward controller and adaptive feedback controller [12] schemes were used to regulate the output voltage. Simulation results and performance analysis for these two controller techniques are discussed in this paper which provides satisfactory performance for disturbance rejection and for tracking of the output voltage.

2. MATHEMATICAL MODELLING OF POWER CONVERTER

The state variables of a boost converter is regulated by a voltage mode controller [13][14]. The state variables are the output voltage error and the derivative of the output voltage error. The theoretical model and its analysis are discussed in this section.

A. Mathematical model of the boost converter

Figure 1 shows the schematic diagram of non isolated boost converter operating in continuous conduction mode (CCM). During switch on, the diode gets reverse biased and during switch off the diode gets forward biased.

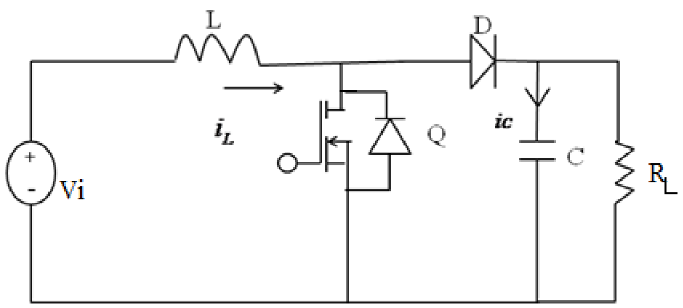

Figure: 1 schematic diagram of boost converter

The ON state and OFF state equations of the boost converter considering the inductor current and capacitor voltage as two states along with control input u, can be expressed in equations (1) and (2) as mention in [15].

$$\frac{di_L}{dt} = \frac{V_i}{L} + \frac{v_C}{L}(u-1) \qquad (1)$$

$$\frac{dv_C}{dt} = -\frac{v_C}{R_L C} + (1-u)\frac{i_L}{C} \qquad (2)$$

L and *C* represent the inductance and capacitance of the boost converter. Let x_1 represents the voltage error and x_2 is the derivative of x_1 which are the two state variables.

$$x_1 = V_{ref} - \beta V_o \qquad (3)$$

$$x_2 = \dot{x}_1 = -\beta\frac{dV_o}{dt} = -\beta\left(-\frac{v_c}{R_L C} + (1-u)\frac{i_L}{C}\right) \qquad (4)$$

βV_o is the sensed output voltage. $u=1$ while the switch is ON otherwise 0. Taking the derivative of (3) and (4), the state space model (SSM) can be stated in (5).

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & \frac{-1}{R_L C} \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{-\beta V_i}{LC} \end{bmatrix} u + \begin{bmatrix} 0 \\ \frac{-\beta V_i}{LC} \end{bmatrix} \qquad (5)$$

B. Modeling of the controller

The objective of the controller is to control the state variables, such as voltage error (x_1) and derivative of voltage error (x_2). The control parameters x_1 and x_2 determines the switching state "*u*" by using the switching function given by

$$u = \begin{cases} 1;\ \text{switch"ON"s>k} \\ 0;\text{switch"OFF"s<-k} \\ \text{unchanged"otherwise"} \end{cases}$$

'*s*' represents the control signal and '*k*' represents the hysteresis bandwidth and is a constant parameter calculated by using the relation as stated in (6).

$$k = V_{od}\frac{(1-d)}{2 f_{sd} L} \qquad (6)$$

Where

$$d = 1 - \frac{V_i}{V_{od}} \qquad (7)$$

f_{sd} is the desired steady-state switching frequency, V_{od} is the output voltage that has to be desired for an input voltage V_i is the input voltage respectively. Again

$$s = \alpha x_1 + x_2 \qquad (8)$$

α is the sliding coefficient and that can be determined by using the relation (9).

$$\alpha = \frac{1}{R_L C} \tag{9}$$

α changes according to the load, that implies switching frequency will differ slightly from the desired switching frequency f_{sd}. α must be positive number for achieving system stability. Hence the control signal is reconfigured as stated in equation (10) and applied to the converter [17].

$$s = k_p x_1 - i_c \tag{10}$$

Where k_p is a constant, shows the fixed gain parameter in voltage error and k_p can be given as $k_p=1/\beta R_L$. k_p value must be changed according to the load resistance.

C. Classification of Problems

When the operating conditions deviate from the nominal conditions, the sliding mode controller along with the hysteresis modulation (HM) suffer a variation in the frequency. From relation (6) it can be observed that the switching frequency has a direct relation with the excitation and response [18]. As the output voltage depends upon the loading conditions, hence it can be concluded that the switching frequency will vary by varying the input voltage and the output load. The objective of this work is to maintain a constant output voltage. Table-1 shows the specification for the step up converter.

Table-1 SPECIFICATION OF BOOST CONVERTER

DESCRIPTION	*PARAMETER*	*NOMINAL VALUE*
Input voltage	V_i	40 V
Capacitance	C	200 μF
Inductance	L	3 mH
Output load	R_L	25Ω
Set point value	V_{od}	115.55 V
Desired switching frequency	f_{sd}	100 kHz

Here, the controller generates a turn on signal $u=1$ if $s>k$ and a turn off signal $u=0$ if $s<-k$. The control signal is determined by the relation (10). By substituting $i_c = i_L - i_R$, the control signal can be obtained as in (11).

$$s = k_p x_1 - (i_L - i_R) \tag{11}$$

D. Solutions methodologies

The above problem can be solved by using two control schemes such as adaptive feed forward controller and adaptive feedback controller scheme [19]. The switching frequency remains constant by adding a constant ramp signal directly into the controller [20].

3. ADAPTIVE FEEDFORWARD CONTROL METHOD

For maintaining the switching frequency constant against the input and load variation an adaptive feed forward control method [21] is introduced that varies the hysteresis band in the hysteresis modulator of the sliding mode controller. The block diagram of the feed forward boost converter is shown in figure 2. In this diagram k_p is the fixed gain parameter and is multiplied with the voltage error to generates a current signal and that is compared with capacitor current

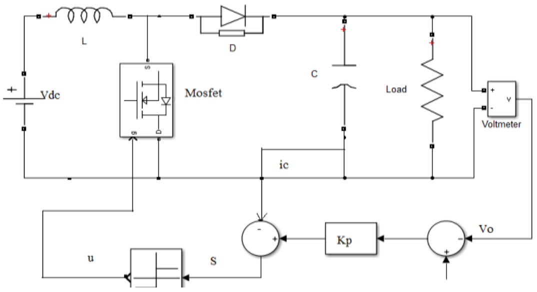

Figure: 2 schematic diagram of feed-forward voltage controlled boost converter

The hysteresis bandwidth depends upon the range of the input voltage. The bandwidth is large for maximum input voltage and is less for minimum input voltage. For getting the desired switching frequency under certain output voltage, the source voltage is properly fed and the hysteresis bandwidth is properly chosen for boost converter. The hysteresis bandwidth can be estimated by using the relation described in (12) for various input voltages.

$$k = \frac{V_{od}(1-d)}{2f_{sd}L} \qquad (12)$$

In a 2-DOF control structure, one is for ensuring that V_{out} always tracks the V_{ref} [17].

4. ADAPTIVE FEEDBACK CONTROL METHOD

The feedback control scheme depends upon the loading condition of the converter. The variation in switching frequency is obtained when the operating load resistance deviates from the nominal load resistance. The sliding coefficient for a given resistance is chosen as given in relation (13) for a 2 stage converter.

$$\alpha = \frac{1}{R_{L(nom)}C} \qquad (13)$$

Equation (13) shows the deviation of the switching frequency from the apparent value. So as to ensure the valid operating condition, it can be carried out by causing a more adaptive sliding coefficient and also the sliding coefficient is designed depending upon the load as stated in (9), thereby improving the system's performances. Figure 3 shows the adaptive feedback controller scheme for boost converter.

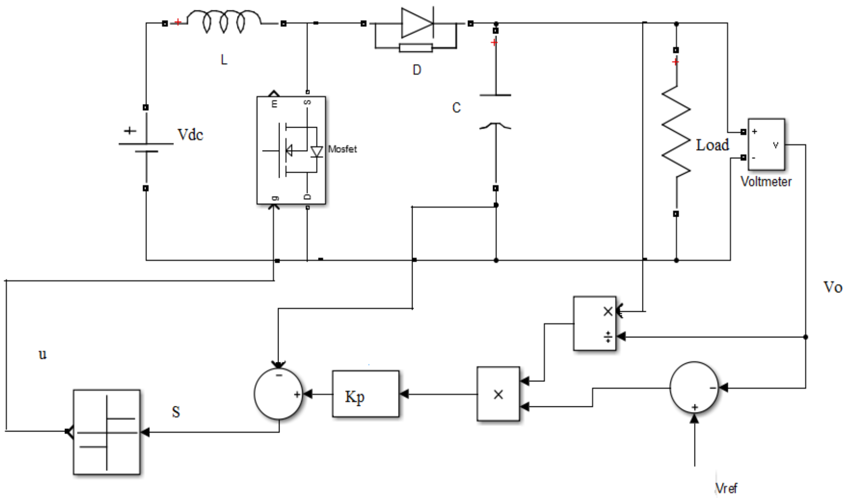

Figure: 3 schematic diagram of adaptive feedback controller to boost converter

5. SIMULATION RESULTS

Due to the presence of non linear elements in the power electronic converter, design of proper disturbance rejection performance will be adjusted and is difficult to design a proper model including such effects. Under this situation, adaptive feed forward compensation plays a great role and is more effective and useful. The simulation is implemented in MATLAB/Simulink platform. The parameter specifications of boost converter are described in Table-1.

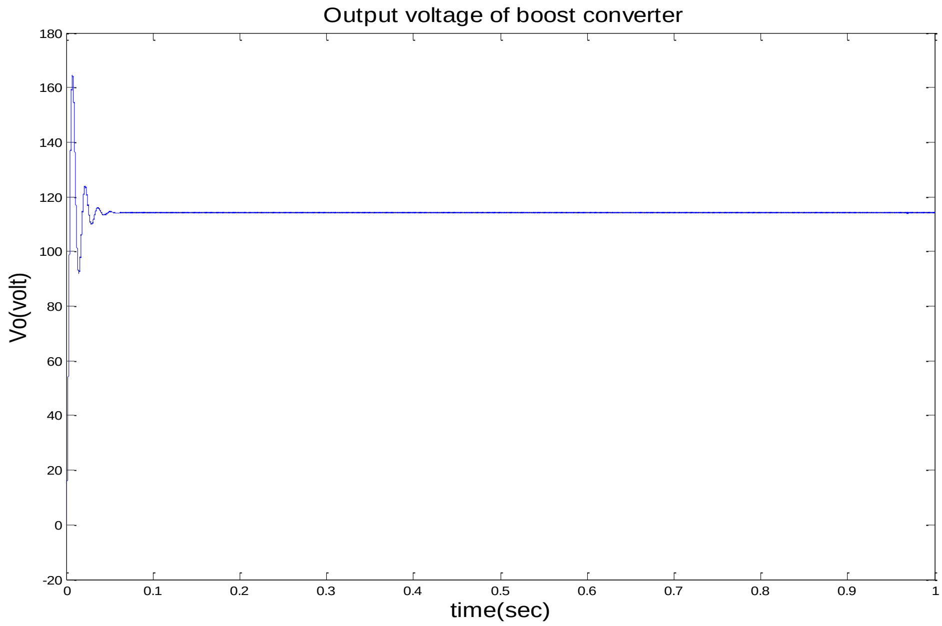

Figure: 4 output voltage of the open loop boost converter

Figure 4 depicts the output of boost converter in open loop mode. It is observed that the output voltage is 117.5 volt that exceeds the desired value having more oscillations at the starting instant. Then it achieves the steady state voltage after few seconds. The peak overshoot is very high approximately 43.9%. Figure 5 illustrates the output voltage of boost converter by varying input voltage.

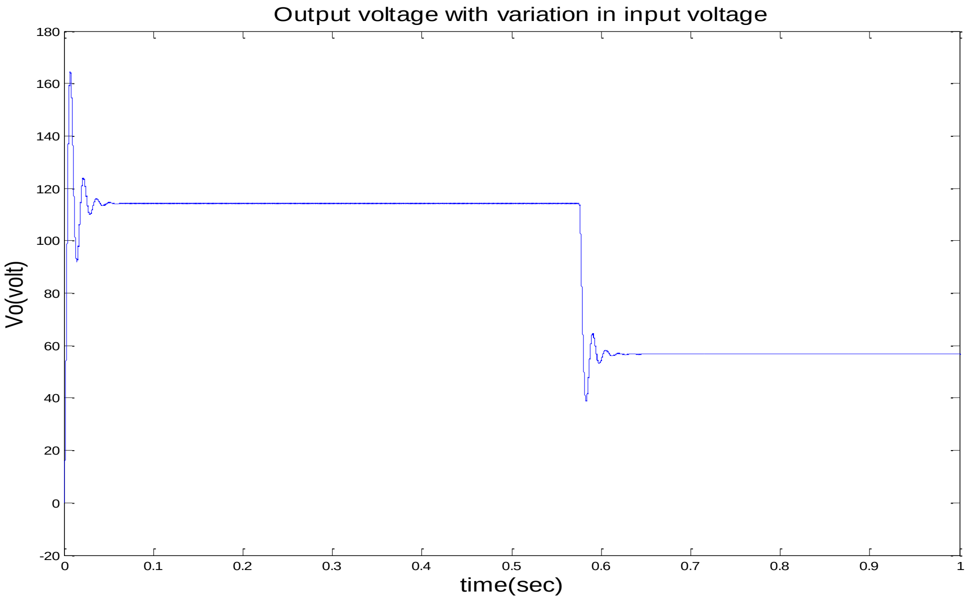

Figure: 5 output voltage of the boost converter by varying the input voltage

It is observed from the above figure that by varying the input voltage, output voltage is different with large overshoot. Disturbance rejection and tracking both are not possible for open loop boost converter. So we design adaptive feed forward controller for disturbance rejection and adaptive feedback controller for tracking purposes. Figure 6 shows the output voltage of the boost converter with adaptive feed forward scheme.

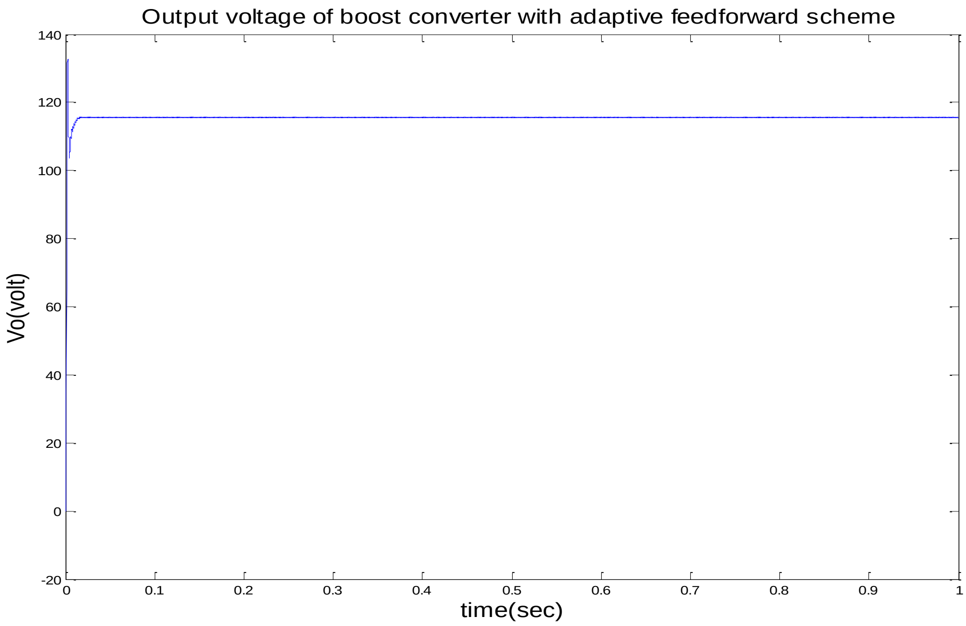

Figure: 6 output voltage of the boost converter with adaptive feed forward scheme

It is observed that the oscillations reduced at the starting instant and also the peak overshoot is reduced from 43.89% to 13.8 % by the use of adaptive feed forward controller and also it settles very quickly than open loop converter. Figure 7 shows the feed forward boost converter output voltage for different input.

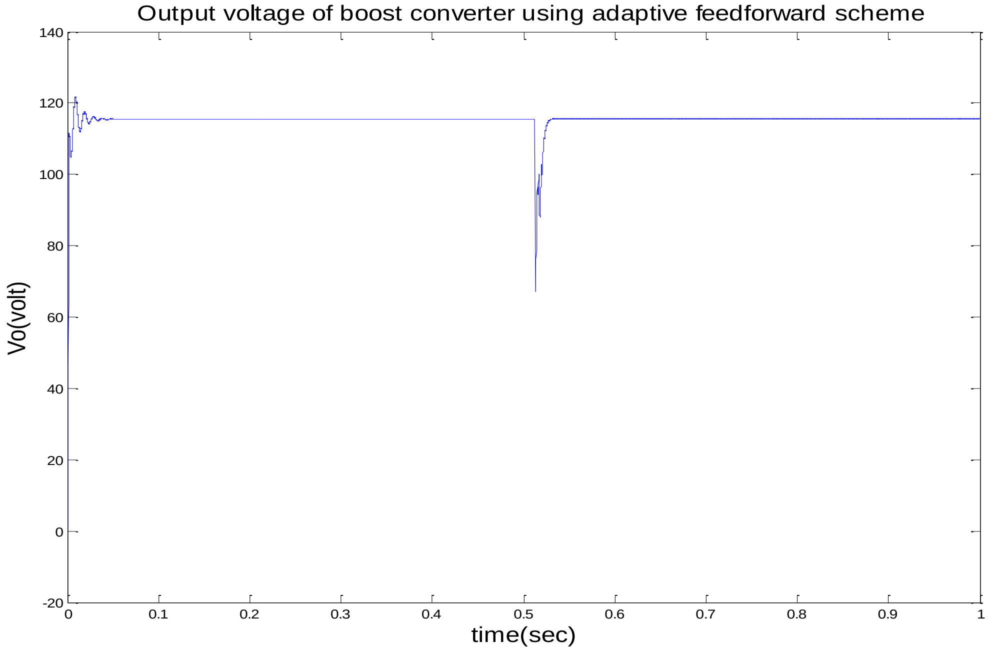

Figure: 7 Output voltage of boost converter using feed forward scheme by varying the input voltage

Initially up to 0.51 sec the input voltage is 20 volt then it is changed to 40 volt. It is observed that even if the input voltage varies it tracks the output voltage always with minimal overshoot and minimum settling time. Figure 8 shows the output voltage of the boost converter by varying the load resistance using adaptive feed forward scheme.

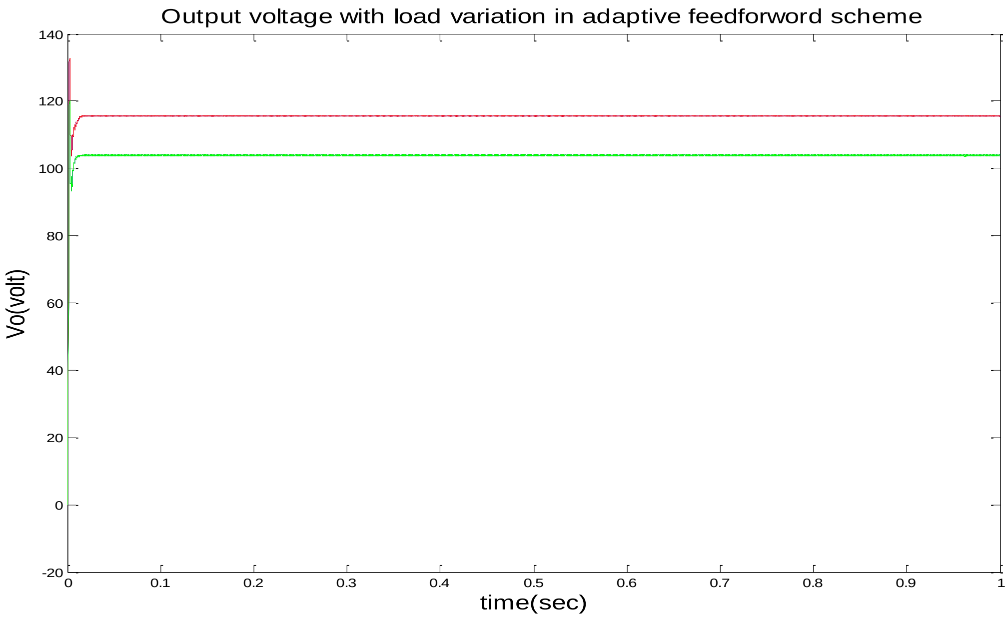

Figure: 8 output voltage of the boost converter by varying R_L using adaptive feed forward scheme

It is observed that by varying the load resistance disturbance rejection occurs very quickly but tracking is not possible. Figure 9 shows the response of boost converter for varying input voltage using adaptive feedback controller scheme.

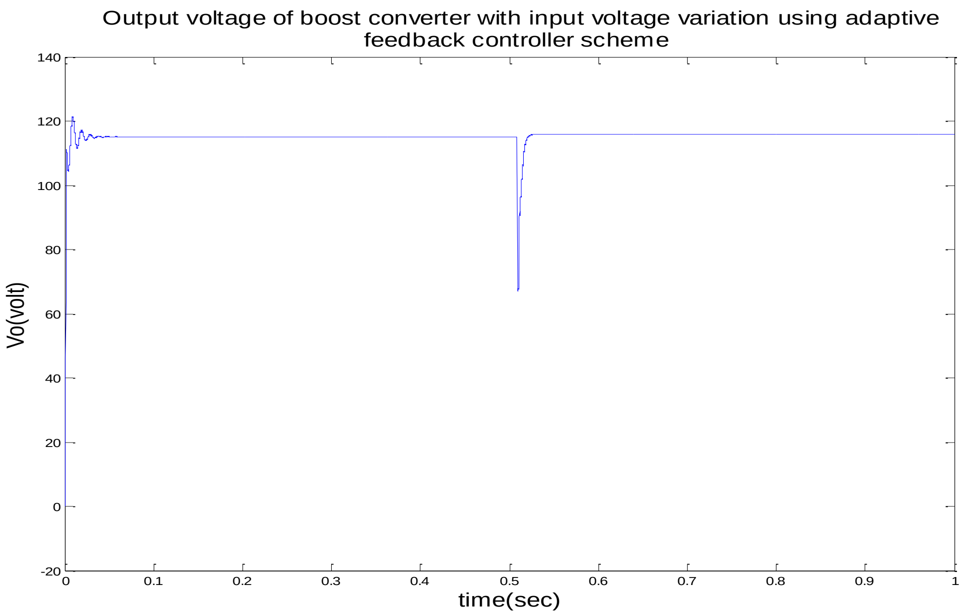

Figure: 9 output voltage of the boost converter using adaptive feedback controller scheme

It is observed that the response remains constant irrespective of the input voltage variation in the range from 20 volt to 40 volt. Figure 10 shows the output voltage of the boost converter by varying the load resistance using adaptive feedback controller scheme.

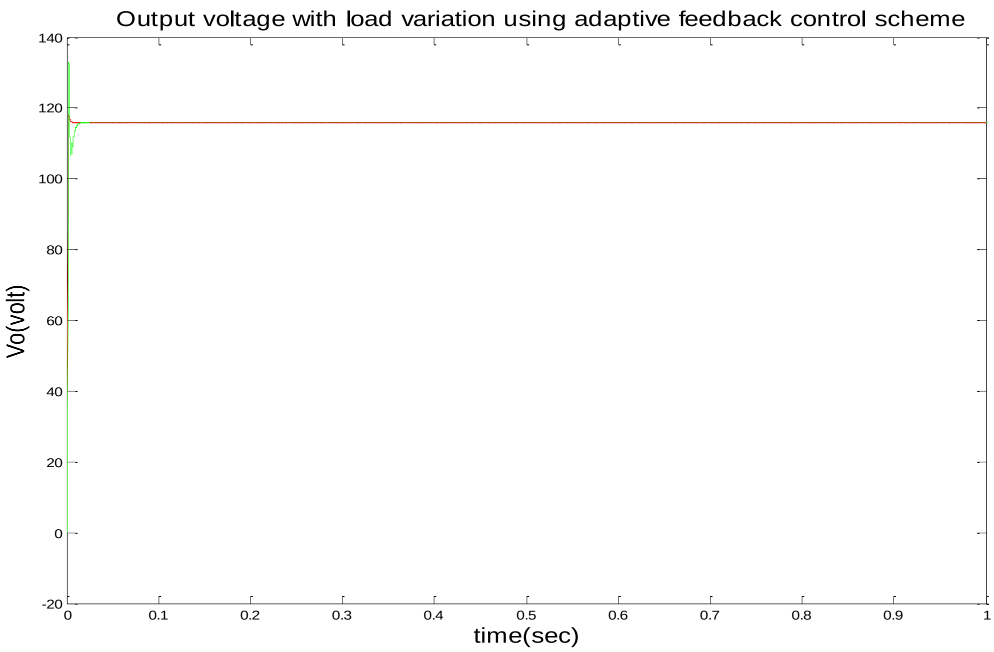

Figure: 10 output voltage of the boost converter for different load resistance using feedback scheme

It is observed that the output voltage remains constant irrespective of the load variation by using adaptive feedback controller scheme.

6. PERFORMANCE COMPARISON

The better conclusion can be derived by comparing two controllers in tabular form. Table-2 shows the performance comparison of two controllers by varying the input voltage and Table-3 shows the performance comparison by varying the load resistance.

Table-2 PERFORMANCE CALCULATION BY VARYING INPUT VOLTAGE

	Input voltage-40 volt			*Input voltage-20 volt*		
	t_s (sec)	M_p (%)	V_o(V)	t_s (sec)	M_p (%)	V_o(V)
Without controller	0.07	43.89	117.5	0.06	14	57
With Adaptive Feed forward controller	0.02	13.8	115.5	0.02	4	115.5
With Adaptive Feedback Controller	0.02	12	115.5	0.02	2	115.5

Table-3 PERFORMANCE CALCULATION BY VARYING LOAD RESISTANCE

	Load resistance-25Ω			*Load resistance-15Ω*		
	t_s (sec)	M_p (%)	V_o(V)	t_s (sec)	M_p (%)	V_o(V)
With Adaptive Feed forward controller	0.005	13.8	115.5	0.005	13.7	105.5
With Adaptive Feedback Controller	0.001	12	115.5	0.001	2	115.5

From the above two tables it can be concluded that feed forward controller attenuates the disturbances very rapidly irrespective of the load resistance and input voltage variation and Feedback controller tracks the output voltage even if the load resistance and input voltage changes.

7. CONCLUSION

This paper proposes an adaptive feed forward controller to enhance the performance of boost converter against fluctuating input voltage. The effectiveness of the proposed controllers has been verified by comparing the time domain specifications. The results show feed forward compensation deliver desired performance on disturbance rejection and feedback controller deliver desired performance on voltage tracking. Various waveforms with varying input and load are illustrated in this paper. Adaptive feed forward controller gives better disturbance rejection and adaptive feedback controller gives better tracking of the output voltage.

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