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# THE IMPLEMENTATION OF ONE CYCLE CONTROL METHOD TO INVERTING BUCK-BOOST CONVERTER

**A. Karaarslan**

*Faculty of Engineering and Natural Sciences, Yildirim Beyazit University, Ankara, Turkey, akaraarslan@gmail.com*

**Abstract-** In this study, One Cycle Control (OCC) method is implemented to Inverting Buck-Boost Converter. An inverting buck-boost converter provides an output voltage that may be less than or greater than input voltage. The output voltage has an opposite polarity than the input. This converter is also known as an inverting regulator. To obtain the constant output voltage, all regulators have a power transfer stage and a control circuitry to detect the output voltage and adjust the power transfer stage. Due to the feedback loop is required to keep on regulation, some type of compensation is inevitable to satisfy the loop stability. It is generally used in variable supply voltage applications when the circuit could be work as buck or boost converter. The aim of the control method is that the controlling the load voltage according to variable supply voltage, reference voltage and load power. The PI control method, being the most widely used controller in industrial areas where speed of the system is not an issue. One cycle control is nonlinear method that uses the concept of control of average value of switching variable at every cycle. In this study, the comparison between one cycle method and PI control method is given and simulated by Matlab/Simulink program.

**Keywords:** Inverting Buck-Boost Converter, One Cycle Control Method, PI Control Method, Matlab/Simulink.

## I. INTRODUCTION

Many electronic systems need to safe, high quality, small, light-weight, reliable and effective power sources. Their switches are operating at high frequencies. The higher the operating frequency, the smaller and lighter the components such as transformers, filter inductors, and capacitors [1, 2]. DC-DC converters are inevitable for renewable energy systems and many industrial applications. It is essentially used to obtain a regulated DC output voltage from input DC sources [3].

There are many topologies in DC-DC converters, fly back, buck, boost, bridgeless, sepic, cuk, etc., the inverting buck-boost converter is commonly used [4]. The output voltage of a DC-DC converter is controlled by operating it in the closed loop, therefore changing its switch gate signal. It is fundamentally controlled by a switching logic, hence forming a set of subsystems depend on the condition (on/off) of duty ratio of an external fixed frequency clock through feedback loops [5].

PI control methods are the most widely used sort of controller. They are constructively ordinary and present durable productivity over an extensive stage of working states [6]. PI control method is mainly used to annihilate the steady state error resulting from P controller. Nevertheless, with respect to the speed of the response and overall stability of the system, it has a negative impact. PI control method is mostly used in applications which speed of the system is not a matter.

Because PI control method has no ability to predict the future errors of the system, it cannot decrease the rise time and eliminate the oscillations. One cycle control is nonlinear control method that uses the control of average value of the switching variable. The purpose of the control methods is adjusting the duty cycle (D) according the perturbations. This nonlinear technique is used for conserving the system performance When perturbations on power side and load side [7]. The OCC system consists of integrator, comparator and controller. Controller is generally RS Flip-Flop. It also returns the error to the resettable input of the integrator.

In this paper, PI control method and OCC control method are implemented to the inverting buck-boost converter. It is generally used in changeable input voltage applications when the circuit can be work as buck or boost converter. The goal of the control methods is that the controlling the load voltage according to variable supply voltage, reference voltage and load power using Matlab/Simulink program.

## II. CIRCUIT ANALYSIS OF INVERTING BUCK-BOOST CONVERTER

The inverting buck-boost converter is a DC to DC converter. The output voltage of the DC to DC converter is less or greater than the input voltage. The output voltage of the magnitude depends on the duty cycle. These converters are also known as the step up and step down transformers and these names are coming from the analogous step up and step down transformer. The input voltages are step up/down to some level of more than or less than the input voltage.

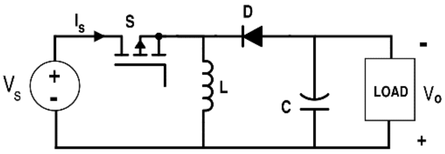

Figure 1. Circuit diagram of an inverting buck-boost converter

For the step up state, the input voltage is less than the output voltage ($V_{in} < V_{out}$). It shows that the output current is less than the input current ($I_{in} > I_{out}$). Therefore, the buck boost converter is a step up state. For the step down state the input voltage is greater than the output voltage ($V_{in} > V_{out}$). It follows that the output current is greater the input current ($I_{in} < I_{out}$). Hence the buck boost converter is a step down state. The two operating states of a buck-boost converter are given, respectively.

### A. State 1 of Inverting Buck-Boost Converter

While in the On-state; when switch is closed then diode is reverse biased. The input current, which rises, flows through inductor $L$ and switch S. This results accumulating energy in inductor $L$. The capacitor $C$ discharges through load $R$.

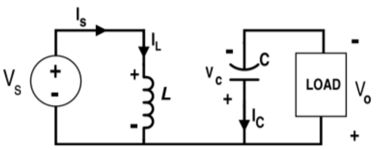

Figure 2. Equivalent circuit of state 1

### B. State 2 of Inverting Buck-Boost Converter

While in the Off-state; when switch is open at that time the current would flow along inductor, capacitor, and load respectively. The stored energy in inductor $L$ would be transmitted to the capacitor and load. Meanwhile, current of inductor would drop. An implementation of ordinary inverting buck-boost converter using Matlab/Simulink is shown in Figure 4.

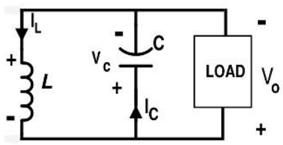

Figure 3. Equivalent circuit of state 2

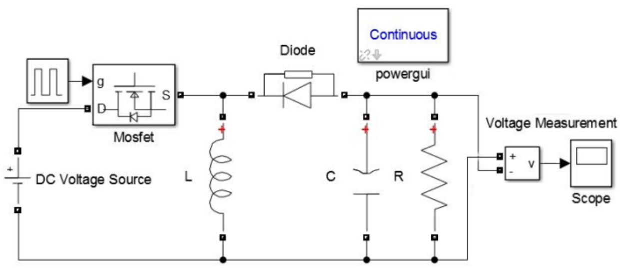

Figure 4. An ordinary inverting buck-boost converter circuit using Matlab/Simulink

## III. PROPOSED CONTROL METHOD OF INVERTING BUCK-BOOST CONVERTER

The proposed control methods are performed by Matlab/Simulink program. The parameters used in converter topology are given in Table 1. Required parameters and necessary equations to design inverting buck-boost converter is indicated in Table 2. A good estimation for the inductor ripple current is 20% and peak to peak ripple voltage ($\Delta V_{out}$) is 2 V [8].

Table 1. Parameters used in inverting buck-boost converter

| | | |
|---|---|---|
| Output Power | $P_{out}$ | 500 [W] |
| Output Voltage (Buck) | $V_{out\_buck}$ | 50 [V] |
| Output Voltage (Boost) | $V_{out\_boost}$ | 150 [V] |
| Input Voltage | $V_{in}$ | 100 [V] |
| Switching Frequency | $f_s$ | 10 [kHz] |
| Inductor | $L$ | 1 [mH] |
| Capacitor | $C$ | 470uF [μF] |

Table 2. Necessary equations to design inverting buck-boost converter

| Parameter | Design Equations |
|---|---|
| Output Voltage | $\frac{V_0}{V_g} = \frac{-D}{(1-D)}$ |
| Inductor Value | $L = (1-D)V_o / f_s \Delta I_L$ |
| Capacitor Value | $C = DV_o / Rf_s \Delta V_c)$ |

### A. Inverting Buck-Boost Converter using One Cycle Control Method

The main idea of OCC method is to use an integrator to measure the mean value of the diode signal in each cycle and force it to be equal to the reference value. The OCC method is a nonlinear control theory that used to control any signal type, physical, electrical and mechanical, etc. and consists of constant frequency clock, comparator and integrator. This theory work as the switch turns on by a constant frequency clock at the start of every cycle; the diode voltage begins increase until it reaches to the reference voltage and the comparator alters its state and cuts the MOSFET off [10].

One cycle control design equation is obtained from the inverting buck-boost converter duty cycle equation that is shown as:

$$V_g D\, T_s = (-V_0)(1-D)T_s$$
$$\frac{V_0}{V_g} = \frac{-D}{(1-D)} \quad (1)$$

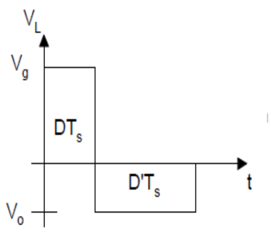

Figure 5. Duty cycle graph

In closed loop, the output voltage $V_o$ should be equal to reference voltage $V_{ref}$ [5]:

$$V_{ref}\,(1-D) = D\;V_d$$
$$V_{ref} = D\left(V_d + V_{ref}\right) \qquad (2)$$
$$V_{ref} = (1/T_s)\int\left(V_d + V_{ref}\right)dt$$

Therefore, one cycle controller is obtained from this equation. The source voltage and constant reference voltage is added. This addition is taken integrated. Finally, this result is product with frequency value. So, the average value of the cycle is obtained. This value and the constant reference value compared. According to result of comparison the duty cycle is adjusted. As a result, the output voltage value cannot change unless reference voltage.

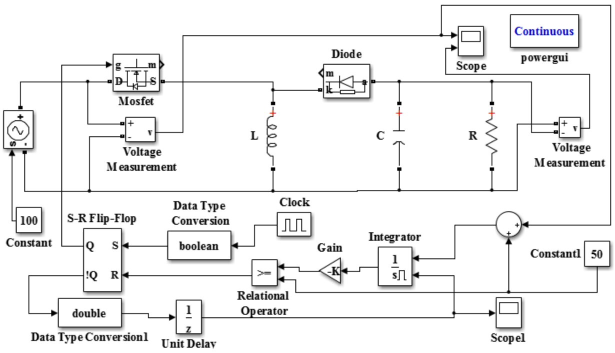


Figure 6. A simple model of inverting buck-boost converter using OCC method

### B. Inverting Buck-Boost Converter using PI Control Method

The output voltage, $V_{out}$ is sampled and contrasted with the reference voltage, $V_{ref}$ to obtain an error signal and then is forwarded to PI controller block to produce a control voltage, $u$. The control voltage, $u$ and saw tooth generator block is compared and then gives MOSFET gate terminal to adjust the output voltage according to reference signal. The PI control method has two parameters which are $K_p$ and $K_i$. These operands might get any real value and determining these values using Ziegler-Nichols method [9].

The model of inverting buck-boost converter using PI controller in Matlab/Simulink is shown in Figure 7. The result of inverting buck-boost converter using PI control method is shown in figure for $K_p$ = 0.04 and $K_i$ = 0.1, which represent maximum overshoot of 2%, settling time 0.03 ms and rise time 0.02 ms.

## IV. PERFORMANCE ANALYSIS OF CONTROL METHODS

### A. Buck State of Inverting Buck-Boost Converter

At the constant reference value, when the input value is changed from 100 V to 150 V and 50 V, the reaction of the output value is shown in Figure 9.

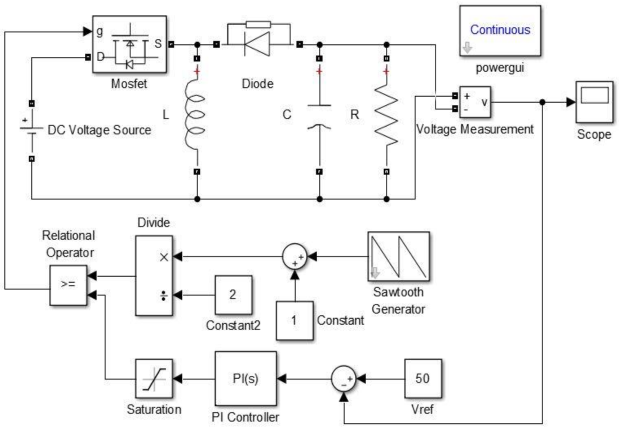


Figure 7. A simple model of inverting buck-boost converter using PI control method

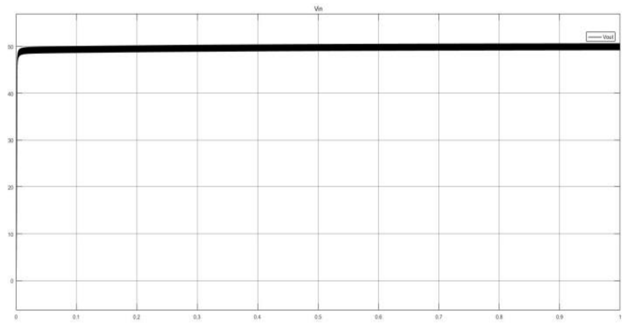

Figure 8. Response of inverting buck-boost converter using PI control method

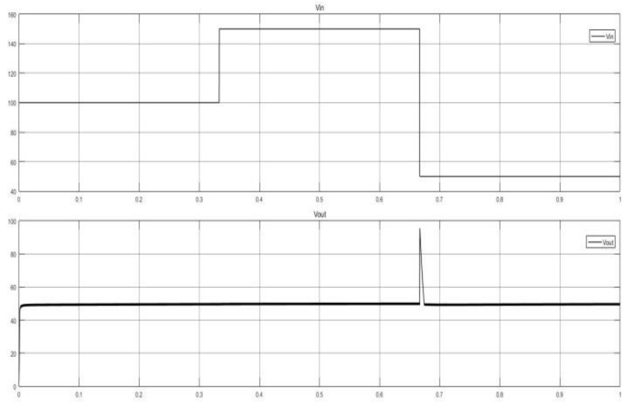


Figure 9. Output voltage ($V_{out}$) response when input voltage ($V_{in}$) change for PI control method

When the input value is changed from 100 V to 150 V, the reaction of the output value is not changed wide values, but when the input values is changed from 150 V to 50 V, the reaction of the output values is important and one peak occurred, the peak value is rising from 50 V to nearly 99 V for PI control method. The output voltage is shown when input voltage changes in Figure 10. When input voltage increases the peak of the cycles is short. However, when voltage changes are bigger, the peak of the cycles is larger.

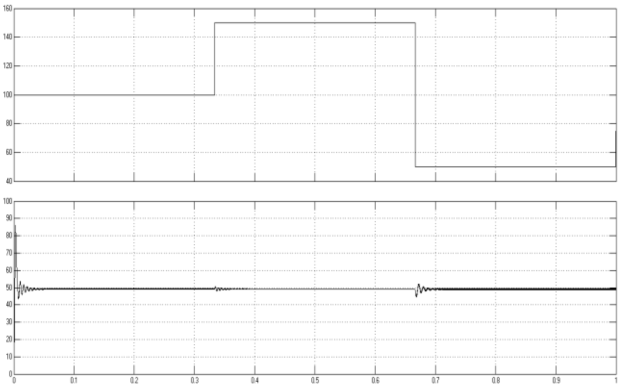

Figure 10. Output voltage ($V_{out}$) response when input voltage ($V_{in}$) change for one cycle control method

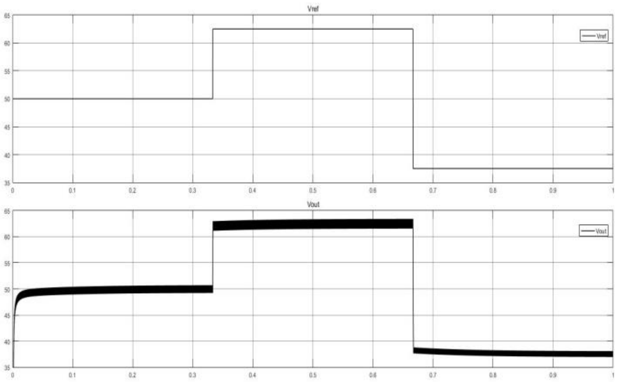


Figure 11. Output voltage ($V_{out}$) response when reference voltage ($V_{ref}$) change for PI control method

At the constant input value, when the reference value is increased by 25 percent and decreased by 25 percent, the response of the output value is shown in Figure 11.

When the reference values are increased by 25 percent, the response of the output value consist of more change on voltage values, yet when reference value is decreased by 25 percent, the response of the output value consist of less change on voltage values for PI control method. It is seen in Figure 12.

At the constant input value and the reference value, when the load power is increased by 50 percent and decreased by 50 percent, the change of the load current value is shown in Figure 13.

When the output power is increased by 50%, the response of the output voltage has more difference on peak to peak ripple voltage values, however, when the load is decreased by 50%, the response of the output voltage has less difference on peak to peak ripple voltage values for PI control method. It is given in Figure 14.

These peak values could be adjustable according to components values. Therefore, every converter work more steady at specific voltage ranges.

**B. Boost State of Inverting Buck-Boost Converter**

At the constant reference value, when the input value is changed from 100 V to 150 V and 50 V, the reaction of the output value is shown in Figures 15 and 16.

When the input value is changed from 100 V to 150 V or the input value is changed from 150 V to 50 V, the reactions of the output value are very few for PI Control method.

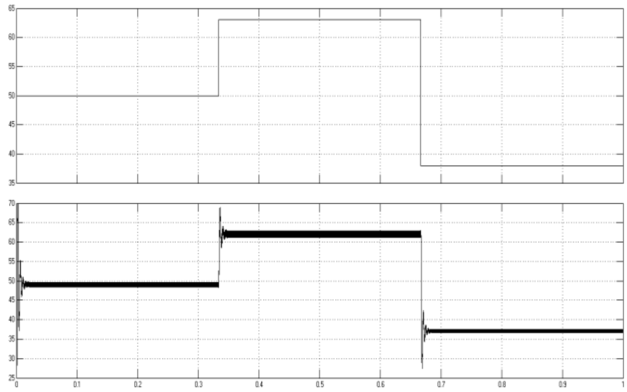

Figure 12. Output voltage ($V_{out}$) response when reference voltage ($V_{ref}$) change for one cycle control method

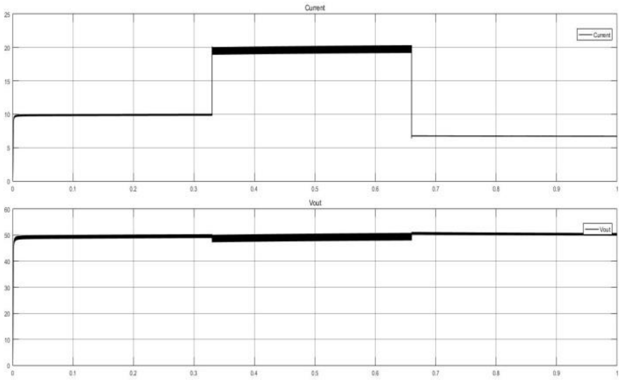


Figure 13. Output voltage ($V_{out}$) response when load current ($I$) change for PI control method

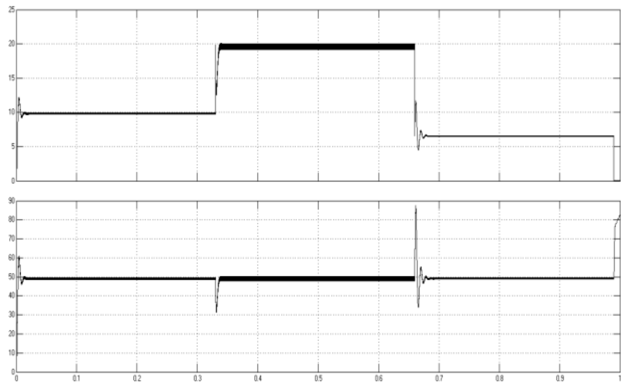

Figure 14. Output voltage ($V_{out}$) response when load current ($I$) change for one cycle control method

As seen in Figure 16, when voltage changes more, the peak value for the response will be more. At the constant input value, when the reference value is increased by 25% and decreased by 25%, the response of the output value is shown in Figure 17.

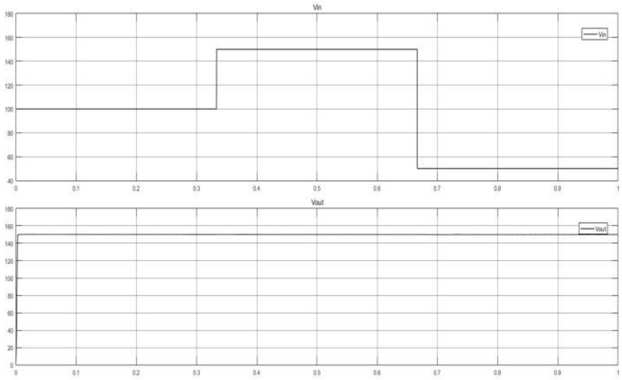

Figure 15. Output voltage ($V_{out}$) response when input voltage ($V_{in}$) change for PI control method

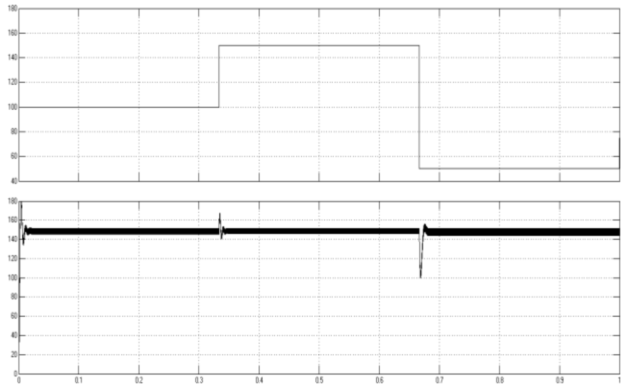

Figure 16. Output voltage ($V_{out}$) response when input voltage ($V_{in}$) change for OCC method

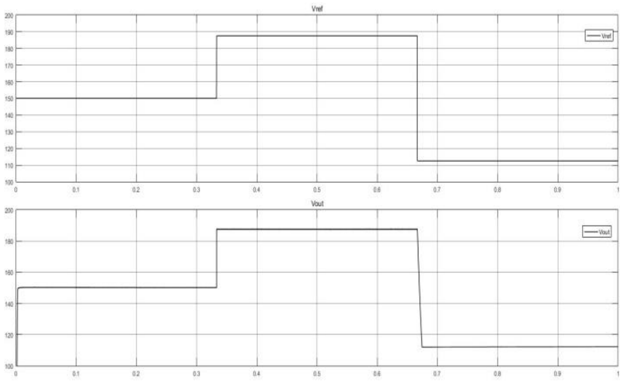

Figure 17. Output voltage ($V_{out}$) response when reference voltage ($V_{ref}$) change for PI control method

When the reference values are increased by 25%, the response of the output value is very quick, but when reference value is decreased by 25%, the response of the output value have some delay for PI control method.

Reference voltage is not much clear because of the ripple voltage that is seen Figure 18. At the constant input value and the reference value, when the load power is increased by 50 percent and decreased by 50%, the change of the load current value is shown in Figure 19.

When the load power is increased by 50%, the response of the output value has more difference on peak to peak ripple voltage vales, but when the load power is decreased by 50%, the response of the output value has less difference on peak to peak ripple voltage values for PI control method.

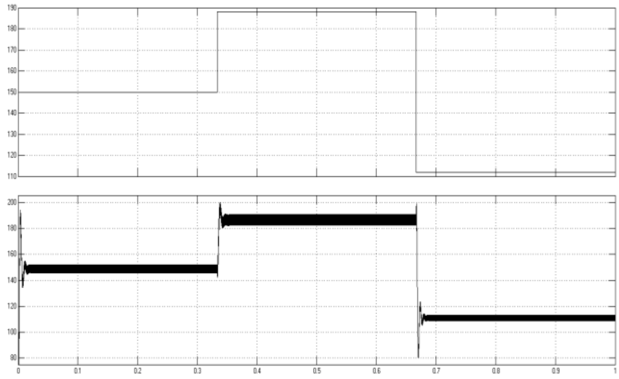

Figure 18. Output voltage ($V_{out}$) response when reference voltage ($V_{ref}$) change for OCC method

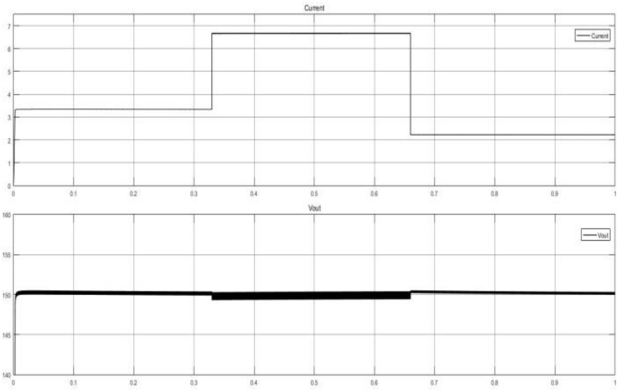

Figure 19. Output voltage ($V_{out}$) response when load current ($I$) change for PI control method

When load current increasing and decreasing, the output voltages are seen Figure 20. When load current increasing, steady state time shorter that when load current decreasing.

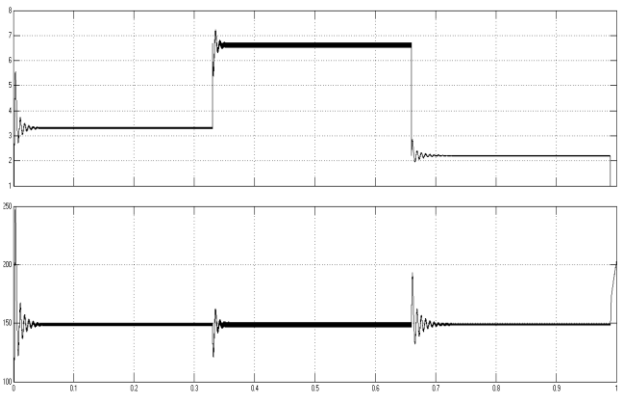

Figure 20. Output voltage ($V_{out}$) response when load current ($I$) change for OCC method

The results of inverting buck-boost converter for OCC method and PI control method are shown in Table 3 for $K_p$ = 0.04 and $K_i$ = 0.1. For OCC method, the gain value will be frequency value.

Table 3. The output voltage response using Matlab/Simulink

| Average Values for Output Voltage | PI | OCC |
|---|---|---|
| Rising Time ($T_r$) | 20.00 µs | 5.00 µs |
| Settling Time ($T_s$) | 30.50 µs | 10.00 µs |
| Maximum Overshoot (*MO*) | 2% | 3% |

## V. CONCLUSION

DC-DC converters maintain an attractive subject and also novel control techniques to obtain preferable regulation and swift temporary response are continuously improved. Inverting buck-boost converters are the essential of power electronic circuits. The most important difficulty to layout switching regulators is to continue nearly stable output voltage with agreeable regulation. Performance and practicality of inverting buck-boost converter is submitted on the base of simulation using Matlab/Simulink.

The design notions are approved by way of simulation and results attained demonstrate which an inverting buck-boost converter will be considerably steady with high yield. The inverting buck-boost converter use to prevalent input voltage and large output power range. The OCC method gives a better transient performance compared to PI control method. The OCC method is faster than PI control method when changing perturbations. The OCC method performs less settling time and less maximum deviation from steady state than PI control method. On the other hand, PI control method has very low overshoot, less oscillation and pure output. The PI control method should be preferred in applications which speed of the system is stable. Eventually both system gives the constant output voltage value application of variation of input voltage, reference voltage and load.

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## BIOGRAPHY

**Ahmet Karaarslan** received the M.Sc. and Ph.D. degrees in Electrical and Electronics Engineering from Gazi University, Ankara, Turkey, in 2005 and 2011, respectively. He is currently an Associate Professor with the Faculty of Engineering and Natural Sciences in Yildirim Beyazit University, Ankara, Turkey. His research interests are in the application of circuits of power electronics, energy conversion systems, programming microprocessors, renewable energy sources, electrical machines and computer applications.