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24V input 12V and 36V output buck-boost converter design

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Abstract

In this modern era of electronic technologies, all the appliances require a separate power supply. To overcome this drawback, the concept of a single converter with multiple power supply has been proposed. Furthermore, the proposed research work clarifies about multipurpose charger, which alters and uses a boost topology to supply different outputs as required for different applications. Proposed method consists of multiple PWM duty cycles to produce multiple regulated power supply voltages, and so it is also referred as multi power boost converter. It uses one converter for obtaining various outputs. For example, mobile, laptop, electric vehicle, or any other electronic appliances can be charged using multi power boost converter.

1. Introduction

Nowadays, most of DC power supply uses are needed in electronic devices. This utilization is required in order to be able to convert DC voltages from certain voltage to desired voltage. Buck-boost converter is a type of switching converter that is able to produce voltage levels greater or smaller than the input voltage. Voltage regulation is carried out by adjusting the duty cycle of Pulse Width Modulation (PWM) [1]. Buck-boost converters are widely used in alternative and renewable energy power plants, portable devices and industrial installations [2]. On the other hand, buck boost converter is capable of producing an output voltage higher/lower than the input voltage and has the ability to generate both steps up and steps down output voltage [3]. Generally a buck converter operates in two conduction mode namely continuous and discontinuous conduction mode whereas, a buck boost converter can be operated either in buck converter mode or boost converter mode [6]. The solutions of buck boost converter usually have lower efficiency and a larger footprint than buck converter solutions [4]. Inductor's reluctance to allow rapid change in current is used to best understand the operation of a buck boost converter [8].

In an electronic circuit, buck converters are commonly used to get the required output voltage from a higher voltage source [9]. Sometimes, may be required negative voltage from a positive input voltage source. The audio amplifiers, line drivers and receivers, or instrumentation amplifiers can include by these applications [7].

2. Material and Method

2.1. Buck-Boost Transducer Design, Modeling and Control

Switched power supplies are widely used today, especially in electric vehicles, renewable energy systems, computers, televisions, mobile phones and many electrical household appliances. The advantage of switch-mode power supplies over other conventional power supplies is that they are quite light, smaller and therefore take up less space.

Dc-dc converters are structures that are used to transform the unregulated or the regulated voltage at the output of a rectifier, battery or solar cell. Buck-boost converter can generally be in two different structures as isolated and non-isolated. However, non-insulated structure is more widely used. The output voltage value of the buck-boost converter can be greater or less than the input voltage value depending on the value of the duty period. In addition, the polarity of the output voltage is opposite to the polarity of the input voltage [5].

2.2. 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. It is equivalent to a flyback converter using a single inductor instead of a transformer [4]. Two different topologies are called buck–boost converter. Both of them can produce a range of output voltages, ranging from much larger (in absolute magnitude) than the input voltage, down to almost zero.

In the inverting topology, the output voltage is of the opposite polarity than the input. This is a switched-mode power supply with a similar circuit topology to the boost converter and the buck converter. The output voltage is adjustable based on the duty cycle of the switching transistor. One possible drawback of this converter is that the switch does not have a terminal at ground; this complicates the driving circuitry. However, this drawback is of no consequence if the power supply is isolated from the load circuit (if, for example, the supply is a battery) because the supply and diode polarity can simply be reversed. When they can be reversed, the switch can be on either the ground side or the supply side.

When a buck (step-down) converter is combined with a boost (step-up) converter, the output voltage is typically of the same polarity of the input, and can be lower or higher than the input. Such a non-inverting buck-boost converter may use a single inductor which is used for both the buck inductor mode and the boost inductor mode, using switches instead of diodes [5], sometimes called a "four-switch buck-boost converter", it may use multiple inductors but only a single switch as in the Sepic and Cuk topologies.

The circuit diagram of the buck-boost converter is shown in Figure 1.

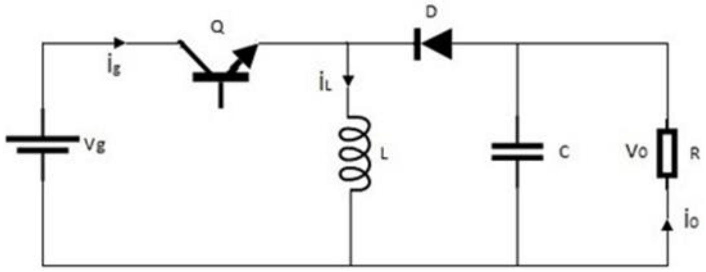

Figure 1. Buck-boost converter circuit

To analyze the buck-boost circuit, it is necessary to consider two cases where switch Q is on (Qon) and switch Q is on cut (Qoff).

If the duty period of the switch is d;

$$d = \frac{t_{on}}{t_{on} - t_{off}} - \frac{t_{on}}{T_s} \tag{1}$$

Here t_{on} and t_{off} are the on and off times of the switch, respectively. T_s is the switching period.

The output voltage of the converter under ideal conditions changes to;

$$V_o = \frac{d}{1-d} * V_g \tag{2}$$

Here, the duty period d varies in the range of 0-1. Different output voltage values can be obtained for different d values. Output voltage; If d<0.5 it becomes buck (reducer), if d>0.5 it becomes boost. The current is also intermittent, as the output of the Buck-Boost converter is a bit too fluctuating.

Like the buck and boost converters, the operation of the buck-boost is best understood in terms of the inductor's "reluctance" to allow rapid change in current. From the initial state in which nothing is charged and the switch is open, the current through the inductor is zero. When the switch is first closed, the blocking diode prevents current from flowing into the right hand side of the circuit, so it must all flow through the inductor. However, since the inductor doesn't allow rapid current change, it will initially keep the current low by dropping most of the voltage provided by the source.

Over time, the inductor will allow the current too slowly increase by decreasing its own resistance. In an ideal circuit the voltage drop across the inductor would remain constant. When the inherent resistance of wires and the switch is taken into account then the voltage drop across the inductor will also decrease as the current increases. Also during this time, the inductor will store energy in the form of a magnetic field.

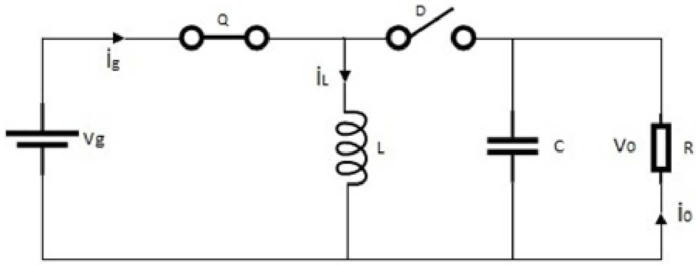

Figure 2. On state of the Q switch in transmission the buck-boost converter circuit

While the switch is transmitting (Qon), the situation in Figure 2 will occur. In this case, switch Q is on, and diode D is off because it is subject to reverse voltage. The input source current flows incrementally through the Q switch and the inductance.

In this case;

$$\frac{d\dot{I}_L}{d_t} = \frac{V_g}{L} \tag{3}$$

$$\frac{dV_C}{d_t} = -\frac{V_o}{RC} \tag{4}$$

When the switch is in cut (Qoff), the situation in Figure 3 will occur. In this case, the Q switch is in cut. The current flowing through the inductance flows through C, D and the load. The energy stored in the inductance is transferred to the load in this way.

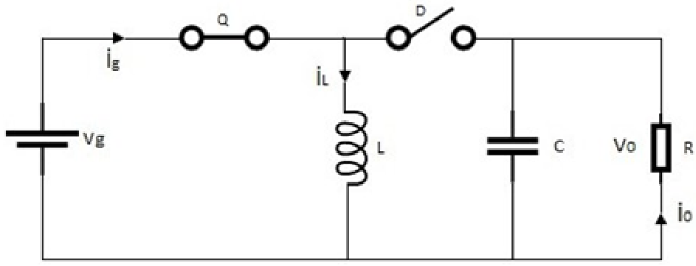

Figure 3. On state of the Q switch in cut the buck-boost converter circuit

In this case;

$$\frac{d\dot{I}_L}{d_t} = \frac{V_C}{L} \tag{5}$$

$$\frac{dV_C}{d_t} = -\frac{I_L}{C} - \frac{V_o}{RC} \tag{6}$$

If the equations (2-5) are combined by considering the duty period, the following equations can be obtained.

$$\frac{d\dot{I}_L}{d_t} = \frac{V_g}{L}.d + \frac{V_C}{L}.(1-d) \tag{7}$$

$$\frac{dV_C}{d_t} = -(1-d)\frac{I_L}{C} - \frac{V_C}{RC} \tag{8}$$

2.3. Proteus Model of Buck-Boost Converter

In this paper, a boost–buck-type dc–dc converter is proposed as the first stage with regulated output inductor current, and a full-bridge unfolding circuit with 50- or 60-Hz line frequency is applied to the dc–ac sage, which will unfold the rectified sinusoid current regulated by the dc–ac stage into a pure sinusoidal current, as shown in Figure 2. Since the circuit runs either in boost or buck mode, its first stage can be very efficient if the low conduction voltage drop power MOSFET and ultrafast reverse recovery diode are used. for the second stage, because the unfolding circuit only operates at the line frequency and switches at zero voltage and current, the switching loss can be omitted. The only loss is due to the conduction voltage drop, which can be minimized with the use of low on-drop power devices, such as thyristor or slow-speed insulated gate bipolar transistor (IGBT). in this version, IGBT is used in the unfolding circuit because it can be easily turned ON and OFF with gating control. Since only the boost dc–dc converter or buck dc–dc converter operates with high-frequency switching all the time in the proposed system, the efficiency is improved. Also, because there is only one high-frequency power processing stage in this complete PCS, the reliability can be greatly enhanced [11]. Finally, after analyzing its model, as shown in Figure 3, an interleaved-boost-cascaded-with-buck converter is proposed to increase the resonant pole frequency by the use of a smaller boost inductor value, which improves both control and stability.

Equations in equality (7) and (8) are modeled as in Figure 4 using the Proteus program.

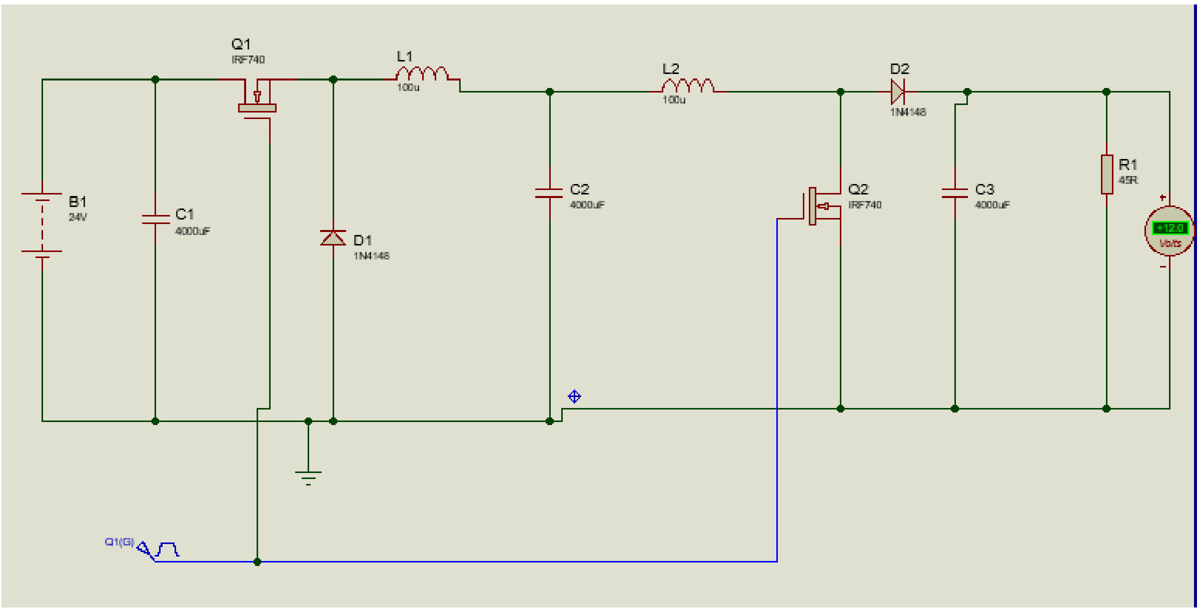

Figure 4. Proteus Model of buck-boost converter

In Figure 4, if the desired output voltage is entered into the model as Vo value, the duty period that will provide this output is calculated and applied as an input to the model.

The model in Figure 4 was operated for different reference output voltage (Vo) values by taking Vg=24 V, C=100 μF, L=4000 μH, R=45 ohm and switching frequency fs=75 kHz, and the following results were obtained. The created model calculates the duty period value of the converter according to the entered reference voltage.

The output voltage of the proposed DC-DC buck boost converter is controlled by altering its MOSFET switch and it is in a closed loop. Generally, a switching logic is used to operate this type of converter. Hence, switching status on-off is a built-in subsystem of this system. For industrial applications of this type of circuit PI controllers are the mostly used as a controller. They are simple in design but demonstrate robust performance regardless of the operating conditions [12].

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current by either increasing or decreasing the energy stored in the inductor magnetic field. In a boost converter, the output voltage is always higher than the input voltage. A schematic of a boost power stage is shown in Figure-2.

- When the switch is closed (on-state), current flows through the inductor in the clockwise direction and the inductor stores some energy by generating a magnetic field. Polarity of the left side of the inductor is positive.
- When the switch is opened (off-state), current will be reduced as the impedance is higher. The magnetic field previously created will be reduced in energy to maintain the current towards the load. Thus, the polarity will be reversed (meaning the left side of the inductor will become negative). As a result, two sources will be in series causing a higher voltage to charge the capacitor through the diode D [13].

If the switch is cycled fast enough, the inductor will not discharge fully in between charging stages, and the load will always see a voltage greater than that of the input source alone when the switch is opened. Also while the switch is opened, the capacitor in parallel with the load is charged to this combined voltage. When the switch is then closed and the right hand side is shorted out from the left hand side, the capacitor is therefore able to provide the voltage and energy to the load. During this time, the blocking diode prevents the capacitor from discharging through the switch. The switch must of course be opened again fast enough to prevent the capacitor from discharging too much [14].

In order to calculate the desired reference output voltage as Vo=36.8 V, when the signal width is entered as PW=66, the duty period, output voltage and inductance current of the buck-boost converter are as seen in Figure 5, Figure 6 and Figure 7. In this case, the model calculated the duty period as d=0.454.

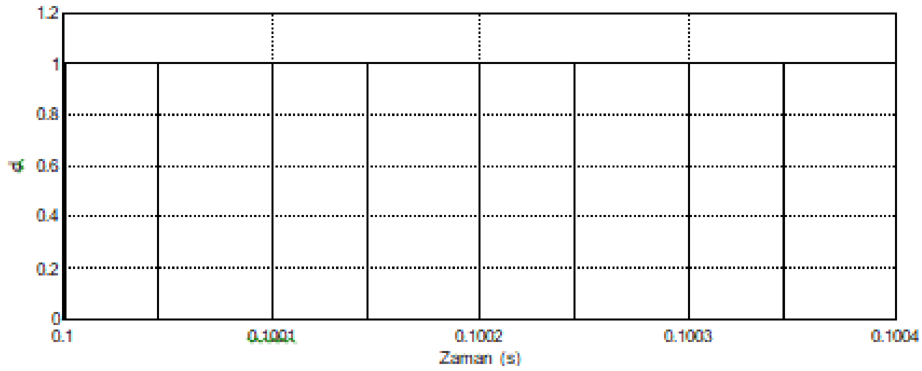

Figure 5. Change of duty period with time for Pw=66 in buck-boost converter

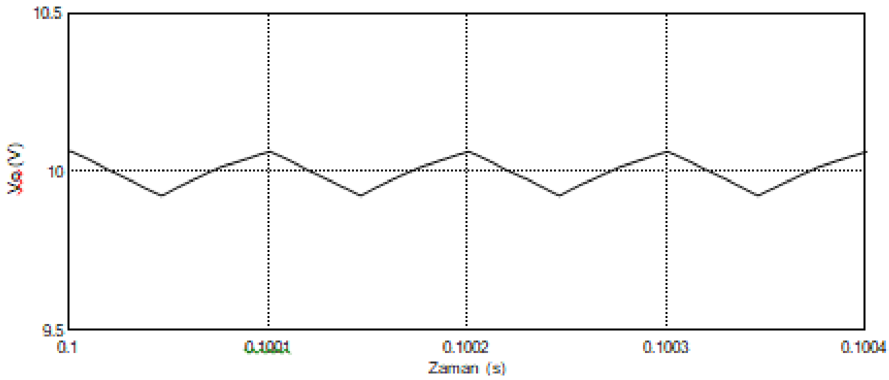

Figure 6. Variation of output voltage with time for Pw=66 in buck-boost converter

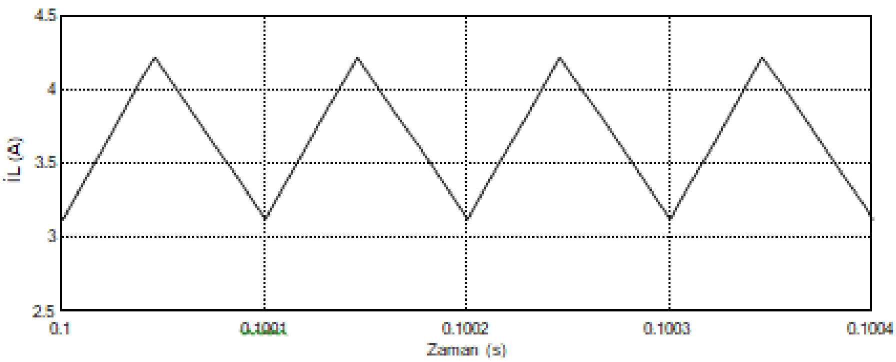

Figure 7. Variation of Inductance current for PW=66 in buck-boost convert

The conceptual model of the buck converter is best understood in terms of the relation between current and voltage of the inductor. Beginning with the switch open (off-state), the current in the circuit is zero. When the switch is first closed (on-state), the current will begin to increase, and the inductor will produce an opposing voltage across its terminals in response to the changing current. This voltage drop counteracts the voltage of the source and therefore reduces the net voltage across the load. Over time, the rate of change of current decreases, and the voltage across the inductor also then decreases, increasing the voltage at the load. During this time, the inductor stores energy in the form of a magnetic field.

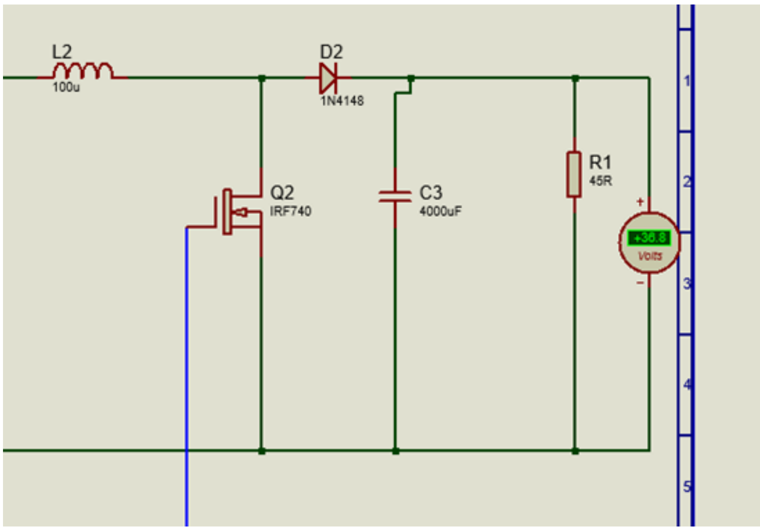

Figure 8. Output voltage value for PW=66 of the buck-boost converter

If the switch is opened while the current is still changing, then there will always be a voltage drop across the inductor, so the net voltage at the load will always be less than the input voltage source. When the switch is opened again (off-state), the voltage source will be removed from the circuit, and the current will decrease. The decreasing current will produce a voltage drop across the inductor (opposite to the drop at on-state), and now the inductor becomes a current source. The stored energy in the inductor's magnetic field supports the current flow through the load.

The "increase" in average current makes up for the reduction in voltage, and ideally preserves the power provided to the load. During the off-state, the inductor is discharging its stored energy into the rest of the circuit. If the switch is closed again before the inductor fully discharges (on-state), the voltage at the load will always be greater than zero.

When the signal width is entered as PW=37 to calculate the desired reference output voltage as Vo=12 V, the duty period, output voltage and inductance current of the buck-boost converter are as seen in Figure 9, Figure 10 and Figure 11. In this case, the model calculated the duty period as d=0.625.

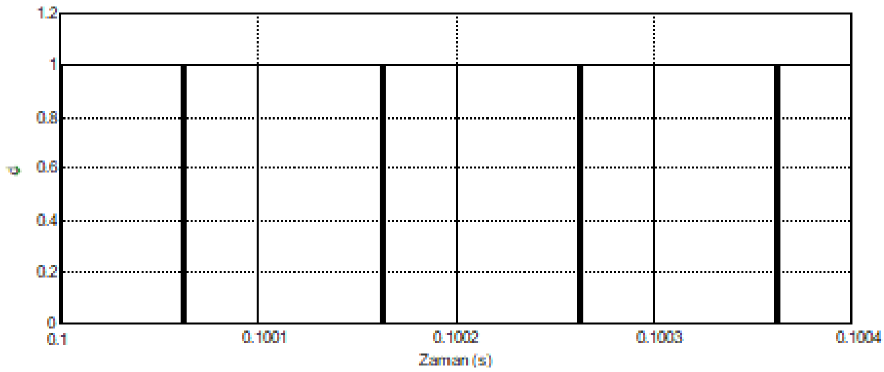

Figure 9. Change of duty period with time for Pw=37 in buck-boost converter

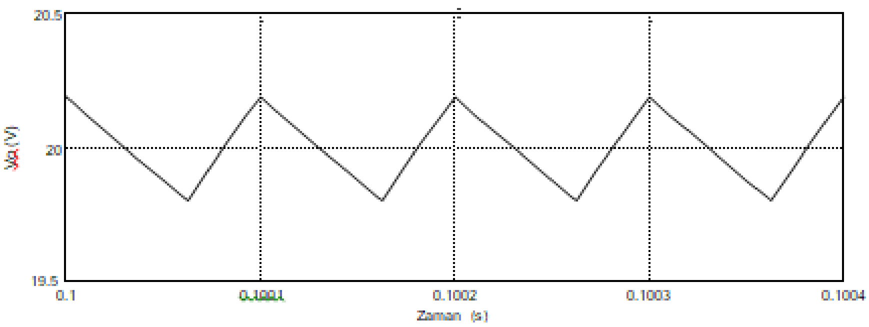

Figure 10. Variation of output voltage with time for Pw=37 in buck-boost converter

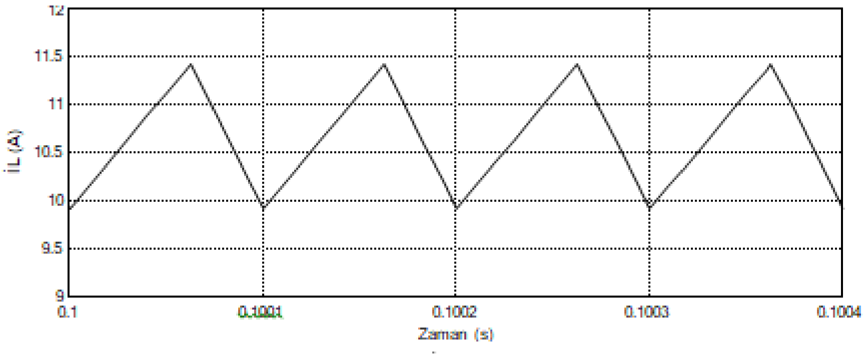

Figure 11. Variation of Inductance current for PW=37 in buck-boost convert

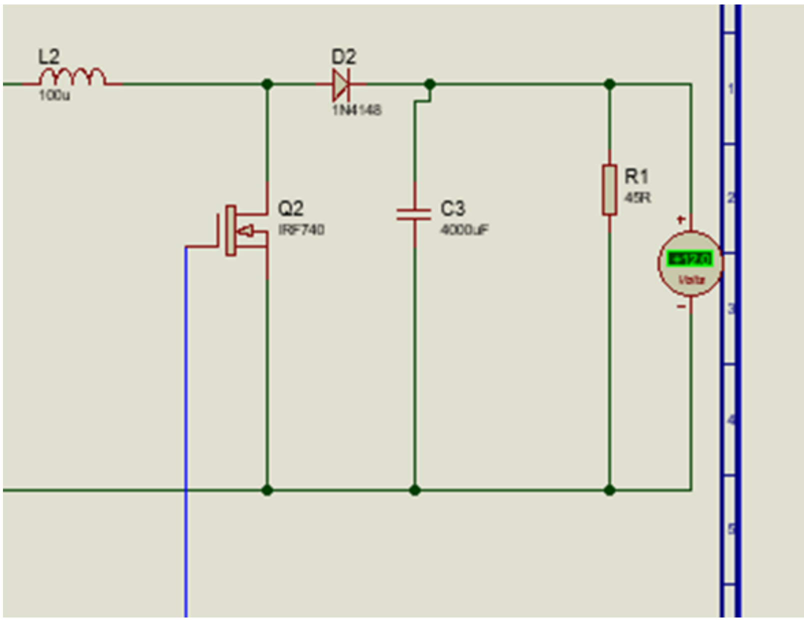

Figure 12. Output voltage value for PW=37 of the buck-boost converter

A buck boost converter can be used for the purpose of both of step up and step down output voltage. In this operation, buck boost converter provides step down output voltage and the total circuit has drawn by using the same element of conventional DC-DC buck converter. It can be concluded from the results of DC-DC buck boost converter output simulations that DC-DC buck converter performs better than the proposed DC-DC buck boost converter with the variation of frequency. An exact opposite result is found from the simulation with the variation of load where the proposed DC-DC buck boost converters performance is higher than the DC-DC buck converter. The voltage gain of experimental DC- DC buck boost converter shown that, it always provides negative output voltage with high voltage gain.

The proposed DC-DC buck boost converter will be suitable to use in audio and instrumentation amplifier, line drivers and receivers.

3. Conclusion

In this study, the design, modeling and control of da-da Buck-Boost transducer are examined. The converter system model and the applied control strategy are simulated in Simulink. The Simulink model is given in Figure-4. Different output voltages are generated against the fixed input voltage corresponding to various corresponding PWM values. It is seen in Figure 12 that the output voltage is reduced at low signal width modulation values and the buck converter circuit is effective. Likewise, when high value signal width modulation is applied, it is observed that the output voltage increases, as in Figure 8. The booster type converter circuit is active in the circuit. The Proteus model of the controlled da-da Buck-Boost converter, which provides the desired output voltage according to different reference voltages, has been realized and the results regarding this situation are presented in detail.

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Author contributions

Muslime Altun: Conceptualization, Methodology, Software **Mehmet Rida Tur:** Data curation, Writing-Original draft preparation, Software, Validation. **Fevzi Çakmak:** Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest
The authors declare no conflicts of interest.

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