Design and implementation of quadratic boost converter employing arduino microcontroller

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ABSTRACT

In modern power conversion applications, efficiency and the ability to significantly boost the voltage are two important aspects to consider. This article discusses the design and analysis of the Quadratic Boost Converter (QBC), a power converter that offers a higher voltage boost ratio compared to conventional boost converters. The Quadratic Boost Converter uses two inductors and two capacitors arranged in such a way as to boost the input voltage to a higher level with better efficiency. This study includes simulations and laboratory experiments to measure the performance of the Quadratic Boost Converter under various load and input voltage conditions. The results show that the Quadratic Boost Converter is not only able to achieve a higher voltage boost ratio but also has better efficiency under various operating conditions. This study also highlights the advantages of the Quadratic Boost Converter in solar power systems and electric vehicle applications, where significant voltage boost and high efficiency are highly required. Thus, the Quadratic Boost Converter is a potential solution for the need for more efficient and effective power conversion in various modern electronic applications.

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1. INTRODUCTION

Renewable energy sources are currently developing, such as solar power plants, wind power plants, and others. The DC output voltage level issued by this renewable energy generation is low, for example, in solar panels that have output characteristics that change as the level of solar irradiation changes [1]- [2], when the output of the solar cell is at a low value, a voltage boost converter is needed, so that this voltage conversion process runs optimally, a DC step-up converter is needed that has a high voltage ratio [3]-[4].

In the current technological era, the development and use of step up DC-DC converters are increasingly widespread. High ratio voltage conversion DC-DC converters are often considered as the most important part of renewable energy sources and are used in industrial applications [5]. The boost DC-DC converter is used to increase the output voltage higher than the source voltage by adjusting the pulse width on the switch [6]. The boost converter requires a duty cycle close to one, to obtain a high output voltage, a converter that uses a high duty cycle will cause problems, namely EMI (Electromagnetic interference) and decreased efficiency [7]-[8], various new topologies for boost converters have been developed to obtain step-up converters with high voltage conversion ratios such as boost converters with coupled-inductors [9]-[10].

However, this type of converter has energy leakage that causes voltage stress and also high levels of electromagnetic interference (EMI) [11]. Another type of topology for high ratio boost converter is two cascade boost converter, however, because this topology uses 2 switches, the efficiency of the converter is reduced [8]-[11]. To obtain a high ratio step-up converter with high efficiency and low EMI, a boost converter with a single switch must be used [12]-[13]. For this purpose, a new type of boost converter topology was developed which only requires a single switch and three diodes [11]-[13]. This converter has a conversion ratio as a quadratic function so it is called Quadratic Boost Converter flyback boost converter, cascade boost converter. hybrid, transformer boost converter, and quadratic boost converter [14]-[30]. In this final project, a Quadratic Boost Converter will be designed and implemented which has the characteristics of being able to increase dc voltage with a high conversion ratio, this boost converter has the advantage of a smaller duty cycle, so that power distribution is more efficient [15]. This paper proposes a Quadratic Boost Converter that has the characteristic of being able to increase dc voltage with a high conversion ratio, this boost converter has the advantage of a smaller duty cycle, so that power distribution is more efficient. QBC control is proposed using an Arduino Mega 2560 microcontroller.

2. METHOD

Quadratic Boost converter is a DC voltage booster that has a conversion ratio equation as a function of the square of the ratio equation of a conventional Boost converter. The topology of this converter is depicted in Figure 1. With the exception of having just one switch, this converter's topology is nearly identical to that of the Cascade Boost Converter. Furthermore, this converter has three diodes acting as passive switches, two inductors, and two capacitors. Due to its high conversion ratio, this quadratic boost converter can be used with DC links that are coupled to inverters in photovoltaic applications. This is due to the fact that the maximum voltage conversion ratio can be reached before the converter's efficiency declines.

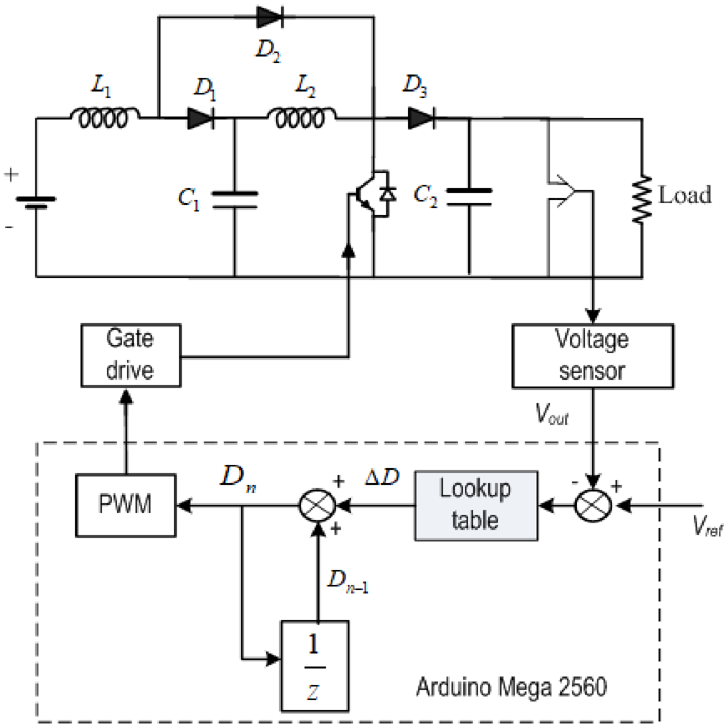

Figure 1. Structure of Quadratic boost converter

In steady state, when the switch is conducting, diode 1 is in reverse condition because the cathode voltage of diode 1 is the same as the voltage of capacitor 1, and the anode voltage is the same as the source voltage, where the voltage of capacitor 1 is greater than the source voltage. Likewise, diode 3 will be in reverse condition while diode 2 will be in forward condition. In this condition, the input voltage of the converter and inductor 1 form a closed loop so that the magnitude of the inductor 1 voltage is the same as the value of the source voltage and the magnitude of the inductor 2 voltage is the same as the value of the capacitor 1 voltage. Inductor L_1 will absorb energy from the source. So that there is a current flow from the source to the inductor L_1, then through the switch to the ground or negative source. The current value in inductor 1 (I_{L1on}) will change positively over time, or in other words increase from zero to a certain value. At the same time, inductor L_2 absorbs the energy stored in capacitor C_1. So that the inductor L_2 current will increase linearly to a certain value and the voltage value of capacitor C_1 will decrease linearly.

The length of time the switch is on will determine the shape of the inductor current signal and also the operating mode of this converter. In Continuous Conduction Mode (CCM) conditions, the length of time the switch is off is kept less than the length of time required to release the energy stored in the inductor until it runs out. When the switch is open, diode 2 will be in reverse bias because the voltage on the cathode side is greater than the voltage on the anode. While diode 1 and diode 3 are in forward bias conditions. In this condition, the voltage source and inductor L_1 will channel energy to capacitor C_1. So that the value of the inductor current L_1 will decrease linearly during the time the switch is closed, while the value of the capacitor voltage C_1 will increase linearly. This condition is described by the following sequence of equations :

$$V_{C1} = V_{in} + V_{L1} = V_{in} + L_1 \frac{\Delta i_{L1}}{\Delta T_{off}} = V_{in} + \frac{V_{in} \Delta T_{on}}{\Delta T_{off}} = V_{in}\left(\frac{T}{T_{on}}\right) = V_{in}\left(\frac{1}{1-D}\right) \tag{1}$$

At the same time, capacitor C1 and inductor L2 will channel the stored energy to capacitor C2. So that the current value of inductor L2 will decrease linearly. This condition is described by the following equation :

$$V_{C2} = V_{C1} + V_{L2} = V_{C1} + L_2 \frac{\Delta i_{L2}}{\Delta T_{off}} = V_{C1} + \frac{V_{C1} \Delta T_{on}}{\Delta T_{off}} \tag{2}$$

$$V_{C2} = V_{C1}\left(\frac{T}{T - \Delta T_{on}}\right) = V_{C1}\left(\frac{1}{1-D}\right) = V_{in}\left(\frac{1}{1-D}\right)^2 \tag{3}$$

In this condition, capacitor C_2 also transfers stored energy to the load. So that the output voltage of this converter is a quadratic function of the conversion ratio formula of the conventional boost converter. Based on Equations (1) to (3), the output voltage equation of the quadratic boost converter can be written as:

$$V_{out} = V_{in}\left(\frac{1}{1-D}\right)^2 \tag{4}$$

Equation (4) shows that the output voltage of the quadratic boost converter is the square of its input voltage, where its value is determined by the duty cycle value *D*. In this paper, the duty cycle value is set using the Arduino Mega 2560 microcontroller, as shown in Figure 1 and block diagram in Figure 2. The block diagram components shown in Figure 2 are the main components of the quadratic boost converter which is the part controlled in this study. Arduino mega 2560 microcontroller, power supply for input to the quadratic boost converter and Arduino, Gate drive which functions as a driver for the MOSFET that will be used in the quadratic boost converter circuit and voltage sensor. The hardware circuit architecture for the proposed quadratic boost converter is displayed in Figure 3.

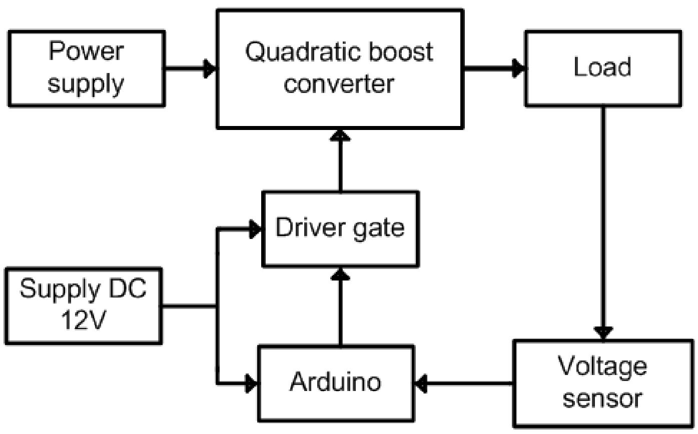

Figure 2. Diagram block of proposed quadratic boost converter

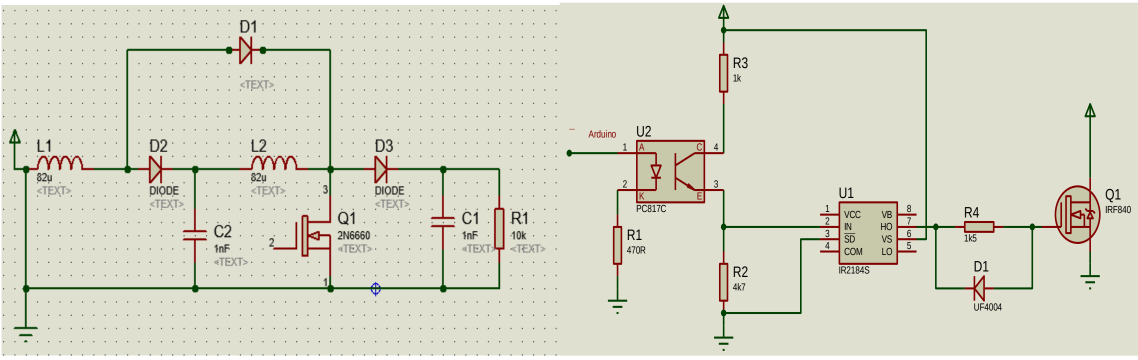

Figure 3. Circuit schematic of proposed quadratic boost converter

3. RESULTS AND DISCUSSION

The design of the quadratic boost converter was tested with various experiments, namely testing the output voltage with varying duty cycle values, changing the duty cycle value is done by changing the pwm value in the simulink mathlab application, the quadratic boost converter is declared valid if the output voltage is quadratic from the source voltage, the output voltage of the quadratic boost converter will be measured with a voltmeter and will also be displayed on simulink mathlab using a voltage sensor.

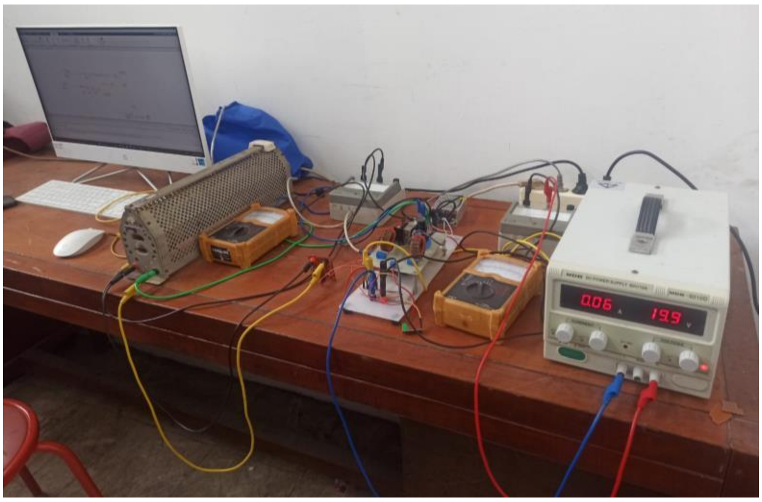

Figure 4. Experimental setup of quadratic boost converter

The experiment is carried out with input voltages of 12V and 20V, while the PWM values to be input are 90, 100, 110, 120, and 130, which means the duty cycle values used are 35%, 39%, 42%, 47%, and 51%. The quadratic boost converter switch is modulated with a switching frequency of 31 kHz. Testing the duty cycle value is done through the output terminal of the gate drive. Testing is done by looking at the PWM pulse on the oscilloscope, as shown in Figure 5.

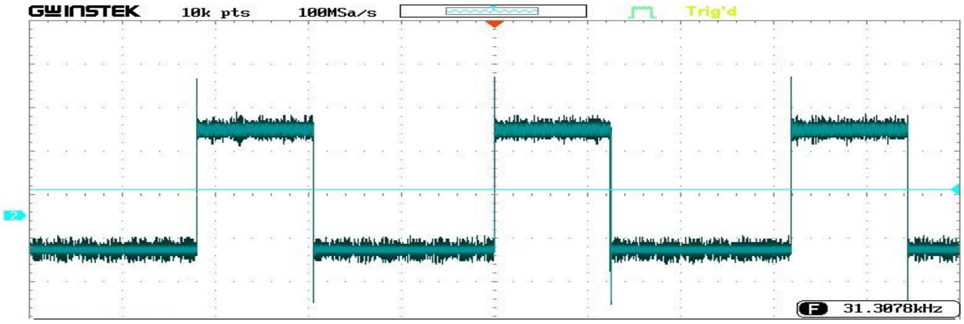

Figure 5. PWM pulse at driver gate terminal

After ensuring the output of the gate drive is good, the next step is to test the output voltage of the quadratic boost converter with 12V input, and varying duty cycle values using Matlab Simulink. Figure 6 shows the output voltage graph and duty cycle graph when the input voltage is 12 Volts.

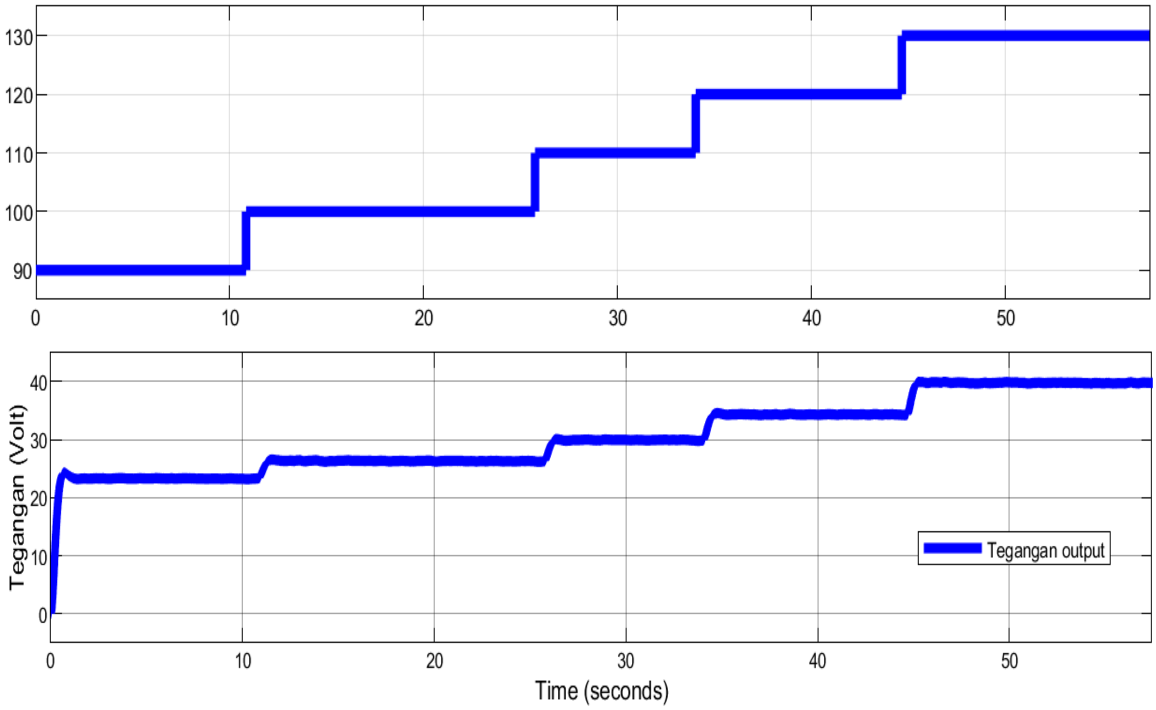

Figure 6. Experimental results with input voltage 12 Volt

The first experimental result when the input voltage is 12 volts, the output voltage is 22 Volts when the Arduino duty cycle is 90 or 35%. When the duty cycle is made 130 or 51%, the output voltage is 40 Volts. This result shows that the output value of the quadratic boost converter is twice the input voltage, or the quadratic of the input voltage value.

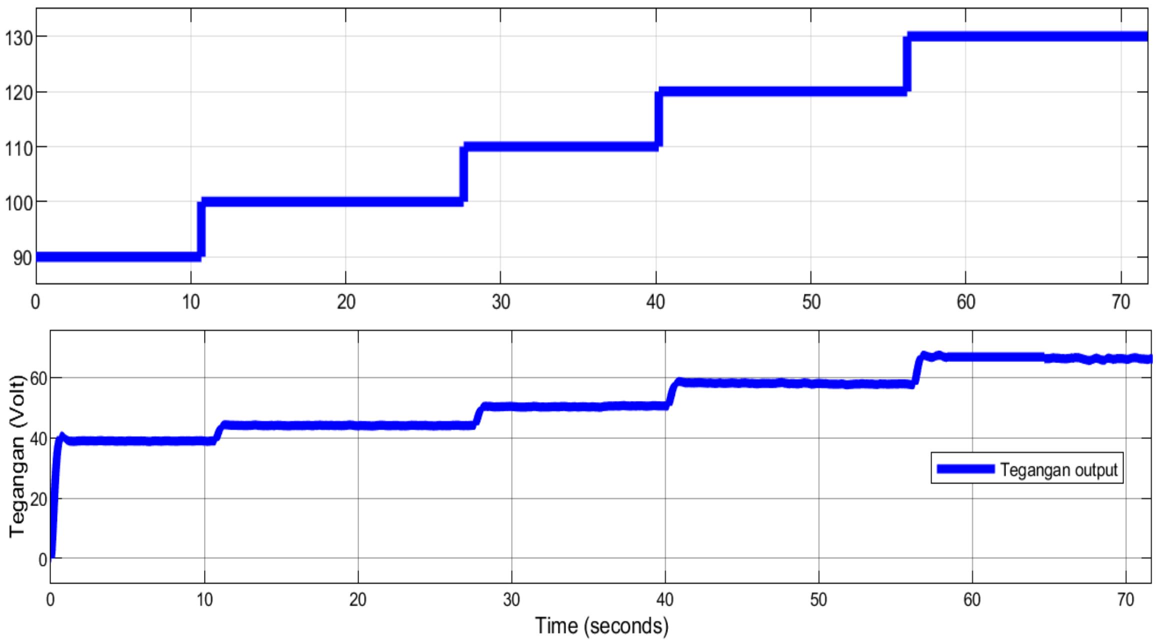

Figure 7. Experimental results with input voltage 20 Volt

The second experimental result when the input voltage is 20 volts, the output voltage is 40 Volts when the Arduino duty cycle is 90 or 35%. When the duty cycle is made 130 or 51%, the output voltage is 67 Volts. This result also shows that the output value of the quadratic boost converter is twice the input voltage, or the quadratic of the input voltage value. Table 1 describes the experimental results obtained from all experiments.

Table 1. Experimental results

Duty Cycle		Input Voltage	Output Voltage
Arduino	%		
90	35	12 Volt	22 Volt
100	39	12 Volt	26 Volt
110	42	12 Volt	30 Volt
120	47	12 Volt	34 Volt
130	51	12 Volt	40 Volt
90	35	20 Volt	40 Volt
100	39	20 Volt	45 Volt
110	42	20 Volt	53 Volt
120	47	20 Volt	60 Volt
130	51	20 Volt	67 Volt

4. CONCLUSION

Based on the results of the research that has been done, the quadratic boost converter has succeeded in increasing the voltage quite high compared to the regular boost converter and with a low duty cycle value, after conducting several experiments it can be seen that the duty cycle value depends on the width of the PWM pulse that is set, the higher the PWM value the higher the duty cycle value produced, and after being tested with input voltage values of 12V and 20V and with varying duty cycle values it can be concluded that the higher the duty cycle value used, the higher the output voltage produced, with the results obtained it can be concluded that the output voltage produced by the quadratic boost converter has a higher value than the voltage produced by the regular boost converter.

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