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High Efficiency Switched Inductor Based Quadratic Boost Converter

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ABSTRACT:In renewable applications, A high efficiency switched inductor-based quadratic boost converter is designed here. This converter work at high efficiency without having high duty ratios. The usage of Renewable energy sources reduces the usage of fossil fuels, reducing global warming. A high step-up converter topology is used with a suitable duty ratio to attain high efficiency and high gain. It requires renewable energy applications. The use of the switched inductor concept boosts the converter's voltage and improves the converter's gain. It reduces the voltage stress and enhances efficiency. It acts as a voltage multiplier cell. Comparing conventional boost converters, quadratic boost converters, and switched inductor-based quadratic boost converters (QBC) is done. The converter operated in continuous conduction mode. The performance study and analysis of QBC is carried out with MATLAB/SIMULINK.

KEYWORDS: Quadratic Boost Converter, Switched Inductor, High Efficiency.

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I.INTRODUCTION

Power electronic devices are used in many applications. Nowadays global energy crisis is increasing. As a result, environmental issues, global warming is also increased. These converters reduce the usage of fossil fuels and expanding the use of renewable energy sources. But the solar panel and fuel cells have low and variable output voltage. These energy sources need a DC-DC converter with a high ratio to attain the high output voltage. High step-up converter topologies with suitable duty ratios are used to get the high gain and efficiency. A voltage lift technique is employed in the positive cascade boost converter [2]. The voltage is lifted stage by stage by using the super lift technique and increases the voltage level. But the complexity of the circuit is high and less efficient. The boost converter has a feature of low buffer capacitor stress [3]. Here the converter has low stress across the capacitor. The converter is capable of converting the input voltage into a high voltage level. The converter has two input filters, and it isn't easy to design it. It has a pulsating input current. It requires a converter with a continuous input current, and the quadratic boost converter has a low input current and constant [4]. The quadratic boost converter has only one low-stress active switch and no instantaneous change in capacitor voltage. There is no abrupt over-current and voltage in the complete cycle of inductor currents and storage elements, and It used for fuel cell applications. The inductor will reduce the efficiency of the converter. But for the fuel cell application requires a high-efficiency high conversion ratio converter required. To obtain this, switched inductor concept is combined. Switched inductor cells act as a voltage multiplier, and the converter can boost the voltage and achieves a high gain. The high DC-DC converter uses the switched inductor concept and acts as a voltage multiplier [5]. It has many advantages, such as high gain, efficiency, and a high-power conversion ratio, and it also provides low voltage stress across the switches. SIBC replaces the inductor with a switched inductor cell [6,9]. The maximum power from the photovoltaic modules is extracted and provides maximum output voltage. The SIBC is applicable for grid applications. A novel quadratic boost converter with low inductor current was developed to overcome these drawbacks and modified this paper to achieve a high gain and efficiency [1]. It has continuous input current and low inductor current. It is a double switch converter operating at the same frequency.

In addition to this, a switched inductor-based quadratic boost converter is developed. It has high efficiency and high gain. The switched inductor concepts are used to increase the gain. As per the no of components, the switchedinductor-based quadratic boost converter has moderately less compared with simple switched inductor high gain converter [7]. It has a high no of components. The switched inductor for PV application [6] has significantly less component count and is also simple in construction. Comparing with the modified switched inductor boost converter with low voltage stress [8] has less no of components with the switched inductor-based quadratic boost converter. The high efficiency switched inductor-based quadratic boost converter has less no of components than other switched inductor boost converters. The converter is reliable and suitable for renewable applications.

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II.METHODOLOGY

The switched inductor-based QBC has two MOSFET switches (S_1 and S_2), three inductors (L_1, L_2, and L_3), five diodes (D_1, D_2, D_3, D_4, and D_5), and two capacitors (C_1 and C_2). V_{in} is the input voltage R_L is the load resistance. The converter operated in two modes.

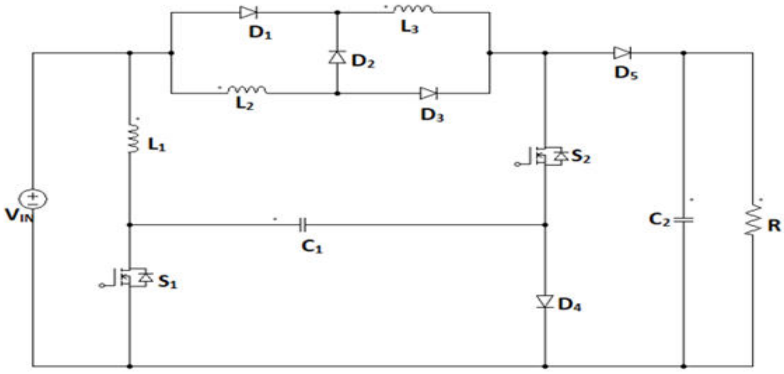

Fig. 1 Quadratic boost converter

III.MODES OF OPERATION

In mode 1, both the switches are in an ON state. The diodes D_1, D_3 are forward biased, and all other diodes D_2, D_4, and D_5 are reverse biased. The input voltage source charges the three inductors L_1, L_2, and L_3, in mode 1. The capacitor C_1 discharges, and C_2 feeds the load and supply current to the load. The current path is shown in fig. 2.

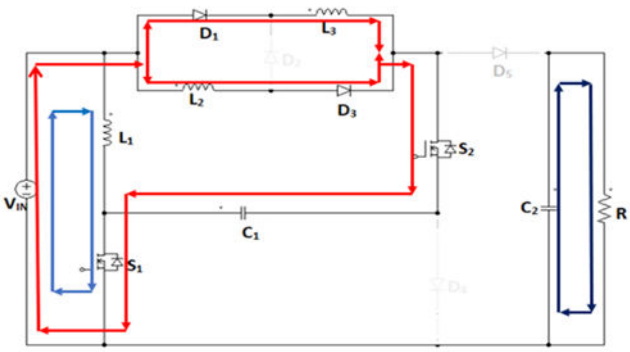

Fig. 2Mode 1 Operation of QBC

In mode 2, both the switches are turned OFF. The diodes D_1, D_3 are reverse biased, and all other diodes D_2, D_4, and D_5 are forward biased. The three inductor L_1 discharges through capacitor C_1. The inductor L_2 and L_3 are discharges through a load in mode 2. The capacitor C_1 charges, and C_2 feeds the load and supply current to the load. The flow of the current path is shown in fig. 2.

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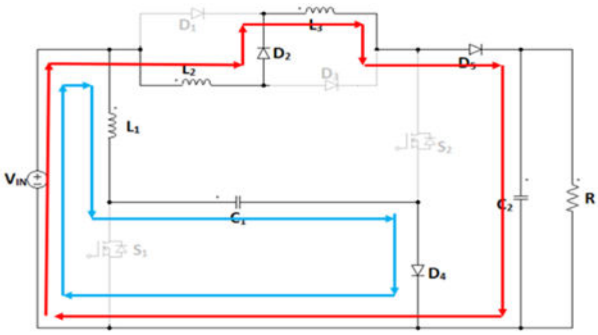

Fig. 3Mode 2 Operation of QBC

Figure 4 shows the theoretical waveform of the quadratic boost converter. Here shows the waveform of the mode 1 and mode2 operation of quadratic boost converter.

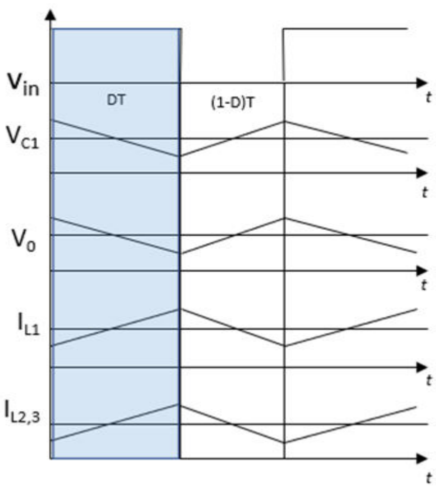

Fig.4 Theoretical waveforms of QBC

IV.DESIGN OF COMPONENTS

In order to operate the converter properly, the components should be designed appropriately. The output power is taken as 72W with a switching frequency of 50kHz. Consider the duty ratio fixed as 46.55%, and the input voltage is 20V. The output voltage is taken as 120V. The load resistance is 200Ω. Then the gain of the converter is six, and the duty ratio is approximated to 0.4655.

$$D = 1 - \frac{1}{\sqrt{M}} \quad (1)$$

$$M = \frac{V_O}{V_{in}} \quad (2)$$

$$i_0 = \frac{P_0}{V_0} \quad (3)$$

On solving equation (1), the gain is 6, and solving equation (2) output current is approximated to 0.6A.

$$L_1 \geq \frac{R_L * T * (1-D)^4}{0.3} \quad (4)$$

The inductor L_1 is given in equation (3) and approximated as 3mH. The inductor current of L_2 and L_3 is given in equation (4), and solving it is approximated as 1.122A.

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$I_{L2} = I_0 * \frac{1}{(1-D)}$ (5)

The current ripple of inductor L_2 and L_3 is less than 40%. So $\Delta I_{L2} = \Delta I_{L3}$ = 0.449A. The inductor L_2 and L_3 is given in equation (6) and taken as 1.5mH

$$L_{2,3} \geq \frac{(2-D)*DT*V_{in}}{(1-D)\Delta I_{L2}} \quad (6)$$

The capacitor C_1 is taken as 10µF, and C_2 is taken as 100 µF by solving the below equations (7) and (8)

$$C_1 \geq \frac{DT}{0.1R_L(1-D)^2} \quad (7)$$

$$C_2 \geq \frac{DT}{0.001R_L} \quad (8)$$

V.SIMULATION AND RESULTS

The simulations of QBC done by using the MATLAB/SIMULINK by choosing the parameters are listed in table 1. The switches are MOSFET/Diode with a switching frequency 50kHz. Simulation parameters of QBC are input voltage V_{in} is 20V, Rated power P_0 is 72W Inductor L1 is 3mH, Inductor L_2, $L_3$is 1.5mH and Capacitor C_1, C_2 10µF,100µF.Fig. 5 shows the gate pulse of two switches. The voltage stress across the two switches is 38.2V and 113.5V

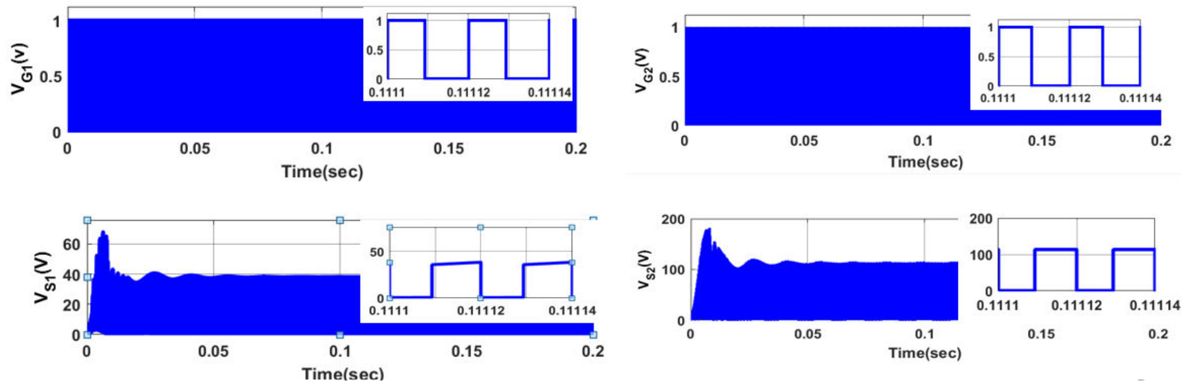

Fig. 5. Gate pulse and voltage stress vs Simulation time of Switch S_1 and Switch S_2

Fig. 6 shows the input voltage and input current. It is taken as 20V and 3.401A as a ripple of 1.86A and output voltage and output current vs time. It is measured as 113.5V and a ripple of 0.070V. The output current is measured as 0.5677A and a ripple of 0.00037A

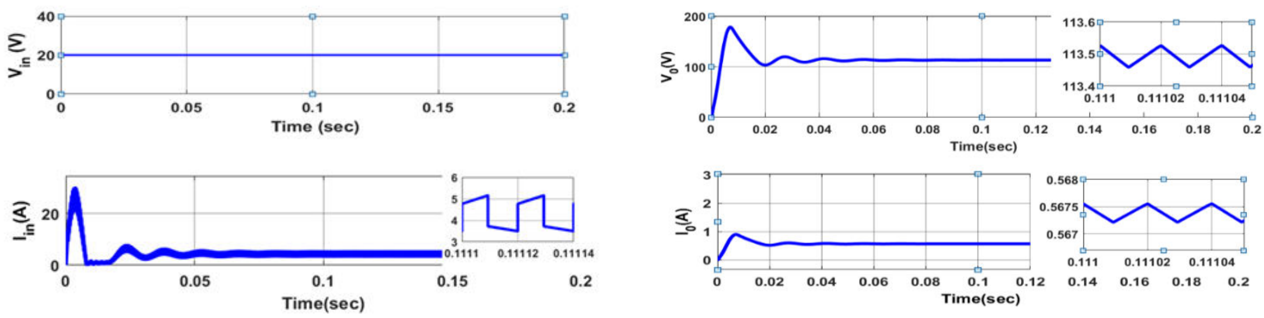

Fig. 6.Input voltage and current vs time and output voltage and current vs time

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Fig. 7 shows the inductor current of three inductors, L_1, L_2, and L_3. The inductor L_1 has a current of 2.367A and a ripple of 0.069A. The inductor L_2 and L_3 have a current of 1.007A and a ripple of 0.37A. And capacitor voltage of C_1 and C_2.

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The capacitor voltage of C_1 is measured as 37.44V and a ripple of 2.82V. The capacitor voltage of C_2 is measured as 113.5V and a ripple of 0.070V.

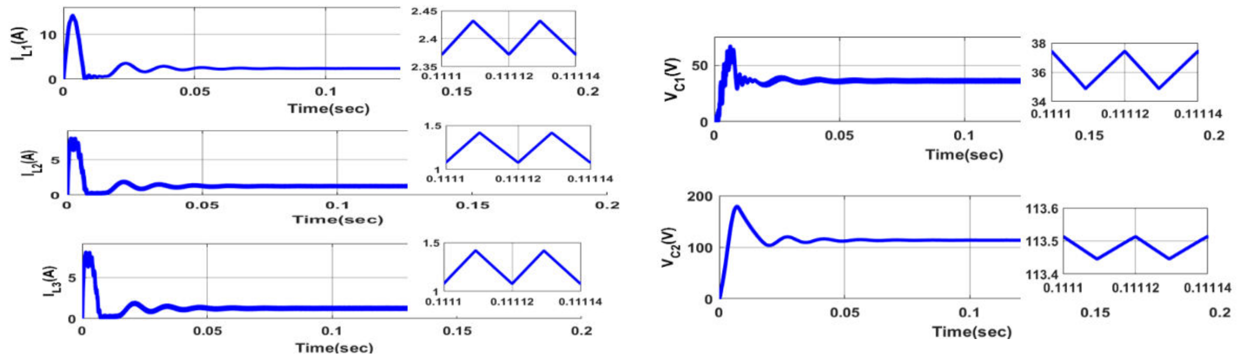

Fig. 7. Inductor current of L_1, L_2, L_3 vs time and Capacitor voltage of C_1 and C_2 vs time

VI.PERFORMANCE ANALYSIS

The efficiency of power equipment is defined as the ratio of output power to input power. The efficiency tells the fraction of input power delivered to the load. Fig.8 shows the efficiency versus Output power graph with R load and RL load. The converter has an efficiency of 95% at 72W power. It can achieve maximum efficiency of 98% in case of R load. In case of RL load it has a maximum efficiency of 98%. The efficiency is gradually increased within output power.

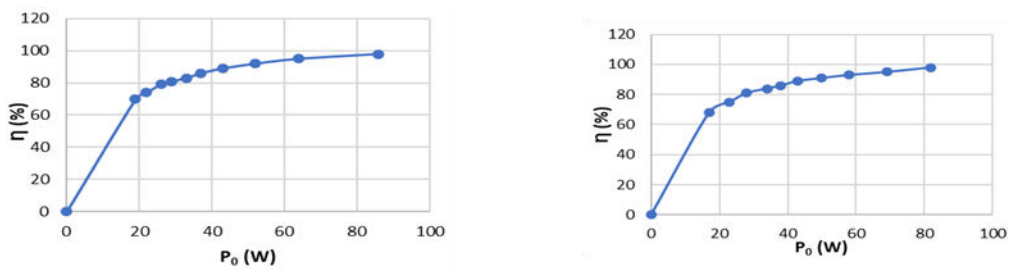

Fig .8efficiency analysisR and RL load vs Output power

Fig. 9 shows the ripple vs duty ratio. It seems that as the duty ratio increases, the ripple also gradually increases. The percentage ripple voltage varies from 0.01% to 0.1% when the duty cycle increases from 15 to 80%. The gain vs duty ratio shows that the gain increases with the duty ratio. The converter has a gain of 6 at a duty ratio of 46.55%.

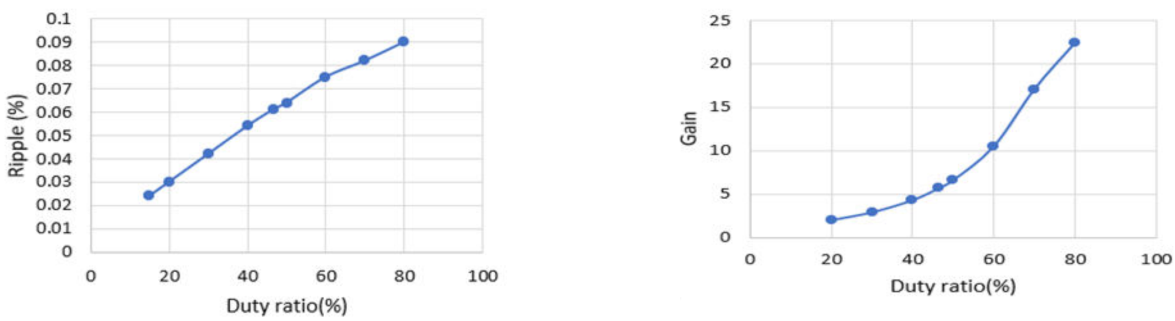

Fig.9Analysis of ripple vs Duty ratio and Gain Vs Duty ratio

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Fig.10 shows the percentage ripple Vs switching frequency as the ripple decreases with an increase in switching frequency. Here the lowest ripple at 0.070% at a switching frequency of 50kHz.

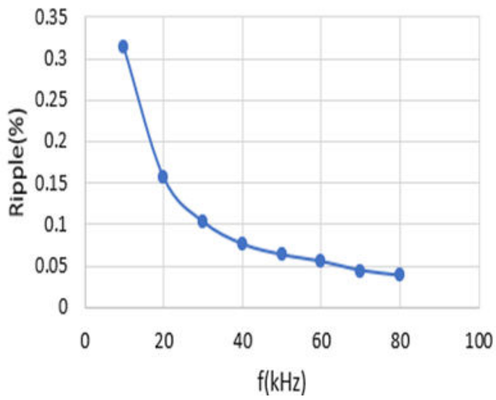

Fig .10Ripple vs Switching frequency;

VII.CONCLUSION

The high efficiency switched inductor-based quadratic boost converter is proposed in this paper, which has the advantage of high efficiency and improved gain. The converter operates in a constant duty ratio and providing a high voltage conversion ratio. Its commonly used for renewable energy applications like solar panels, fuel cells, etc. The proposed converter has only two switches. The switch S_1 has low voltage stress compared with switch S_2. The performance and analysis are done using MATLAB/SIMULINK model. From the analysis, it's clear that it has high efficiency and gain. The output voltage ripple of the converter is low, and also the switching losses are reduced. These features make the topology excellent for renewable energy application

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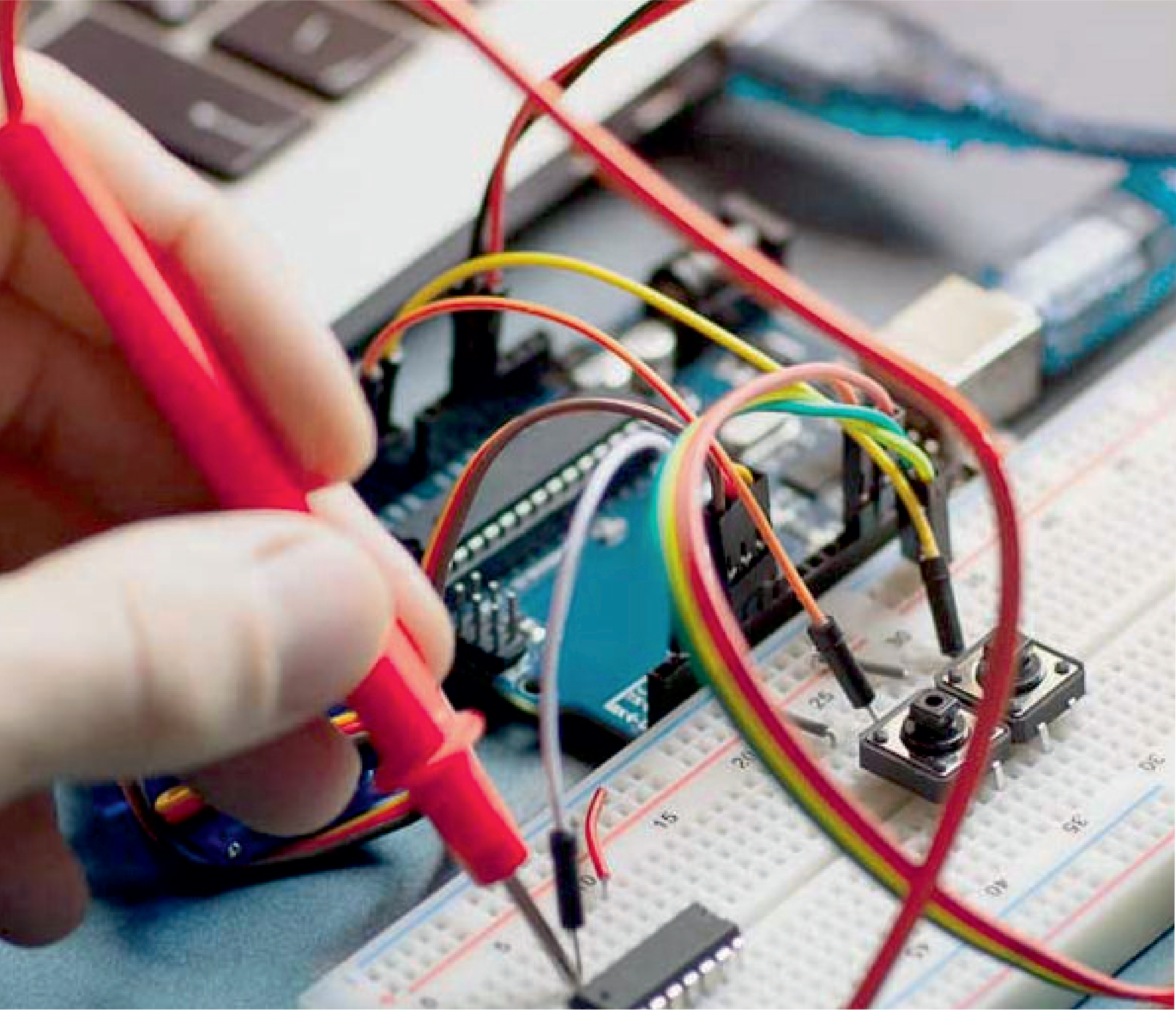

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