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Design and Analysis of a Novel High Gain Boost Converter for a Renewable Energy System

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ABSTRACT: Renewable energy sources such as solar panels, fuel cells, and wind systems typically produce low DC voltages that are insufficient for most applications. To overcome this, efficient DC–DC converters are needed to boost the voltage to a usable level. This paper focuses on designing a high-gain boost converter that effectively increases the output voltage while reducing switching component stress and minimizing output ripple. The converter uses inductors and capacitors to efficiently store and transfer energy. An ATmega8 microcontroller generates PWM signals to control the switching process, ensuring stable operation and proper voltage regulation. The system is designed to improve efficiency, reduce losses, and deliver better performance than traditional boost converters. Overall, the proposed converter is a suitable solution for renewable energy applications that require reliable voltage step-up.

KEYWORDS: Renewable energy system (RES), Novality, High gain, Boost converter, ATMEGA8 PWM control.

I. INTRODUCTION

The rapid growth of Renewable Energy Systems such as Solar PV panels, Fuel Cells, and Wind Energy Systems has been driven by increasing demand for clean, sustainable energy. However, they typically generate low DC voltages, which aren't sufficient for practical applications such as electric vehicles, DC microgrids, and power supplies. A boost converter is often chosen because it's straightforward, but traditional designs require very high duty cycles to achieve significant voltage gain. This leads to more stress on components, higher losses, and lower efficiency. This paper focuses on a high-gain boost converter that addresses these issues. It produces higher voltage output with less ripple, reduced switching stress, and improved efficiency. An ATmega8A microcontroller generates PWM signals and controls the converter's operation. Overall, this design enhances the performance and reliability of renewable energy systems by enabling efficient, stable voltage conversion.

II. LITERATURE SURVEY

Several studies have explored integrating solar and wind power into standalone inverter systems. This section reviews relevant research on.

2.1 High Voltage Quadratic Boost Converter

Several topologies of the quadratic boost converter (QBC) have been introduced. These topologies are designed to produce significantly higher voltages at lower duty cycles by effectively minimizing stress on the switching devices; however, at higher duty ratios, the inductor core is more likely to saturate [1], [2], & [3]. A novel quadratic boost converter is designed to minimize inductor current ripple and reduce switch stress [4]. A quadratic boost converter is introduced by implementing the voltage lift technique [5].

2.2 Quasi – Z – Source Converter

Quasi-Z-source converters are proposed for a renewable energy generation system [6] & [7]. This converter replaces the inductor with an impedance network in the high-gain boost converter topology, but it operates within a constrained duty cycle range.

2.3 Interleaved Boost Converter

An interleaved boost converter is developed that enhances both the output voltage and efficiency with fewer switches [8]. An interleaved high-gain boost converter is carried out by combining two boost converters [9]. A multiphase interleaved converter combined with a Z-source network achieves a high gain with a low input current ripple and eliminates the need for an input filter [10].

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2.4 Inductor-Based DC-DC Converter

A non-isolated coupled inductor-based high step-up DC-DC converter with ultra-high voltage gain facilitated by an active switched inductor [11]. Its broad voltage-gain range offers versatility, low semiconductor spikes to enhance reliability, and a simple gate-driver control system, making it user-friendly.

2.5 MPPT and Control Strategies

Particle Swarm Optimization (PSO) is used in Maximum Power Point Tracking (MPPT) techniques, namely Perturb & Observe and Incremental. The results shown in the system are improved tracking speed and efficiency for grid-connected photovoltaic (PV) systems [12]. Moreover, combining control methods with high-gain converters improves overall system performance by maintaining a stable output voltage despite varying inputs.

III. CONVERTER AND ITS OPERATION

The proposed converter efficiently steps up the low-voltage output of renewable sources to a higher-level DC for practical applications by providing a specific system architecture. The proposed converter operates in 2 modes.

3.1 System Architecture

The complete system consists of a renewable energy generation source, a voltage sensing unit, an ATmega8 microcontroller, the proposed high-gain boost converter topology, and a high-voltage DC load. As illustrated in Figure 3.1, the converter receives the input DC voltage (Vin) from a renewable energy source, such as a photovoltaic (PV) panel or a fuel cell. Since renewable sources typically provide low, variable output voltage depending on environmental conditions, it must be boosted to a higher, more stable level. The input voltage is measured by a voltage-sensing circuit and provided as a reference voltage signal (Vref) to the ATmega8 microcontroller. The microcontroller reads this signal through its internal ADC for continuous voltage monitoring. Based on the measured value, the ATmega8 generates a PWM control signal. This converter steps up the input voltage to a higher output voltage (Vout).

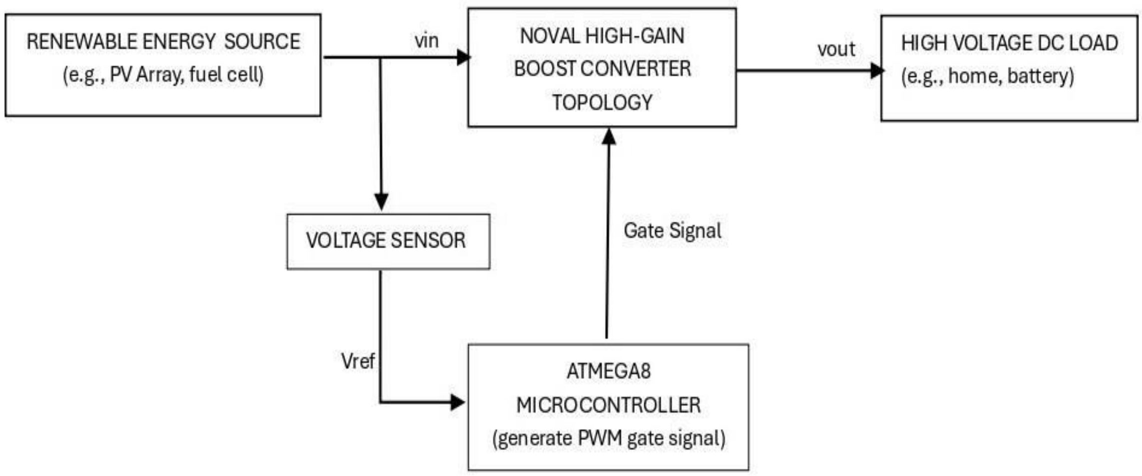

Figure 3.1 Block diagram of boost converter

3.2 Circuit Diagram

A type of DC-DC power converter designed to step up a lower input voltage to a higher output voltage. As shown in Figure 3.2, this circuit includes an input filter capacitor (C1) and a main energy-storing inductor. A notable feature of this design is the use of two MOSFET switches (Q1 and Q2) connected in parallel; this is a technique used in higher-power applications to share the current load, reduce electrical resistance (and therefore conduction losses), and improve heat dissipation. Finally, a diode directs the energy to the load, while parallel output capacitors (C2 and C3) act as a filter to smooth the stepped-up voltage and minimize output ripple.

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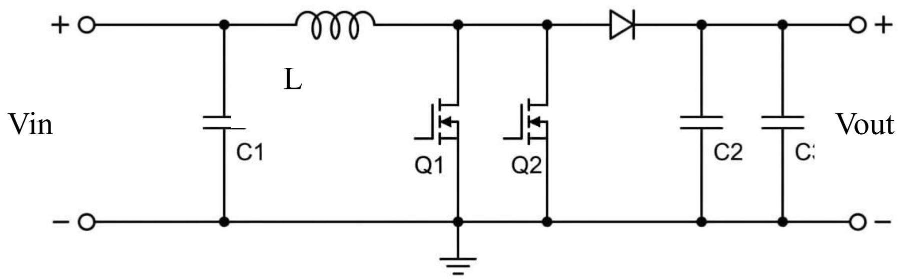

Figure 3.2 Proposed Boost Converter

Mode 1: Switches Q1 and Q2 are ON

When switches Q1 and Q2 are turned ON, they provide a conducting path to ground, as shown in Figure 3.3. The current enters from the input source, through the inductor, and then flows through the switches to ground.

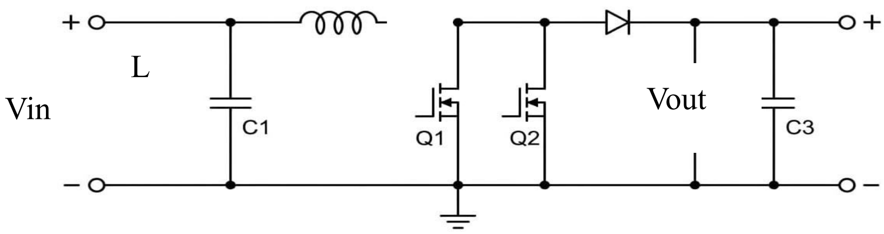

Figure 3.3 Mode 1 Operation Of Boost Converter

During this interval, the inductor stores energy as a magnetic field. Since the input voltage is applied across the coil, the current through the inductor increases slowly. This is where the diode becomes reverse-biased, preventing current from passing to the output side. This causes the output voltage to drop, and during this time, the load is temporarily supplied by the C2 and C3 output capacitors, which discharge slowly to keep the output voltage. C1 is the input capacitor that stabilizes the input voltage and reduces input ripple. In this mode, energy transfer occurs from the inductor to the output at subsequent switch OFF instances, while the circuit serves as an energy storage element.

Mode 2: The case when Switch Q1 and Q2 are OFF

When the switches Q1 and Q2 turn OFF, the path to ground is removed, as shown in Figure 3.4. Since the current in an inductor cannot change instantaneously, the stored energy in its core keeps some current flowing.

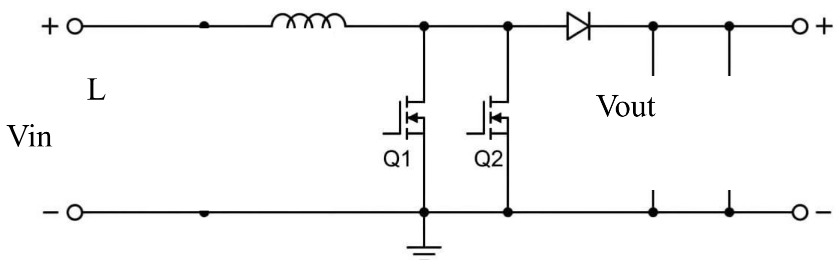

Figure 3.4 Mode 2 Operation Of Boost Converter

This reverses the polarity across the inductor and forward biases the diode. Consequently, the stored energy in the inductor is released to the output capacitors C2 and C3 and then to the load. The capacitors provide charging that smooths the output voltage, helping reduce ripple. As a result of this energy transfer process, the output voltage is higher than the input voltage. Through these switching processes, the converter generates high voltage gain for renewable energy applications.

3.3 Overall system operation

The proposed system is designed to efficiently convert low, varying voltage from a solar photovoltaic (PV) source into a high DC output voltage, as shown in Figure 3.5, using a novel high-gain boost converter. Initially, the solar PV array

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generates a low and fluctuating DC voltage depending on sunlight conditions. This variable voltage is first applied to two 6V batteries connected in series, forming a 12V battery bank. The batteries act as an energy storage system and help in stabilizing the input supply. The battery's output is then fed to the high-gain boost converter. At the converter's input, capacitor C1 reduces voltage ripple and provides a stable DC input. The converter consists of an inductor (L), two switches (Q1 and Q2), a diode (D), and output capacitors (C2 and C3).

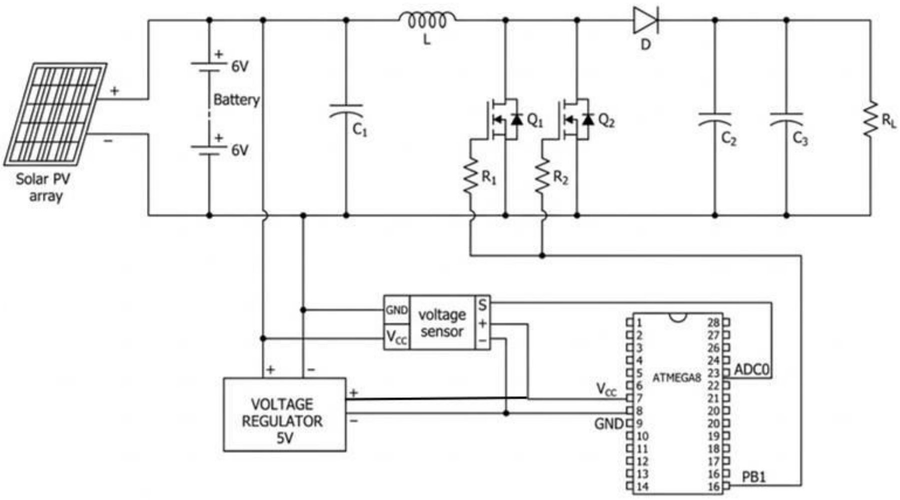

Figure 3.5 Circuit diagram of the proposed system

A voltage regulator (5V) is used to supply a constant voltage to the ATmega8 microcontroller. A voltage sensor is connected at the converter's input to measure the input voltage and provide a reference signal to the microcontroller. Based on this reference voltage, the microcontroller generates PWM gate pulses for both switches (Q1 and Q2). When the switches are ON, the inductor stores energy. When the switches are OFF, the stored energy is transferred through the diode to the output capacitors and load. Due to this switching action and converter topology, the output voltage is boosted approximately 10 times the input voltage. Thus, the system ensures efficient voltage step-up, reduced ripple, and stable operation for renewable energy applications.

IV. HARDWARE IMPLEMENTATION

The proposed high-gain boost converter is implemented using 2 MOSFET switches. The ATMEGA8 microcontroller is programmed to generate gate signals for the proposed high gain boost converter.

4.1. Solar Photovoltaic (PV) Panel

The solar photovoltaic (PV) panel, as shown in Figure 4.1, is the primary renewable energy source used in this system. It converts solar radiation directly into electrical energy through the photovoltaic effect. The PV panel produces a low DC voltage. In this hardware implementation, the PV panel provides approximately 6V DC, 6W, and 1A under normal sunlight conditions. Since the generated voltage is relatively low and unstable, it cannot directly power many electronic loads.

4.2. Battery

The battery, as shown in Figure 4.1, stores the electrical energy generated by the solar panel for later use. Two 6V, 4.5Ah batteries are connected in series and used as the energy storage element. The battery helps maintain continuous system operation during periods of low solar irradiance or at night. When the solar panel generates excess power, it is stored in the battery. During insufficient solar generation, the battery supplies power to the converter and the connected load.

4.3. Voltage Regulator

The voltage regulators (L7805 & L7809), as shown in Figure 4.1, provide a stable, constant voltage supply to the control circuits, especially the microcontroller and sensing modules. A 5V voltage regulator is used to ensure the reliable operation of the electronic components. Since the input voltage from the battery or converter may fluctuate, the regulator maintains a fixed output voltage required for the control unit to function properly. And we use another voltage regulator

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that converts 12V to 9V for input voltage indication. The regulated voltage is displayed in the meter as shown in Figure 4.1

4.4. **Microcontroller**

The microcontroller (ATMEGA8-A)**, as shown in Figure 4.1, acts** as the control unit of the entire system. It generates the pulse-width modulation (PWM) signals required to control the boost converter's switching operation. By adjusting the duty cycle of the switching pulses based on the converter's input voltage, the microcontroller regulates the output voltage and ensures stable converter operation. The controller also receives input signals from the converter input through a voltage-sensing circuit, as shown in Figure 4.1, and processes them through its analog-to-digital converter (ADC).

4.5. High-Gain Boost Converter

The high gain boost converter, as shown in Figure 4.1, is the main power conversion stage of the system. Its purpose is to increase the low DC voltage generated by the solar PV panel to a higher DC voltage suitable for the load, as shown in Figure 4.1. The converter consists of an inductor, switching devices (MOSFETs), diodes, and capacitors. The inductor stores energy when the switching device is on and releases it when the switch is off. Capacitors help reduce voltage ripple and maintain a stable output voltage. The converter's output is displayed on the meter, as shown in Figure 4.1. By adjusting the switching duty cycle, the converter achieves higher voltage gain and improved efficiency compared to conventional boost converters.

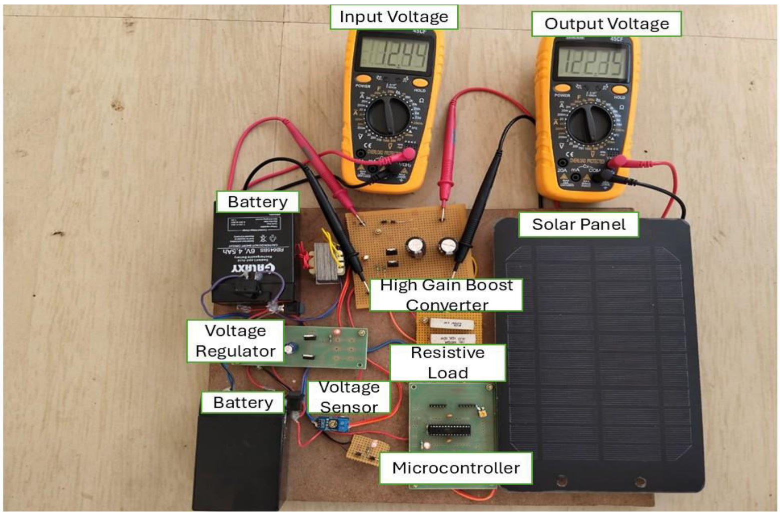

Figure 4.1 Hardware implementation of the proposed system

Parameters	Specification
Input voltage	V_{in}=9V&12V
Maximum power	P_{max}=6W
Load	R_L=10K,10W ||1K,10W
Frequency	F=10KHz-200KHz
Inductor	L=100-150mH
Capacitors C_1, C_2 & C_3	C_1=100µF(25V), C_2= C_3=100µF(250V)
Power MOSFET	TIP122,100V,5A
Diode	1N4007
Microcontroller	ATMEGA8A-U
Voltage Regulator	L7805(5V), L7809(9V)

4.6. Controller Algorithm

The controller algorithm for the proposed high gain boost converter consists of 12 steps as given below,

Step 1: Start

Step 2: Initialize ADC module

Step 3: Initialize PWM (Timer1)

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Step 4: Set initial duty cycle
Step 5: Read ADC value
Step 6: If ADC value < minimum threshold → set to safe value
Step 7: Calculate duty cycle using the inverse formula
Step 8: Limit duty cycle within safe range (40%–90%)
Step 9: Apply a smoothing filter to the duty
Step 10: Update PWM register (OCR1A)
Step 11: Wait for a small delay
Step 12: Repeat from Step 5

4.7 PWM Generation for High-Gain Boost Converter

The software for the proposed high gain boost converter is implemented in embedded C and runs on the ATmega8 microcontroller. Its main function is to control the converter's switching operation by generating a PWM signal and dynamically adjusting its duty cycle based on sensed voltage feedback. The program begins by initializing both the ADC and PWM modules. The ADC uses AVCC as the reference voltage and reads the analog signal from the voltage-sensing circuit, converting it to a digital value ranging from 0 to 1023 for processing. PWM generation is performed using Timer1 in 10-bit Fast PWM mode, with the output delivered to the OC1A pin (PB1) to drive the MOSFET switch. A prescaler value of 8 is selected, resulting in a switching frequency of approximately 4 kHz. In the main loop, ADC values are continuously monitored, and a minimum threshold is enforced to prevent unstable operation. The duty cycle is calculated using an inverse relationship: lower voltage results in a higher duty cycle, which is ideal for boost converters. The duty cycle is constrained to 40%-90%, smoothed by a filter, and updated in the OCR1A register.

V. RESULT AND ANALYSIS

The proposed novel high-gain boost converter is experimentally tested to verify its voltage-boosting capability for renewable energy applications. This Hardware prototype operates with low input voltages of 9 V (Figure 5.1) and 12 V (Figure 5.2), and the corresponding output voltages are 10 times greater than the input voltages. A 10 W solar panel was used to test the performance of the high-gain boost converter.

INPUT VOLTAGE	OUTPUT VOLTAGE
9V	90V
12V	120V

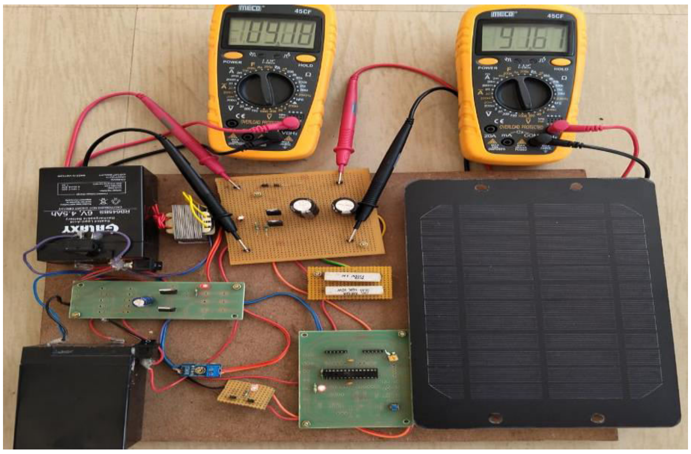

Figure 5.1 Gain pattern 1(Input = 9V)

This hardware prototype operates on a low input voltage of 9V and boosts it to 10 times that value. This is shown in Figure 5.1

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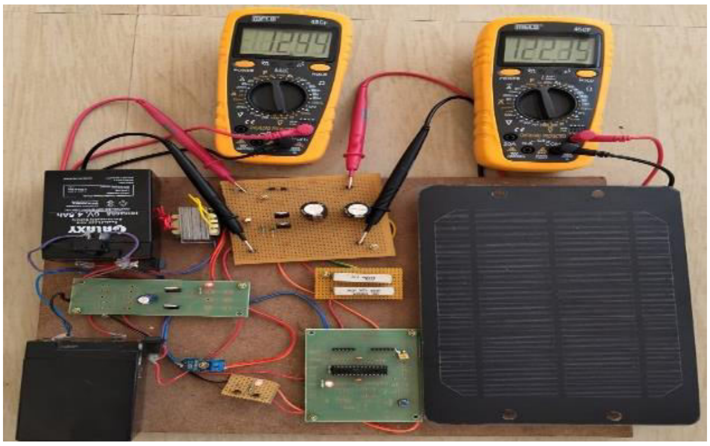

Figure 5.2 Gain pattern 2(Input = 12V)

This hardware prototype operates on a low input voltage of 12 V and boosts the input voltage to 10 times. This is shown in Figure 5.2

VI. CONCLUSION

The proposed high-gain boost converter is experimentally analysed for input voltages of 9V and 12V. The results show that the converter can achieve approximately 10 times voltage gain under controlled PWM operation. With a 9V input, the output voltage is boosted to nearly 90V. In contrast, for an input of 12V, the output reached approximately 120 V. The converter employs two MOSFET switches to improve switching performance, enhance voltage gain, and reduce stress on individual components. The use of dual MOSFETs also improves efficiency and reliability under varying load conditions. The results demonstrate stable operation and consistent gain across varying input conditions. Hence, the system is well-suited for renewable energy applications, where low-input-voltage sources such as solar panels require efficient high-step-up conversion.

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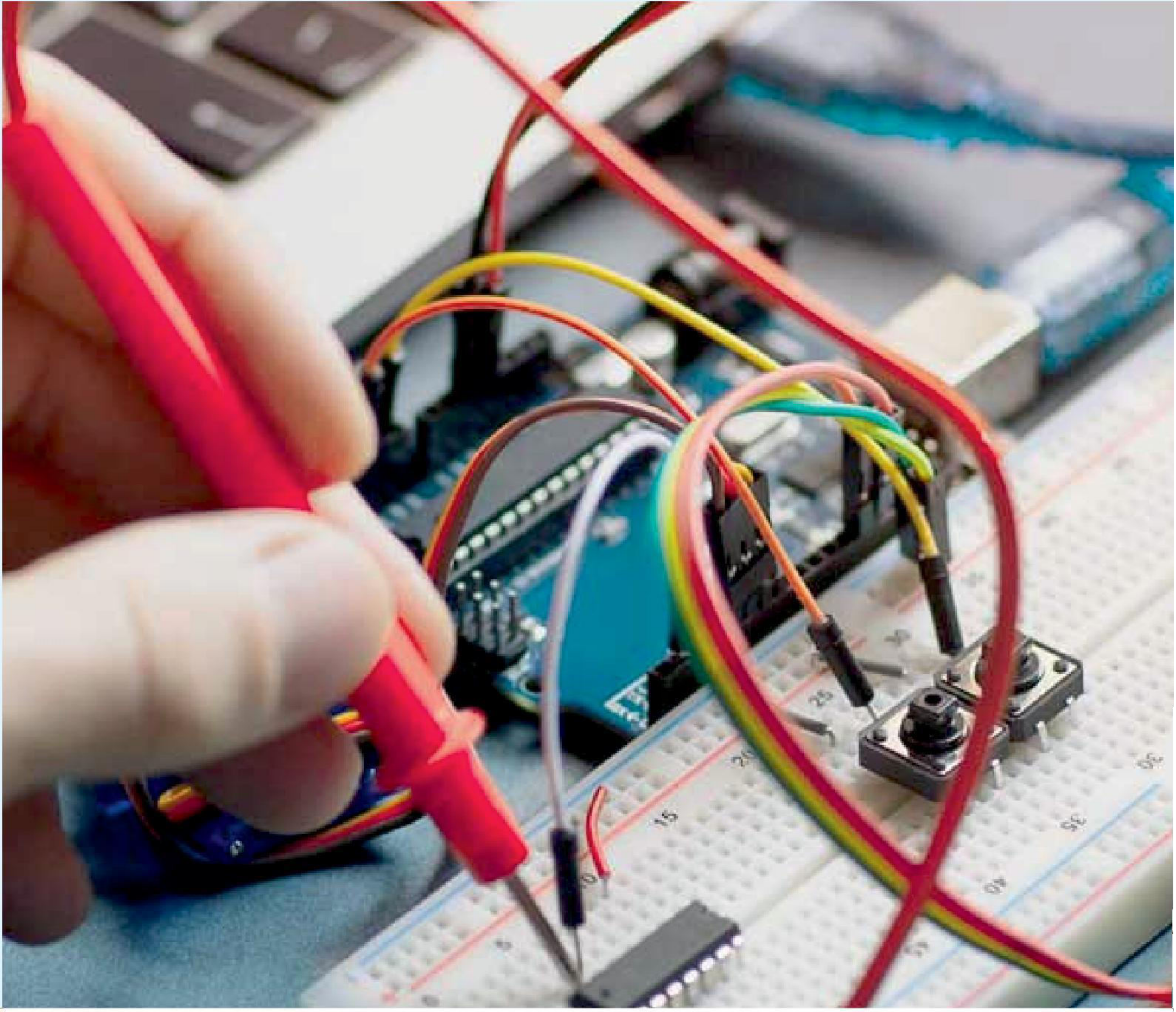

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