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Extended Hybrid DC-DC Converter Adopting Voltage Multiplier Cell for High Voltage gain

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ABSTRACT: —Photovoltaic cells and fuel-cell stacks are examples of renewable energy sources that are growing rapidly around the world. The high voltage ratio boosting converter is becoming more popular due to the widespread use of renewable energy with low output voltage. This paper describes a voltage multiplier cell with a high step-up extensible hybrid DC-DC converter. A twophase interleaved boost converter, a switched capacitor (SC) boost circuit, and a voltage multiplier cell make up the converter. Two capacitors, two diodes, and one inductor make up the voltage multiplier cell. It is used on the converter's output side to boost voltage gain. High voltage gain, low switching voltage stress, and reduced input current ripple are all advantages of the converter. The converter's input current ripple was further decreased by increasing the number of parallel channels or SC units. The converter's performance is investigated using MATLAB/SIMULINK R2017a. The converter has 73% efficiency and a voltage gain of roughly 13.25, according to the simulation results

KEYWORDS: High step-up, interleaved, low input ripple, Voltage multiplier cell

I.INTRODUCTION

The energy problem and environmental degradation have become more apparent in recent years. Photovoltaic cells and fuel-cell stacks are examples of renewable energy sources that are gaining traction around the world. The rapid expansion of renewable energy systems necessitates the creation of a new generation of high gain DC-DC converters that are both efficient and inexpensive. The front end of a "Plug and Play" PV system normally requires a step-up converter that can boost the voltage from 35V to 380V while maintaining regulation. [1] Presents an interleaved switch-capacitor based high step-up extensible hybrid DC-DC converter. A two-phase interleaved boost converter and a switch-capacitor (SC) boost circuit are used in the converter. Low switching voltage stress and reduced input current ripple are advantages of this converter. Because of their simple structure and great dependability, isolated high step-up DC-DC converters are frequently utilized; further, the voltage gain may be altered flexibly by modifying the transformer's turns ratio. However, a high turns ratio will invariably result in decreased efficiency and power density. When isolation is not required, the traditional boost converter is popular in many step-up applications. The converter has fewer parts and is simple to use. However, once the high boost ratio is achieved, the switch duty cycle will increase, causing a significant reverse recovery current spike in the output diode.

A very high switch duty cycle might also result in decreased efficiency and dependability. In terms of voltage stress and power density, high step-up converters with SC circuits perform better. In most cases, the inductor or input source charges the capacitors in the unit in one stage and discharges them in the next. Although the switched capacitor DC-DC converter has a high efficiency, it has pulsing current and weak regulation. The use of a resonant switched-capacitor converter can reduce pulsing current but does not address the issue of regulation. [4] Proposes a single-stage boost converter topology based on SC circuits. The converter works on the idea of parallel-charging-series discharging, which can aid with voltage rise. It maintains the benefits of a boost converter, reducing semiconductor voltage stress and input current ripple significantly. Nonetheless, in some situations, the voltage gain, which is just two times that of a normal boost converter, is insufficient. [3] Proposes a three-phase high step-up converter. This converter's voltage gain is larger than that of [4], However, the three inductors result in a bigger converter volume, and the three MOSFETs complicate design.

A hybrid boost converter circuit expansion technique proposed in [6]. The expansion concept will allow the converter to be used in a wider range of applications. Moreover, the converter's input current ripple is rather significant, which could damage the life of emerging energy sources like solar cells and fuel cells. An interleaved boost converter with

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voltage multiplier cell is provided in this research. Low switching voltage stress and reduced input current ripple are advantages of this converter. This paper describes how to apply the voltage multiplier technique to a non-isolated DC-DC converter to achieve high voltage gain while reducing the converter's voltage stress by lowering the maximum switch voltage. These features enable for high static gain and efficiency, allowing for the design of a compact circuit for applications that do not require isolation.

II. WORKING PRINCIPLE

Fig. 1 depicts the proposed topology. A two-phase interleaved boost converter, switch-capacitor (SC) boost circuit and voltage multiplier cell are used in the proposed converter. One of the boost channels charges the capacitors in the SC circuit, while another boost channel supplies power to the load in series with the capacitors. The voltage multiplier cell is used on the converter's output side. The converter provides excellent voltage gain, decreased semiconductor voltage stress, and lower input current ripple because to its arrangement.

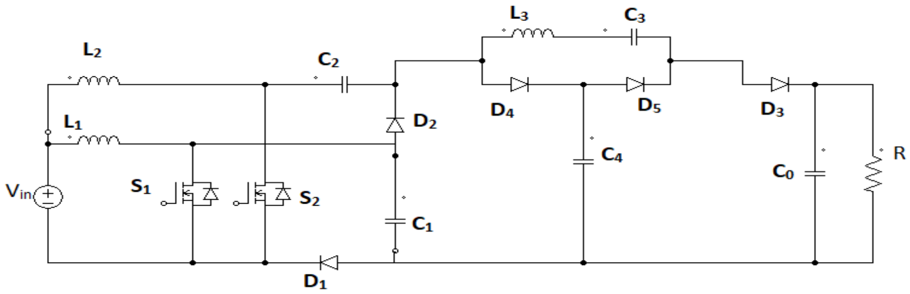

Fig. 1 The proposed circuit diagram

The inductor L_1, the switch S_1, the diodes D_1, D_2 and the capacitors C_1, C_2 constitute a boost converter and the inductor L_2, the switch S_2, the diode D_3, and the output capacitor C_0 constitute another boost converter. The voltage multiplier cell consists of two diodes D_4, D_5, inductor L_3 and capacitors C_3, C_4.

2.1 Modes of Operation

The switching period T_s is divided into four operating modes. The equivalent circuit of different working modes are explained below.

Mode 1: In this mode at time t= t_0, the switches S_1 and S_2 are both turned on. The inductors L_1 and L_2 are linearly charged by the input source Vin. Capacitor C_0 supplies power to the load. Fig.2 shows the equivalent circuit diagram of the converter and current paths for this mode.

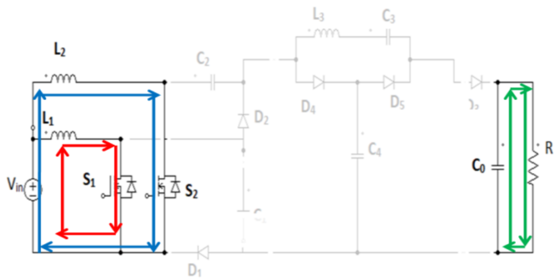

Fig. 2 Mode 1

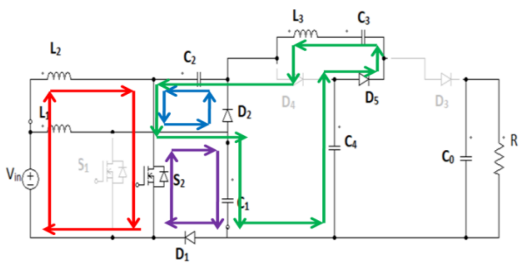

Fig. 3 Mode 2

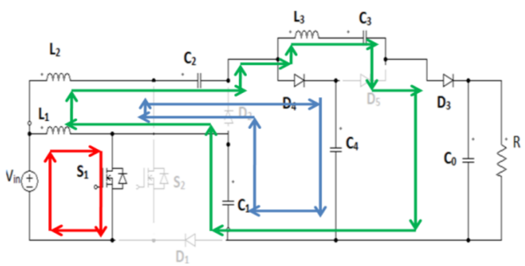

Fig. 4 Mode 4

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Mode 2: At t=t_1, the switch S_1 is turned off and S_2 is turned on. The inductor L_1 releases energy to the capacitors C_1 and C_2, and current through L_1 decreases linearly. At this time, there are two current paths. One is through the D_1, S_2 to charge capacitor C_2 and in other the inductor current charges capacitor C_1 through D_1. Inductor L_2 is charged by the input source Vin and the inductor current continues to rise linearly. Capacitor C_0 supplies power to the load. In this mode capacitor C_3 and C_2 are discharged to charge L_3 and C_3. Fig.3 shows the equivalent circuit diagram of the converter and current paths for this mode.

Mode 3: As shown in Fig. 2, this mode is same as mode 1.

Mode 4: In this mode at time t_0, the switch S_2 is turned off and S_1 continuous to conduct. At the same time inductor L_1 is connected in series with Vin, C_1 and C_2 to supply power to the load through C_1 and D_3, L_3 and C_3. The voltage across L_1 is same as that of the input voltage Vin and current of L_1 continuous to rise linearly.

2.2 Design Consideration of Main Components

The input voltage is taken as 48 V. The pulses are switched at the rate of 100 kHz with a duty ratio of 0.631.

A. Duty Cycle

$$\frac{V_{out}}{V_{in}} = \frac{3}{1-D} \tag{1}$$

B. Inductors

$$L_1 = L_2 = \frac{D*V_{in}*T_s}{\Delta I_L} \tag{2}$$

$$L_3 = \frac{V_{out}-V_{C4}}{\Delta I_{L3}} \tag{3}$$

C. Capacitors

$$C_1 = \frac{(1-D)*I_{L1}}{2*f_s*\Delta V_{C1}} \tag{4}$$

$$C_2 = \frac{(1-D)*I_{L2}}{2*f_s*\Delta V_{C2}} \tag{5}$$

$$C_3 = C_4 \geq \frac{P_{max}}{V_{C3}{}^2*f_s} \tag{6}$$

$$C_0 = \frac{(1-D)*I_0}{f_s*\Delta V_{C0}} \tag{7}$$

ΔV_{C1}, ΔV_{C2} and ΔV_{C0} are the maximum tolerant voltage ripple on the capacitors C_1, C_2 and C_3 respectively. ΔI_{L2} is current ripple on input current. In order to design for operation in CCM and the inductor current ripple is assumed as 10% of input current. The inductor L_1, L_2 is 600µH and L_3 is 1µH. The capacitors C_1, C_2 are designed as 2.2µF and capacitor C_3, C_4 and C_0 are 47µF.

$$\text{Input current } I_{in} = \frac{3I_0}{1-D} \tag{8}$$

III. CONTROL STRATEGY

The duty cycle of switches S1 and S2 are greater than 0.5 and interleaved with 180 degree phase shift is shown in Fig.5

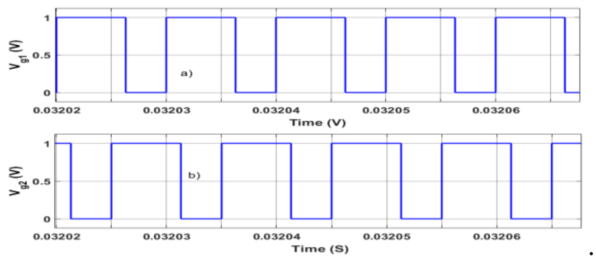

Fig. 5 Switching pulses to S_1 and S_2

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IV. SIMULATION RESULTS

The proposed converter is simulated in MATLAB/SIMULINK by choosing the parameters listed in Table1 and the Simulink model is shown in Fig.6. The simulation results of the hybrid DC-DC converter are shown in the following figures.

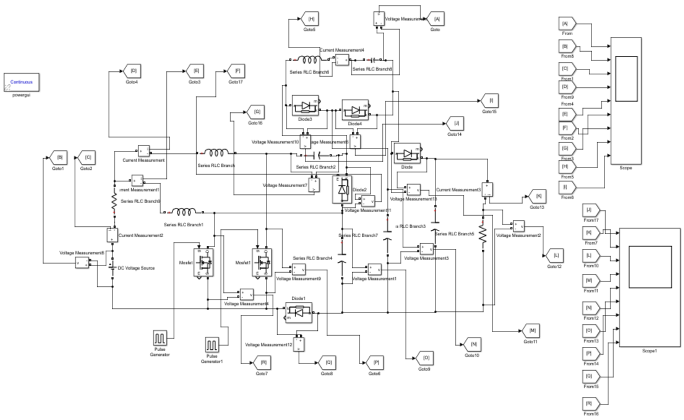

Fig. 6 Simulink model of converter

From Fig.7, it can be seen that the input voltage Vin is 48 V and the input current I_{in} is 7.14 A. The switching frequency is chosen to be 100 kHz and the duty ratios of S_1 and S_2 is equal to 0.631. The output voltage Vout=637 V and ΔVout=0.08, Iout=0.4412 A and ΔIout=0.00005 A.

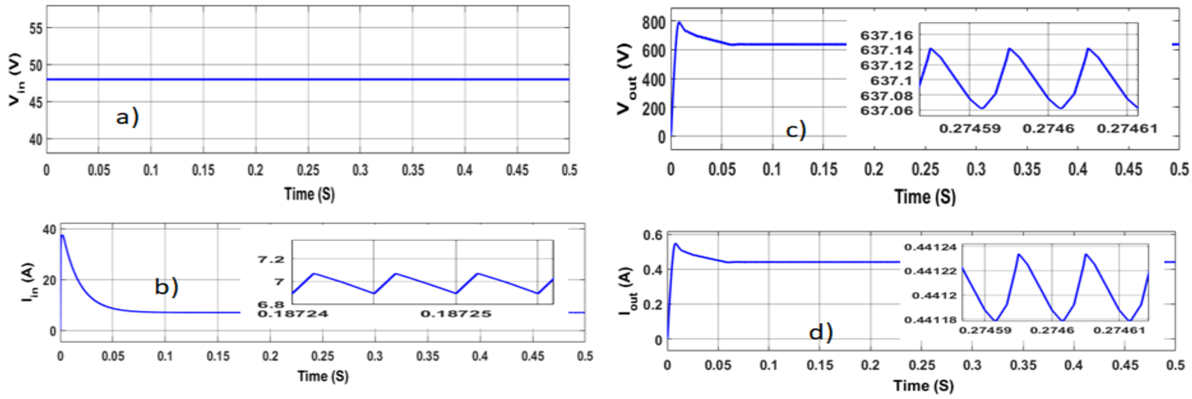

Fig. 7 a) Input voltage b) Input current c) Output voltage d) Output current

Fig.8 shows the current through inductor. Current through inductor with I_{L1}= 5 A and ΔI_{L1}=0.4 A, I_{L2} = 3.8 A and ΔI_{L2}=0.4 A, I_{L3}=2.2A.

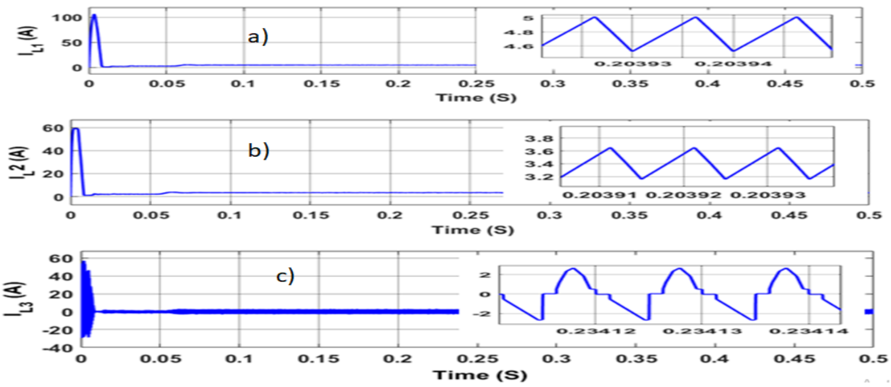

Fig. 8 Inductor current a) I_{L1} b) I_{L2} c) I_{L3}

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Fig.9 shows the voltage across capacitors with magnitude V_{C1}=129.7 V and ΔV_{C1}=1.3 V, V_{C2}=129.7 V and ΔV_{C2}=0.8V, VC3=255 V and ΔV_{C3}=0.1 V, V_{C4}=382 V and ΔV_{C4}=0.1 V.

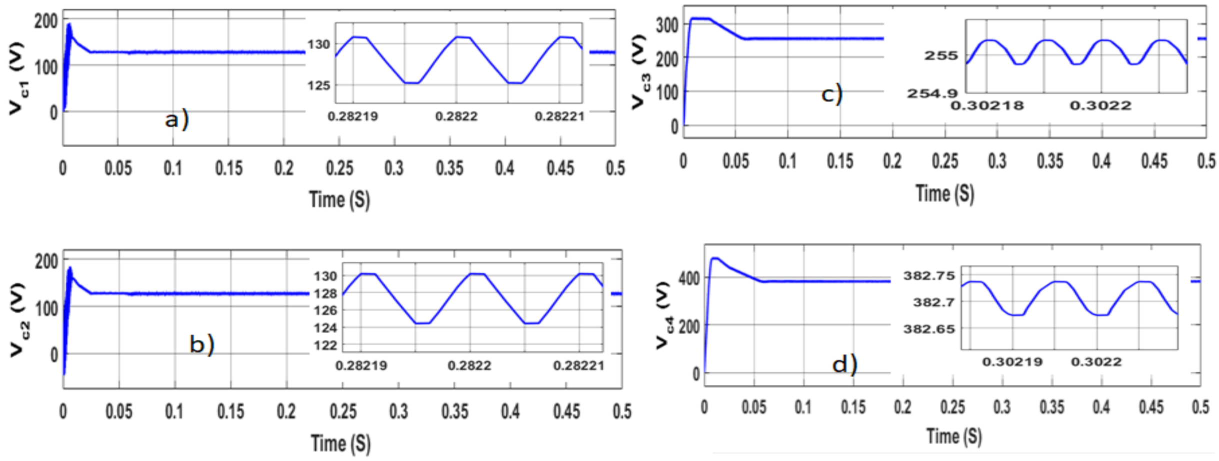

Fig. 9 Voltage across capacitor a) C1 b) C_2 c) C3 d) C_4

TABLE I
SIMULATION PARAMETER

Parameters	Specification
Input voltage (V_{in})	48V
Output voltage (V_0)	650V
Switching frequency (f_s)	100KHz
Inductor L_1, L_2	600µH
Inductor L_3	1µH
Capacitors C_1, C_2	2.2µF
Capacitor C_3, C_4	100µF
Output capacitor C_0	47µF

V. ANALYSIS

Analysis of DC-DC converter with voltage multiplier cell is carried out by considering parameters like voltage gain, efficiency, and duty cycle.

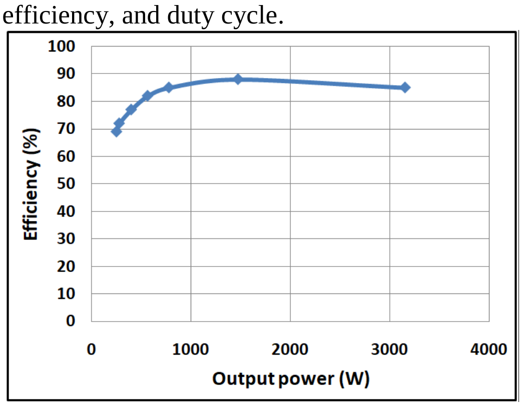

Fig. 10 Efficiency vs Output power

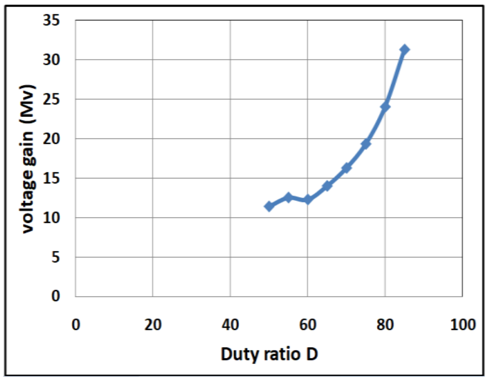

Fig. 11 Voltage gain vs Duty cycle

Fig.10 shows the efficiency curve of the converter. The efficiency increases first and then it decreases after reaching the maximum value. The maximum efficiency of the converter is around 89%. The plot of voltage gain Vs duty cycle is shown in Fig.11. The voltage gain increases with increasing duty cycle. The converter voltage gain is around 13.27. From analysis it is observed that maximum voltage gain of 34 is reached at duty cycle of 0.85.

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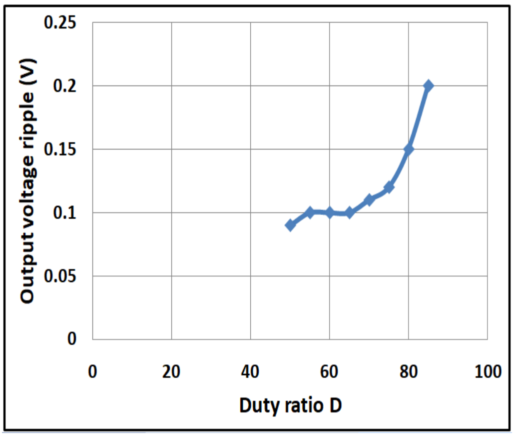

Fig. 12 Output voltage ripple vs Duty cycle

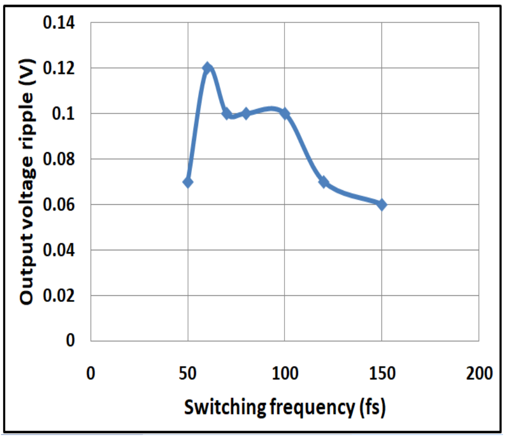

Fig. 13 Output voltage ripple vs switching frequency

Output voltage ripple vs duty cycle is shown in Fig.12. The converter has lower output voltage ripple about 0.1 V at duty cycle of 0.631. The output voltage ripple is increases with increasing duty cycle. The plot of output voltage ripples vs switching frequency shown in Fig.13. Initially voltage ripple is increased with switching frequency and it reaches maximum at 100 kHz. Further increase of switching frequency, output voltage ripple is decreases.

VI.CONCLUSION

The increased voltage gain is provided by the high step-up hybrid DC-DC converter. The interleaved construction contributes to decrease input current ripple, which helps renewable energy modules last longer. To boost the voltage gain, a voltage multiplier cell is utilised. The converter can be expanded on both the output and input sides, increasing the voltage gain and lowering the input current ripple. The circuit has strong expandability because it may be enlarged by adding more parallel boost channels or switched-capacitor boost units. The voltage strains on the switch and diodes are rather minimal. The large step up voltage gain is demonstrated by the input voltage of 48 V and the output voltage of 637 V. The converter has a maximum efficiency of around 89% and a voltage gain of 13.27, according to analysis. This can be utilised in renewable energy applications that require a high dc voltage, such as fuel cells and solar cells.

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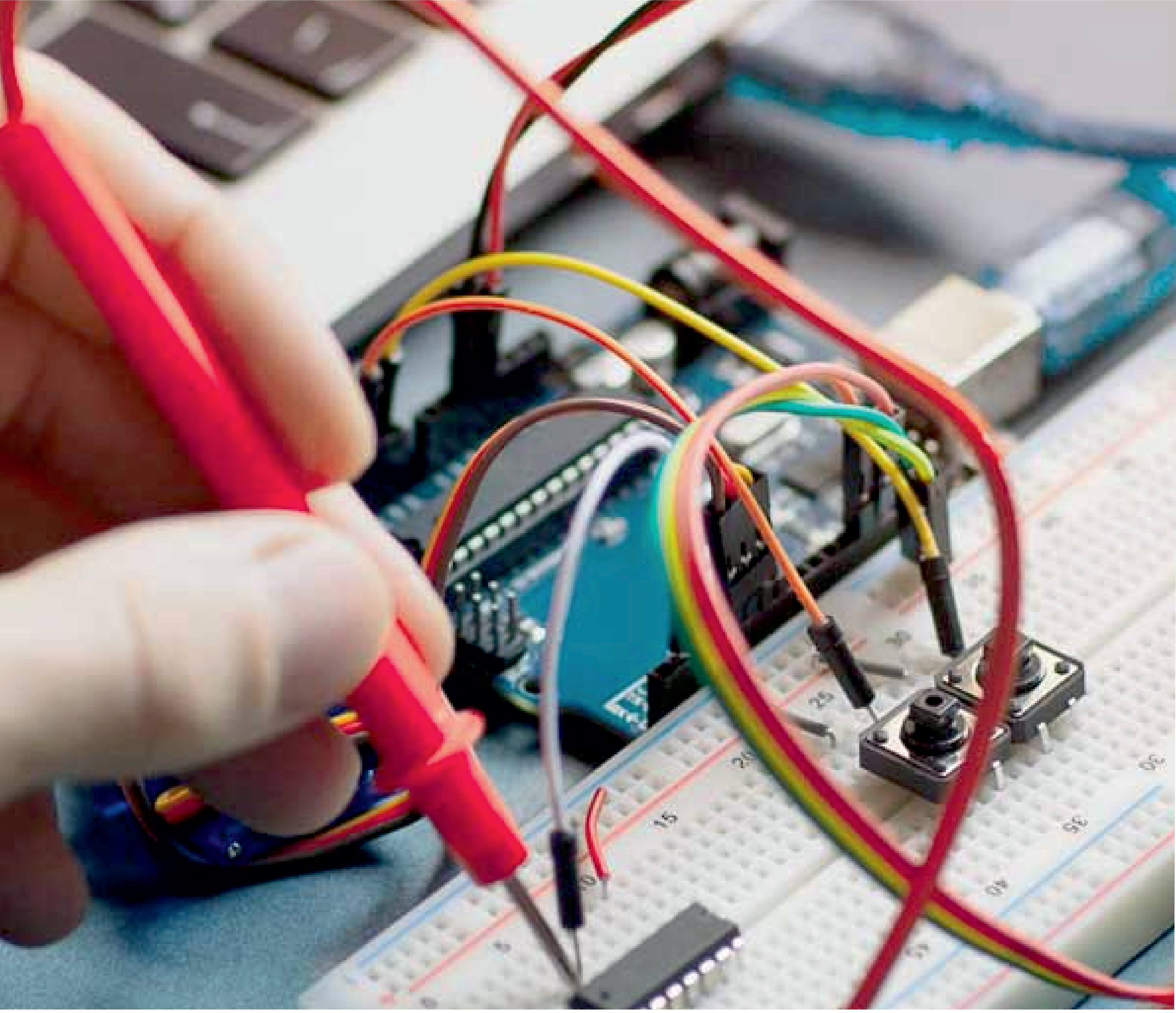

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