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A High Gain DC-DC Converter with Switched Capacitor-Inductor Network

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ABSTRACT: High gain voltage conversion is a feature required for several applications, especially for power processing of low voltage renewable sources in grid connected systems. In grid-connected solar PV, the size and cost become higher due to the presence of a transformer. This transformer deteriorates the entire solar PV system efficiency. To over-come this limitation, a high gain DC-DC converter with switched capacitor-inductor network is presented in this paper. The main advantage of the switched capacitor-inductor network based converter is high voltage gain say greater than 10. In these converter with switched capacitor-inductor network having non-inverting output voltage. So it can operate at wide output voltage range only by changing the duty cycle of the power switch pulse. Due to switched approach of inductor and capacitor, the converter provides lesser ripple content in the output voltage and current. The performance study of the switched capacitor-inductor network based converter is carried out with MATLAB/SIMULINK R2017a. From the analysis, it is observed that maximum efficiency is 93.5% with the output power of 381 W.

KEYWORDS: Voltage Conversion, Renewable sources, Switched Capacitor-Inductor network.

I.INTRODUCTION

Renewable energy based distributed generation of power production got tremendous development as a most essential power producing sector due to its clean and environment friendly nature. And these power production results in low voltage profiles where there is a need for different converter topologies. High step-up converter design needs some key requirements such as high power density, reduced switching voltage stress, low weight, and low cost. In transformer based converters high voltage conversion can be achieved by adjusting the turns ratio which creates large leakage inductor problem. Also, it utilizes high frequency which impacts on high switching voltage stress, increase of range weight, volume and size, as well as the efficiency gets reduced. The non-isolated high step-up converters generate the high voltage gain with reduced switching frequency for boosting up the voltage. Conventional boost converter is used in general, for stepping up the voltage for the non-isolated DC-DC converter family. Normally, it needs high duty cycle to generate the high output voltage. The switching voltage stress is equal to the output voltage in boost converter and introduces large inductor current ripple. Hence it creates the large conduction loss and reverse recovery issues which affects the conversion efficiency and high voltage gain.

To achieve high step-up voltage gain and to improve conversion efficiency, many step-up dc-dc converters are proposed in. The step-up converter is upgraded by using switched capacitor and coupled inductor, voltage doubler, diode-capacitor and voltage lift techniques. Some researchers introduced topologies that combines converters like classical boost converter with Single Ended Primary Inductor Converter (SEPIC), integrate double boost with SEPIC, integrate boost with flyback converter, and interleaved boost converters. A hybrid switched inductor-based power converter is reported with the dc-voltage gain. The above converter is modified with a passive switched inductor network in the bottom side to achieve the more DC-voltage gain. However, it requires additional inductors and diodes, and also these additional components result in reduced efficiency. A cascaded boost type configuration is proposed in to obtain high gain with a reduced number of components. But, these converters achieve high gain only at the duty ratio of 80% and less than that the voltage gain is drastically reduced to four at the duty ratio of 50%. In this paper, a DC-DC converter with high gain obtained by using switched capacitor-inductor network with two operating switches is derived from the conventional quadratic boost converter by including a capacitor and a diode. Design of all components of the converter, efficiency calculation of the converter especially considering the share of all passive and active components on the losses of the converter are reported in this paper.

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II.DC-DC CONVERTER WITH SWITCHED CAPACITOR-INDUCTOR NETWORK

Switched capacitor-inductor based converter with single switch configurations can drastically develop the voltage gain The number of components are comparitivily with other excisting DC-DC converters. The structure consists of two semiconductor switch S and S_1, three diodes D_1,D_2 and D_3 , two inductors L_1 and L_2 and three capacitors C_1,C_2 and C_3.Figure 1 shows a basic structure of the high gain converter with switched capacitor-inductor network..

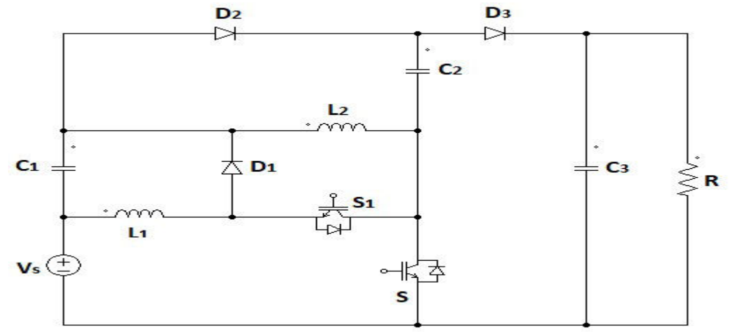

Fig.1 DC-DC converter with switched capacitor-inductor network

III.MODES OF OPERATION

Based on the switching operation of the switch S, two modes of operations are identified in continuous conduction mode.

A. MODE 1 OPERATION

When the semiconductor switch S is turned on during t_0 to t_1, inductor L_1 starts charging from the input source V_S. The capacitor C_1 together with the input source V_S, simultaneously charges C_2 and L_2, which are connected in parallel as shown in Figure 2. The current of L_1 and L_2 increases with a positive slope as shown in Figure 4.

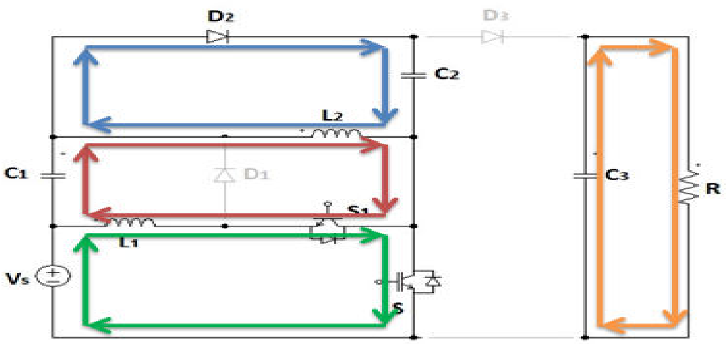

Fig 2.Operating circuit of mode 1

B. MODE 2 OPERATION

During the interval t_1 to T_S, the switch S is turned off. Stored energy in the reactive elements L_1, L_2 and C_2 along with the input source V_S is delivered into the load side in cascaded form. Such cascaded discharge of energy into the load side leads a tremendous increase in the output dc-voltage gain. Here, the inductor L_1 delivers current to the inductor L_2 and simultaneously charges the capacitor C_1. The inductors L_1 and L_2 current drop down with a negative slope, as shown in Figure 4. Figure 3 shows the equivalent circuit diagram of the converter and current paths for this mode is also shown.

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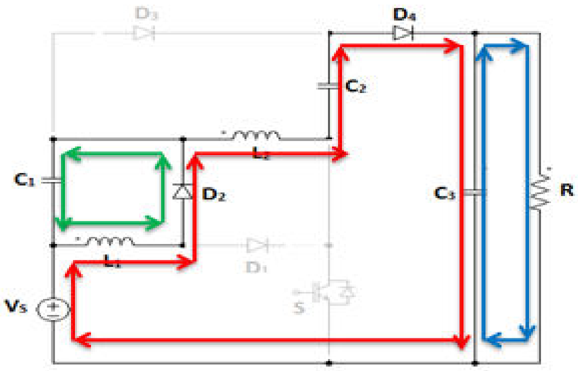

Fig. 3 Operating circuit of mode 2

The below figure shows the theoretical wave form of the circuit which shows gate pulses and charging and discharging conditions of all the elements with the operation of switches.

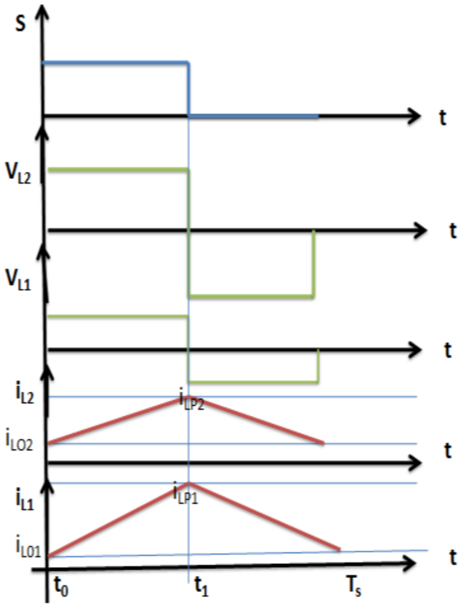

Fig. 4 Theoretical Wave form of high gain converter

IV.DESIGN CONSIDERATIONS

The input voltage is taken as VS is 20 V and output voltage Vo is 325 V and output current Io is 1.538 A. Output power Po is 500W. The pulses are switched at the rate of 50 kHz with a duty ratio of 0.719.

A. DESIGN OF INDUCTORS

During on state of switch *S*, the values of current ripple of the inductors are expressed as,

$$\Delta I_{L_1} = \frac{V_S}{L_1} D_{T_S}$$

$$\Delta I_{L_1} = \frac{V_S}{L_2(1-D)} D_{T_S}$$

Then the value of Inductors L_1 and L_2 are obtained by equation,

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$$L_1 \geq \frac{(1-2D+D^2)DV_S}{F_S * \Delta_{I_{L_1}}(1-D)^2}$$

$$L_2 \geq \frac{DV_S}{F_S * \Delta_{I_{L_2}}(1-D)}$$

The inductors are chosen by assuming the current ripple of less than 10% in CCM operation.

B. DESIGN OF CAPACITORS

The output voltage ripple is lesser than 1% of output voltage V_0, where ESR is neglected. The capacitors C_1, C_2 and C_3 are charged during on state of the switch S, and the stored energies in the capacitors are considered then the values of capacitors C_1, C_2 and C_3 are,

$$C_1 \geq \frac{DV_O}{R * F_S * \Delta_{V_{C_1}}}$$

$$C_2 \geq \frac{DV_O(1-D)}{R * F_S * \Delta_{V_{C_2}}}$$

$$C_3 \geq \frac{DV_O}{R * F_S * \Delta_{V_{C_3}}}$$

Using the above expressions, the value of capacitors is selected by assuming the minimum range of load resistance R.

V. SIMULATION AND RESULT

The simulation of the converter is done using MATLAB/SIMULINK 2017a and thesimulink model is shown below in Fig 5 and analysis are done.

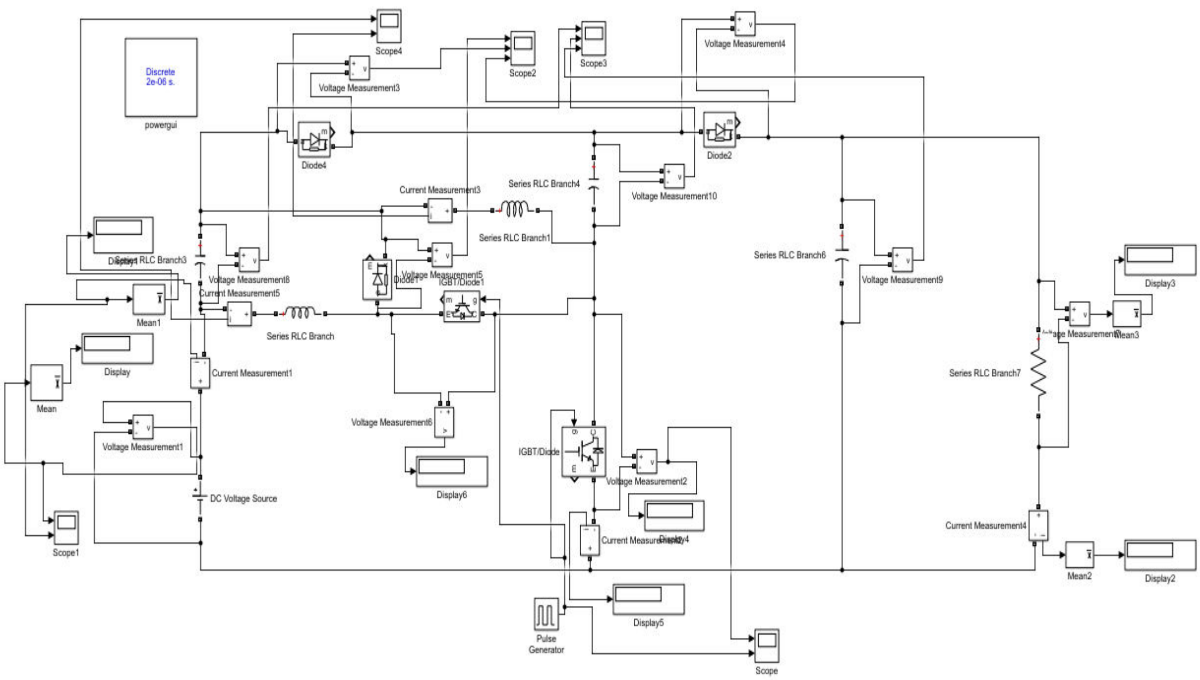

Fig. 5 Simulink model of converter

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Simulation parameters for the Converter is given in Table 1. An input voltage V_{in} of 20 V gives an output voltage $V_o$of 325 V for an outputpower P_o of 500W.

Table.1 Simulation Parameter

Parameters	specification
Input voltage (V_S)	20V
Output voltage (V_O)	325V
Switching frequency (F_S)	50kHz
Rated output power (P_O)	500W
Inductor L_1	5µH
Inductor L_2	15µH
Capacitor C_1	100µF
Capacitor C_2, C_3	330µF
Load resistance ,R	211.25Ω

A. SIMULATION RESULTS

The simulation results of the high gain DC-DC Converter with switched capacitor-inductor network are shown in the following figures.

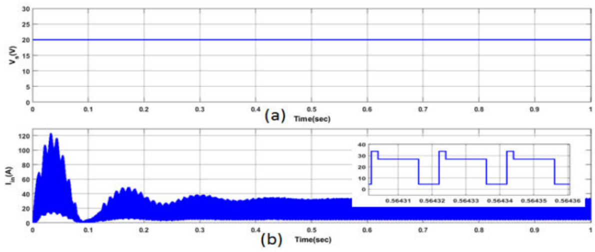

Fig 6. (a) Input Voltage (b)Input current

It can be seen that the input voltage $V_{in}$is 20V. The switching frequency is chosen to be 50kHz and the duty ratios of $S_1$and S_2 is equal to 0.716. Fig 6 shows input current is 24A with a voltage ripple of 10A .

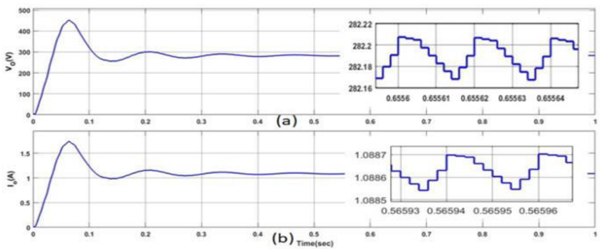

Fig 7. (a) Output Voltage (b)Output current

The output voltage is getting as 282V with a ripple content of 0.2V and the output current is 1.06A and the output current ripple is 0.01A.

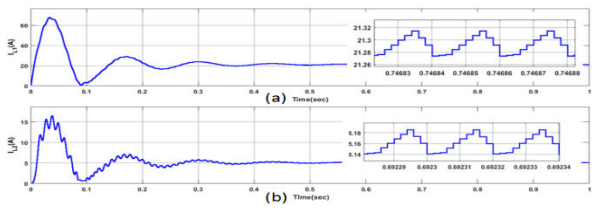

Fig 8. (a) current through L_1 (b) current through L_2

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Figure 8 shows current graph which flows through each of the inductors. Current through the Inductor L_1 is same as that of the input current and the value of this current is 21A with 0.5A ripple. The current through inductor L_2 is 5A with 0.1A ripple content.

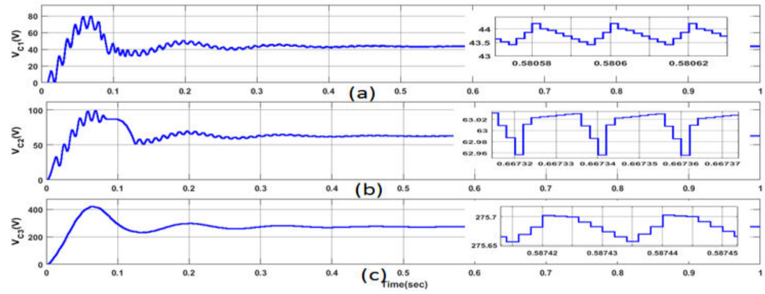

Fig 9. (a) voltage through C_1 (b) voltage through C_2 (c) voltage through C_3

The capacitor voltages V_{C1}, V_{C2}, $V_{C3}$are 44V, 64V, 282V with capacitive voltage ripple of 0.5V, 0.2V, 0.3V respectively are shown below Fig 9.

VI. ANALYSIS

The analysis of high gain DC-DC converter with switched capacitor-inductor network is carried out by considering parameters like efficiency,duty ratio, output voltage ripple and switching frequency .

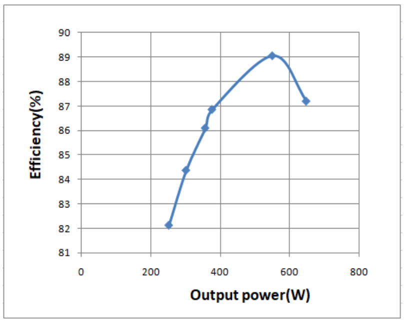

Fig 10.Efficiency Vs Output Power

From the analysis of efficiency Vs output power in Fig 10, it is seen that the efficiency increases with increase of output power. Converter having 89% efficiency in 500KHz.

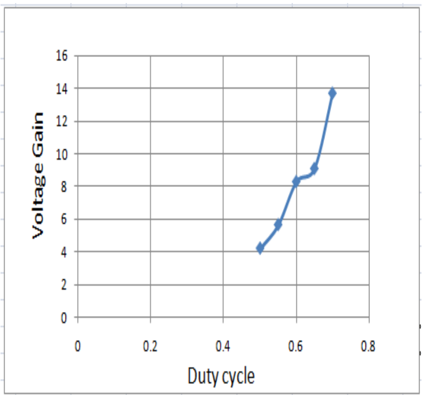

Fig 11. Fig 10.Voltage gain Vs Duty cycle

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. Fig 11 shows the variation of conversion ratio with duty ratio. As the duty cycle increases voltage gain also increases. For this converter the voltage gain is 14 at 0.70 duty cycle.

VII.CONCLUSION

The high gain dc-dc converter with switched capacitor- inductor network offers an improved voltage conversion ratio, low inductor current ripple and output voltage ripple. the input voltage is 20 v and output voltage are 325v . the converter has an efficiency of 89% and voltage gain of 14.The prime target of this paper to obtain a high gain DC-DC converter with least number of components by applying switched capacitor inductor technique.

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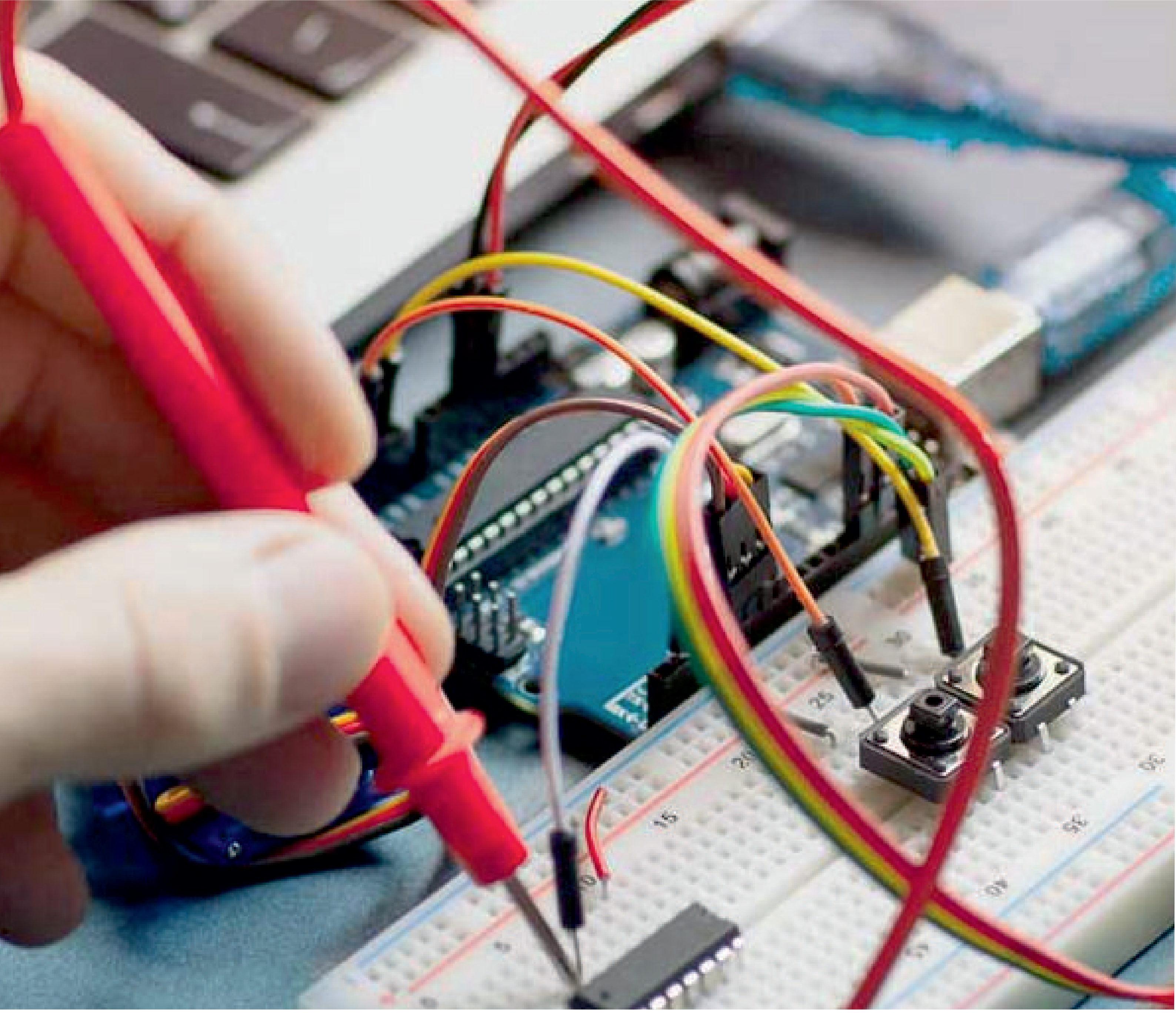

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