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Design and implementation of extendable switched-inductor and capacitor-divider network based high-boost DC-DC converter for solar PV application

Nimi N.P

Assistant Professor, Dept. of EEE, Government Engineering College, Thrissur, Kerala, India

ABSTRACT: A DC-DC high boost converter employing a switched-inductor and capacitor divided network presents a viable solution for both industrial and renewable energy applications. This non-isolated, extendable topology achieves high voltage gain without reliance on extreme duty cycles or coupled magnetic components, unlike traditional boost converters. The single-switch configuration minimizes component count and complexity. Operational principles are clearly defined, and simulation results obtained using MATLAB Simulink demonstrate superior performance compared to conventional boost topologies. Key performance indicators include enhanced voltage gain, reduced switch stress, and continuous input current, solidifying its potential as an efficient and reliable power conversion solution.

KEYWORDS: DC-DC converter, Solar PV, SLCD

I. INTRODUCTION

The escalating environmental concerns of pollution and climate change have spurred a global movement towards renewable energy sources. Among these, photovoltaic (PV) energy has emerged as a promising and rapidly expanding alternative. However, the effective utilization of PV energy necessitates the integration of power electronic devices, most notably DC-DC converters, to successfully full fill electrical power demands. Within PV systems, DC-DC converters are primarily employed to optimize power delivery from PV panels, ensuring the maximum available power is harnessed. This functionality is critical for the efficient and practical application of solar energy as a viable energy solution. Renewable energy sources (RES) like solar photovoltaic cells and fuel cells typically generate low terminal voltages (12-24V). To facilitate efficient utilization, these voltages must be elevated for direct use by local loads or integration into microgrid systems. Traditional boost converter topologies are often inadequate for this purpose, as achieving the required high gain necessitates extreme duty ratios. This leads to compromised performance, diode reverse recovery issues, electromagnetic interference, increased conduction losses, and high voltage stress on the switch. This paper introduces an expandable switched-inductor and capacitor-divider circuit (n-SLCD) employing a single switch. The proposed converter offers continuous, non-pulsating input current, a common-ground structure, high gain, simplified control, and low maintenance coupled with reduced electromagnetic interference. Its minimum phase nature, lacking a right-hand plane zero, enhances transient voltage response and facilitates high bandwidth control. Stability is ensured by the location of all poles on the left-hand plane. Furthermore, the voltage stress on the switch is halved compared to the output voltage, and the converter maintains high gain across a broad range of duty ratios. The single-switch design reduces cost, and the limited stress on the switch allows for the use of lower-rated switching devices, thereby improving efficiency. The paper introduces a novel single-switch SLCD converter designed for high voltage gain applications. This converter distinguishes itself by maintaining a continuous input current while surpassing the voltage gain capabilities of traditional topologies like buck-boost, SEPIC, Cuk, and Zeta converters. The design utilizes a single switch, thereby minimizing voltage stress and enhancing its suitability for renewable energy and fuel cell applications. Experimental results are presented to validate the effectiveness of the proposed converter design, confirming its ability to achieve high gain without relying on extreme duty cycles or coupled inductors/transformers, as detailed in reference.

II. SLCD CONVERTER

The Single Switch LC Divider (SLCD) Converter presents a novel approach to DC-DC conversion, leveraging switched inductor and capacitor networks to achieve high gain. This topology distinguishes itself through several key characteristics: a single switch for simplified control, continuous input current minimizing input ripple, a common ground structure facilitating ease of implementation, and expendability allowing for tailored voltage division ratios. The confluence of these features culminates in a converter that, as demonstrated, offers distinct advantages over alternative topologies. Specifically, the SLCD Converter exhibits characteristics conducive to easier control strategies,

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reduced maintenance demands stemming from its simplified design, diminished electromagnetic interference (EMI) due to the continuous input current, and improved overall efficiency. These attributes collectively position the SLCD Converter as a promising solution for applications demanding high-gain DC-DC conversion with enhanced performance and reliability.

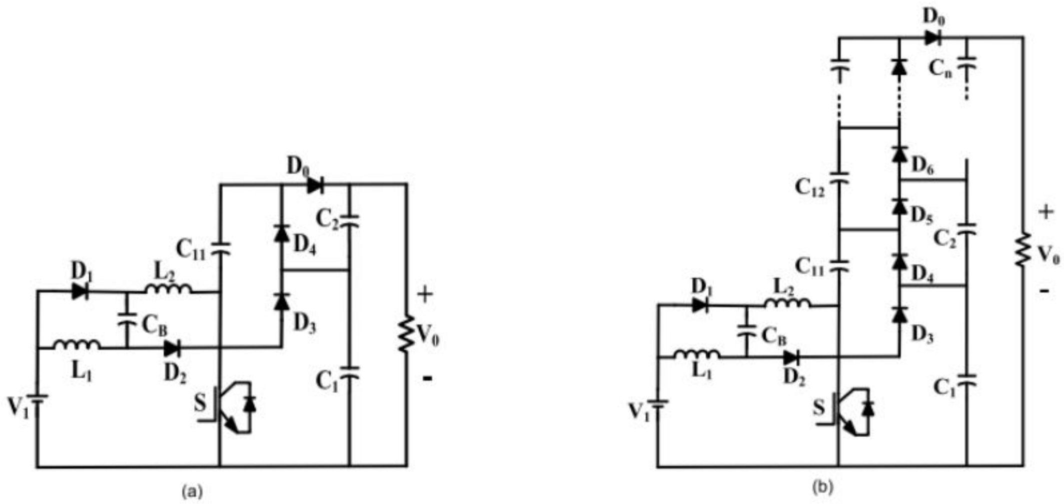

Fig. 1.(a) SLCD Converter, (b) Extended SLCD Converter

The SLCD converter has two inductors (L1 and L2), one boosting capacitor (CB), one charge storing capacitor (C11), two output voltage divider capacitors (C1 and C2), five diodes (D1, D2, D3 and D4 and one output diode D0) and one switch (S) as shown Fig 1.(a) The SCLD converter operates in two modes. When the inductor currents IL1 and IL2 remain always positive, the converter operates in continuous conduction mode (CCM) and when it reaches zero before the end of the switching off interval, the converter operates in discontinuous conduction mode (DCM).This converter operates in two modes during one switching cycle.

2.2 Modes of Operation

The SCLD converter operates in two modes. When the inductor currents IL1 and IL2 remain always positive, the converter operates in continuous conduction mode (CCM) and when it reaches zero before the end of the switching off interval, the converter operates in discontinuous conduction mode (DCM).

2.2.1 CCM Operation Mode 1 : During this mode, S is switched on. The inductor L1, L2 and capacitor CB are charging through diodes D1, D2 and switch S as demonstrated in the circuit diagram Figure 2.2inductor currents IL1 and IL2 are increasing linearly with a positive slope. The diodes D3 and D0 are reverse biased. The output capacitor C1 is charging the intermediate capacitor C11 through diode D4 and the output capacitors C1 and C2 are feeding the load. The response of the inductor, capacitor voltages and currents waveform for this mode are showcased in Figure 2.(a)

$$V_{L_1} = V_{L_2} = V_1$$
$$V_{CB} = V_1$$
$$I_{L_1MIN} = I_{L_2MIN} = I_{LMIN}$$
$$I_{L_1} = I_{L_2} = I_L = \frac{V_1}{L} DT_S + I_{L(Min)}$$

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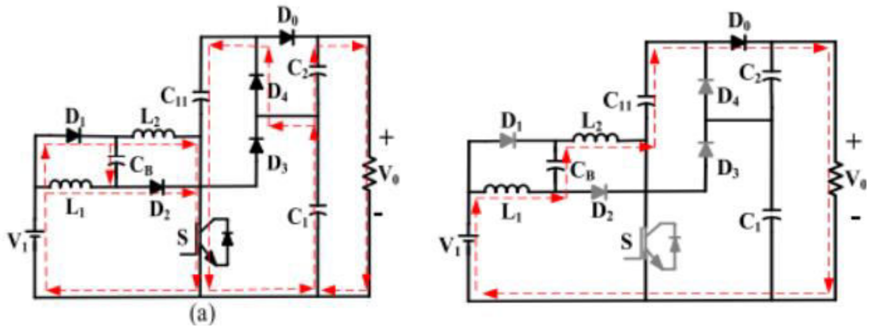
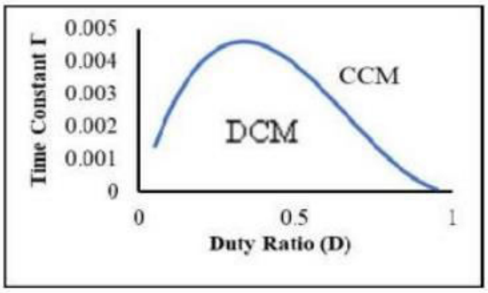


(b)



(c)

Fig. 2: (a) Mode 1, (b)Mode 2, (c) Boundary Region

Mode 2: During this mode, switch S is switched off and the energies garnered in the inductors L1, L2 and capacitors C1 and C2 are released to load in series along with V1. The series discharge of energy of all the passive elements upsurges the gain of the converter. The equivalent circuit operation diagram is demonstrated in Figure 3.3. The inductor currents decline linearly with a negative. The diode D3 limits the voltage stress across the switch to equal to voltage across C1 which is half of output voltage

$$V_1 + V_{L1} + V_{CB} + V_{L2} + V_{C11} = V_0$$
$$V_{L_1} = V_{L_2} = \frac{V_0}{4} - V_1$$
$$I_{L_1\max} = I_{L_2\max} = I_{L\max}$$
$$I_{L_1} = I_{L_2} = I_L = \frac{1}{L}\left(V_1 - \frac{V_0}{2}\right)(1-D)T_S + I_{L\max}$$

DCM operation

Mode 1: This mode is analogous to the first mode of CCM.

Mode 2 : This mode lasts for a time-frame of D'TS and the inductor current declines with a negative slope and reaches zero at the instant (D+D')TS as shown in Fig.2.3. The inductor voltage and current are given below

$$V_{L1} = V_{L2} = \frac{V_0}{4} - V_1$$
$$i_{L1} = i_{L2} = \frac{1}{L}\left(V_1 - \frac{V_0}{2}\right) D'T$$

Mode 3: In the third mode of operation, the output current will flow from the output capacitor to load and diode D0 will be nonconducting. The voltage spanning the inductor becomes zero.

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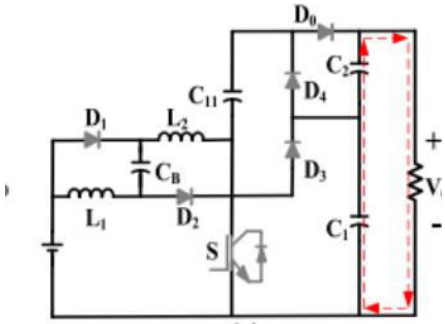

Fig. 3: Mode 3

III. DESIGN OF VARIOUS COMPONENTS SLCD

Input voltage, Vin= 10 V, Output voltage, Vout= 100 V ,Switching frequency, fs = 30 kHZ Duty Ratio= 60%
Inductor Design

$$L1 = L2 \geq \frac{DV1}{\Delta iLfs}$$

$$= \frac{.6x10}{0.55x30000} = 360x10^{-6}H$$

Capacitor Design:

$$CB \geq \frac{2V0D}{(1-D)fsR\Delta VCB} = \frac{2x100x.6}{.4x30000x100x.2} = 4.7 * 10^{-6}F$$

$$C\,11 \geq \frac{V0D}{fsR\Delta VC11} = \frac{(100*.6)}{30000*100*.2} = 100x10^{-6}F,$$

$C1=C2= 10x\ 10^{-6}F$

IV. SIMULATION OF SYSTEM

Simulation done based on the following component values. The following waveform obtained based on this.

Components	Value
L1,L2	$360x\ 10^{-6}H$
CB	$100x\ 10^{-6}F$
C1,C2	$10x\ 10^{-6}F$
R load	100 ohm
Duty ratio	60%
Frequency	30K

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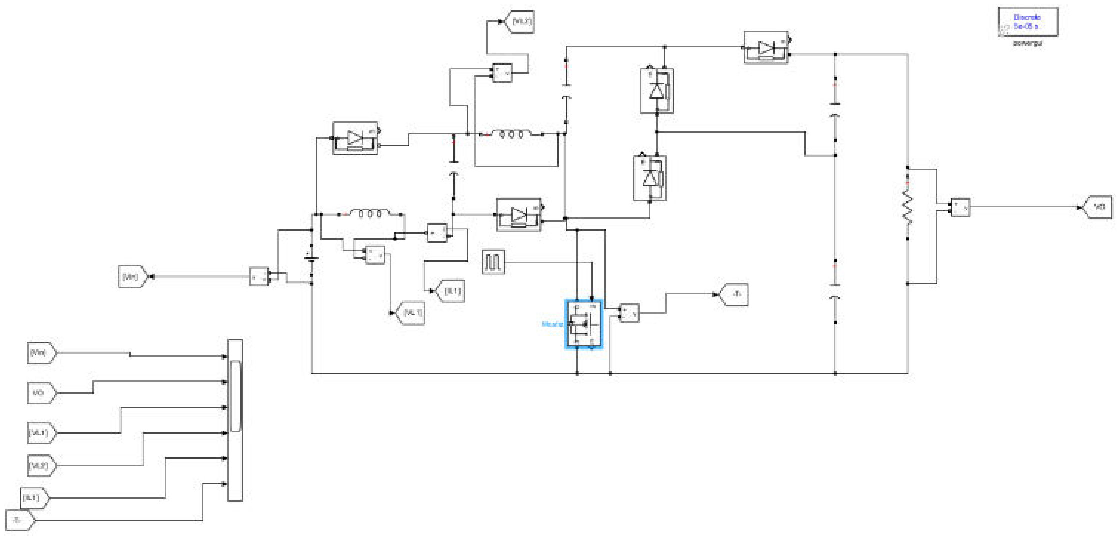
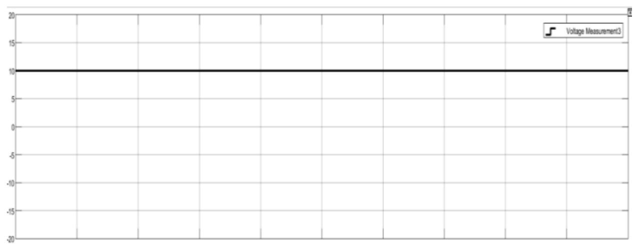


Fig. 4 :simulation diagram



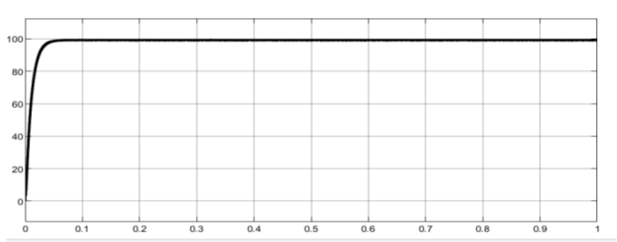


Fig. 5: Input voltage(Vin)

Fig. 6 :Output voltage(V0)

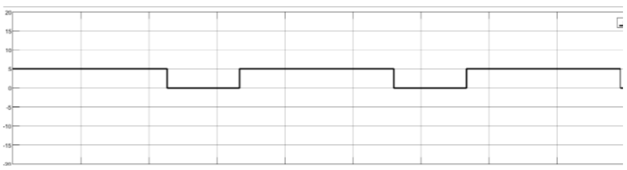


Fig. 7 :Gate pulse

Fig. 8 : Load current

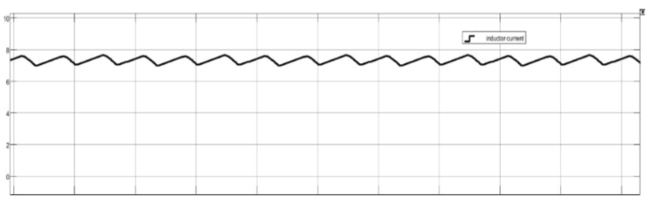


Fig. 9 :Inductor Current

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V. HARDWARE AND RESULTS

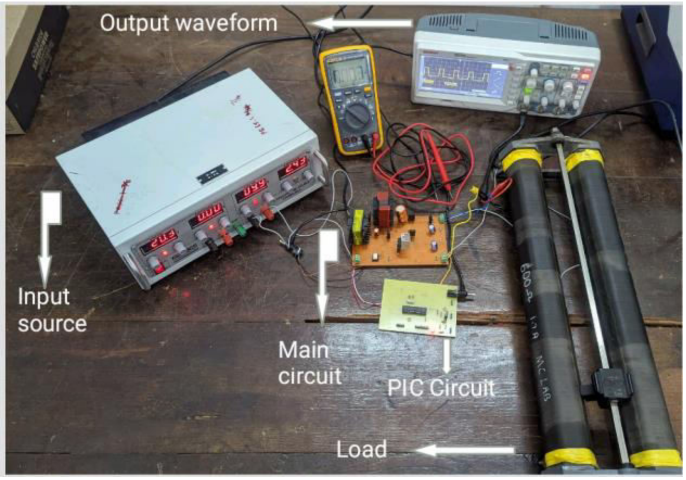

Fig. 10 Hardware

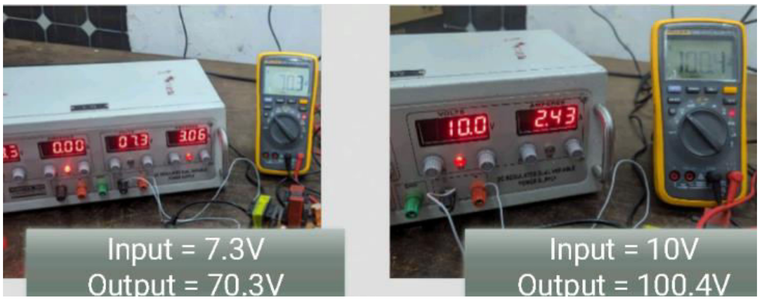

Fig. 11 Hardware output showing 10 times boosting of two different input voltages

VI .CONCLUSION

The Switched Inductor Capacitor Divider (SLCD) network-based high boost DC-DC converter presents a compelling solution for efficient DC-DC conversion. Comprehensive MATLAB simulations demonstrate a 10 times boosting, underscoring the SLCD converter's viability. These simulations, conducted across diverse operating conditions, offer valuable insights into the converter's performance and potential for practical application in high boost scenarios, allowing for observation of key design parameters and waveforms. The theoretical and mathematical analysis has been validated by experimental results. Furthermore, the converter's performance has been verified through regulation at varying duty cycle values during simulation. By demonstrating the feasibility of the proposed design, this work contributes meaningfully to photovoltaic power conversion. This successful simulation study positions the SLCD-based high boost DC-DC converter as a robust and promising technology within power electronics.

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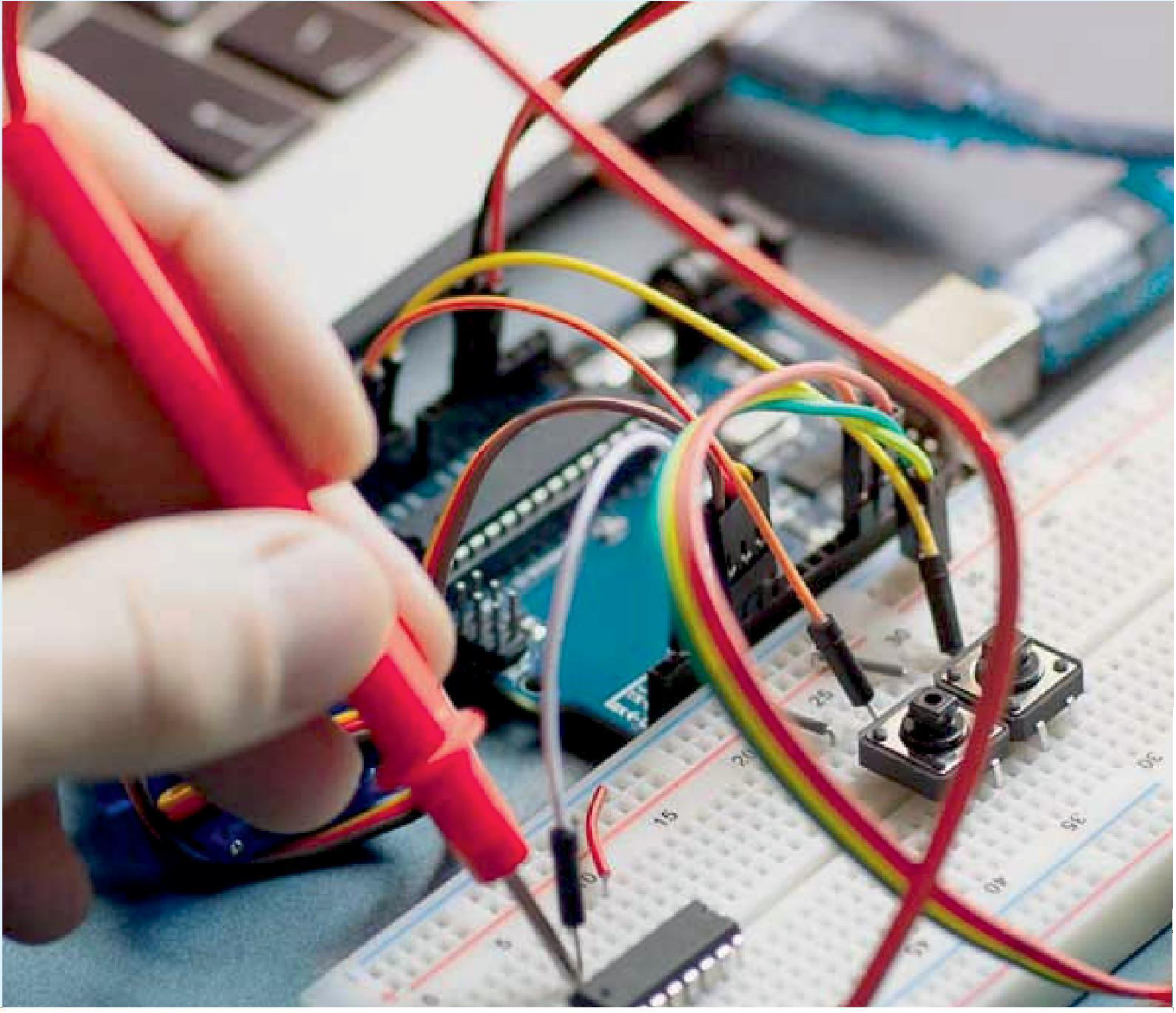

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