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Developing a Super-Lift Boost Converter with Buck Converter

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ABSTRACT:A DC-DC multi-port converter that combines a super-lift boost and a buck converter is introduced. A DC-DC Super-lift converter combined with a buck converter creates two step-up and step-down outputs via one input. The super-lift method uses the step-up output to increase the voltage and step down by a buck converter. In this way, high gain voltages can be generated using simple structures without the need for additional electric circuits, transformer, control and regulation, which has a simple structure and an appropriate control method that provides a wide range of output voltages. Accordingly, the ideal application for the converter is an electric vehicle (EV).Different EVdevices,such as audio systems,lights and electric motorsrequiredifferentvoltagelevels. The performance study and analysis of converter is carried o u t with MATLAB/SIMULINK 2017b.

KEYWORDS:DC-DC multi-port converter, Super-Lift (SL), High voltage gain.

I.INTRODUCTION

In recent years, DC-DC multi-port converters (MPCs) have been an important topic due to the growing industry of electric vehicles (EVs) and higher penetration of renewable energy sources (RESs) such as photovoltaics (PV) incorporated with wide voltage ranges. DC-DC MPCs are divided into two different structures: multi-inputs and multi-outputs. Multi-inputs structures are applied to supply a load utilizing different sources. On the other hand, multi-outputs supply various voltage levels by a single source. These types of converters are used in RESs, mobile transmission, LED drivers and EVs. In this regard, different structures for single-input multi-output (SIMO) converters are presented. The traditional diagram of an EV with multiple outputs including a battery, a bidirectional DC-DC boost converter, DC busses (negative and positive), and two H-bridge converters for main power drives and some other converters for auxiliary equipment power systems. Therein, the DC-DC boost converter is for regulating the voltage of the battery to realize DC bus voltage, and the DC bus exchanges energy from two converters. One of the converters is used to connect the DC bus and the electric motor, and it is used as a converter to consume power to drive the vehicle, while operates as a converter in the deceleration or braking to save the energy. While the other one is for interfacing the electric generator and the DC bus, which works as a converter to start to absorb energy. Due to the complex operation modes and high integrated systems, there are still some unresolved problems of EV, i.e., ten switches with control circuits would cost more and also reduce the robustness, the limited output voltages, which requires a boost converter stage, and the shoot-through problem, which normally caused by mis-ON of these eight switches. Therefore, a novel converter is eagerly required in EV systems for having features of dual outputs, high-voltage outputs, and being immune to the shoot-through problems.

In the current study, a new structureis introduced for the MPCs, which has some features such as generating two different step-up and step-down outputs with a considerable range, low ripples in the output voltage, and not dependent on any electro-magnetic components. Super-lift boost converter with buck converter has same component count as compared to Super-lift buck converter. It allows wider variation of duty ratio with increase in gain. It has a high voltage gain even at low duty ratio and also low voltage stress across switches and diodes. It also has high efficiency as compared to the previous topologies.The study suggested a new approach to generate an MPC by integrating two separate SIMO converters resulting in a reduction of elements number. Also, a DC-DC resonance converter with two isolated outputs to be used in EVs applications.

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II.METHODOLOGY

Super-lift boost converter with buck converter consists of three switches S1, S2, S3, two diodes D1, D2, two inductors L1, L2, one dc blocking capacitor C1, and two output capacitor Co1 and Co2. Vin is the input voltage. Step-up output voltage is denoted as Vo1 and Step-down output voltage is denoted as Vo2.Fig.1.shows a circuit of typical arrangement of Super-lift boost converter with buck converter.

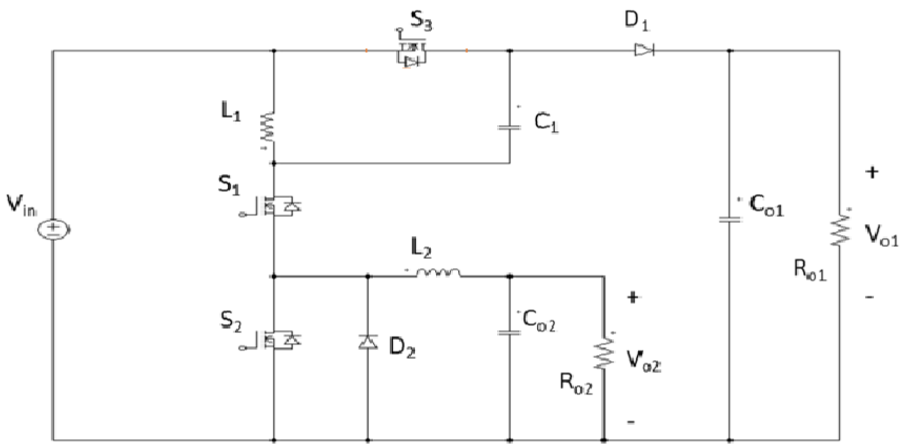

Fig.1.Super-Lift Boost Converter with Buck Converter

The working of the circuit can be explained by 4 modes of operation.

a. Mode1

In this mode, switch S1 and S3 is turned on but switch S2 is turned off. At the same time diodes D1, D2, are turned off. The input voltage charges the capacitor C1. The inductor L1 is discharge to charge inductor L2 and to supply step-down load Ro2. Fig.2 shows the equivalent circuit diagram of the converter and current paths for this mode is also shown.

a. Mode2

In this mode, switches S1, S2, S1 are turned on. The Inductor L1 is charged through Vin, L2 is decreased due to the power transition to step-down load Ro2. Fig. 2 shows the equivalent circuit diagram of the converter and current paths for this mode is also shown.

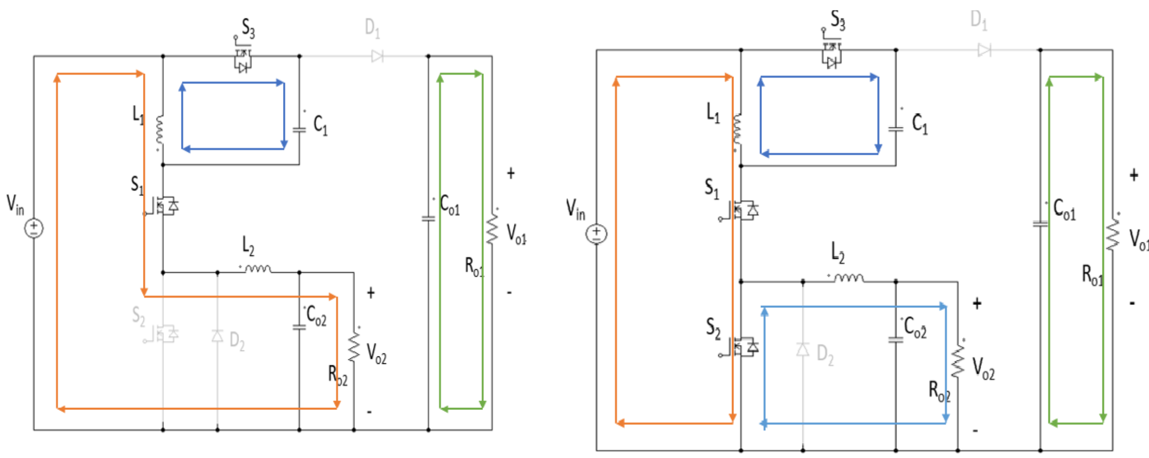

Fig.2.Operating Circuit of Mode 1 and Mode 2 Mode3

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This mode is similar to mode1. In this mode, switch S1 and S3 is turned on but switch S2 is turned off. At the same time diodes D1, D2, are turned off. The input voltage charges the capacitor C1. The inductor L1 is discharge to charge inductor L2 and to supply step-down load Ro1. Fig.3 shows the equivalent circuit diagram of the converter and current paths for this mode is also shown.

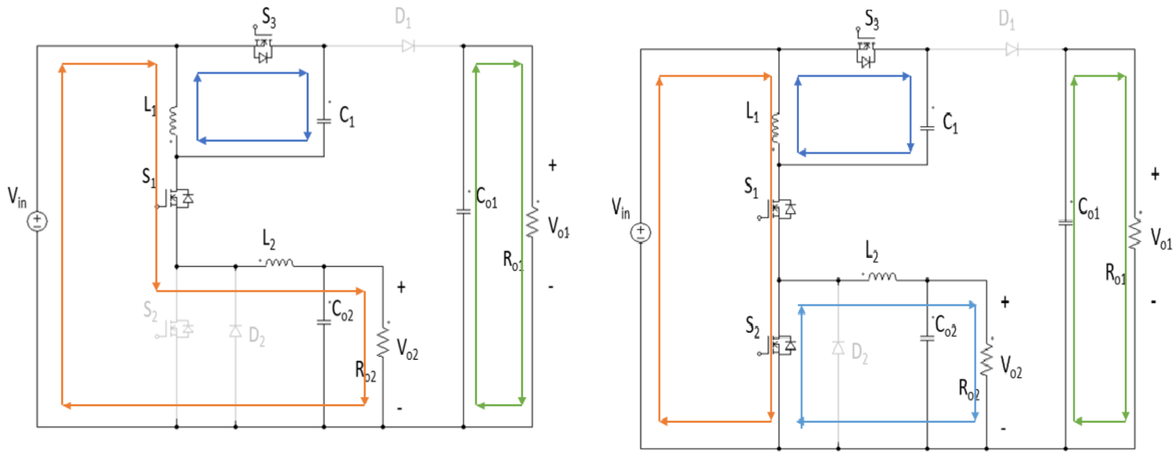

Fig.3.Operating Circuit of Mode 3 and Mode 4

b. Mode4

In this mode, switches S1, S2, S3 are turned off. At the same time diode D1, D2 is turned off. The capacitor C1 releases energy to supply output load. The currents IL1, IL2 decrease to supply both load Ro1 and Ro2 respectively. Figure 3 shows the equivalent circuit diagram of the converter and current paths for this mode is also shown.

III.DESIGN OF COMPONENTS

In order to operate the converter, its components should be designed approximately. It consists of inductors and capacitors. The inputvoltage is taken as 12V. The pulses are switched at the rate of 30kHz. Output power P_{o1} = 40W, P_{o2} = 12W. The output voltagetaken as V_{o1} = 50V, V_{o2} = 5.5V. The voltage gain can be calculated for the step-up output of SLBC converter as follows.

$$(Vin * (D2Ts) = (Vo - 2Vin) * (1 - D2)\ Ts$$
$$Vo1/Vin = 2 - D2/\ 1 - D2 \quad (1)$$

Furthermore, the voltage gain for step-down output is calculated as

$$(Vo2 * (D2Ts) = (Vo - 2Vin) * (1 - D2)\ Ts$$
$$Vo2/Vin = D1 - D2/1 - D2 \quad (2)$$

Design of Inductor L:

The value of inductor operating in CCM should satisfy the following condition bytaking40%ofinductancecurrent,minimumrequiredinductancecanbecalculatedasfollows

$$I_{L1} = I_{o1} * (1 - D_1)$$
$$L1 \geq Vin * D2/\ \Delta i_{L11} * fs \quad (3)$$
$$I_{L2} = I_{o2} * (D_1 - D_2)$$
$$L2 \geq (Vin * (1 - D1) * (D1 - D2))\ /\ (\Delta\ iL2 * fs * (1 - D1)) \quad (4)$$

Onsubstitutingcorrespondingvalue,theinductancevalueapproximatedtoL_1=0.3mHfrom(3).Similarly,L_2=0.2mH from(4).

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Design of Capacitor:

The value of capacitors calculated as,

$C_1 = I_{o2} * ((D1 - D2)) * D1 / (\Delta VC1 * fs)$ (5)

Leaving a certain margin, the selected capacitance value is 220 μF.

$$C_{o1} = \frac{I_{o1} D_2 D_1}{f_s \, \Delta V_{Co1}}$$

(6)

$$C_{o2} = \frac{I_{o2} D_2 (1 - (D_2 + D_1))}{f_s \, \Delta V_{Co2}}$$

(7)

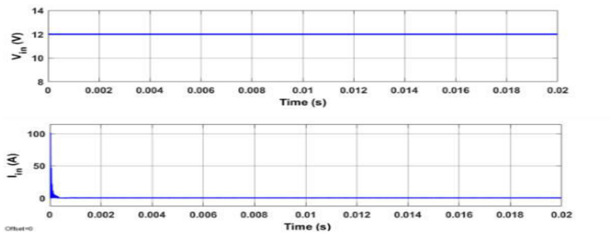
In order to avoid large output voltage ripple at heavy load of the converter, leaving a certain margin, the selected capacitance value is $C_{o1} = 26$ μF and $C_{o1} = 41$ μF

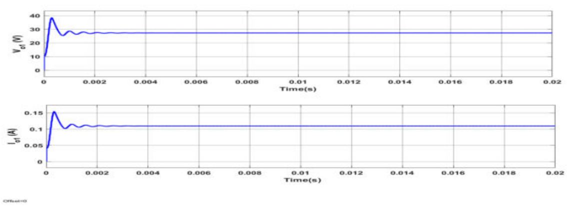
Table1:Simulation Parameter

Parameters	Specifications
Inputvoltage,Vin	12V
Inductors-L_1	0.3mH
Inductors-$L2$	0.2mH
Capacitors-C_1	220μF
Capacitors- C_{01},C_{02}	26μF, 41μF
Switchingfrequency,fs	30kHz
Loadresistance	250Ω, 500Ω

IV.SIMULATION AND RESULTS

The simulation results of super-lift boost converter with buck converter are shown in the following figures. Fig.4 shows that the input voltage Vin is 12V and the input current is 0.42V. Figure 5.10 shows gate pulse and voltage stress across the switch S1. The duty ratio of S1 is 0.6. The voltage stress across switch S1 is 25.9V. Fig.5 shows gate pulse and voltage stress across the switch S2. The duty ratio of S2 is 0.3. The voltage stress across switch S2 is 25.9V. Figure 5 shows gate pulse and voltage stress across the switch S3. The duty ratio of S3 is 0.6. The voltage stress across switch S3 is 25.9V. The switching frequency is chosen to be 30kHz for both switches.





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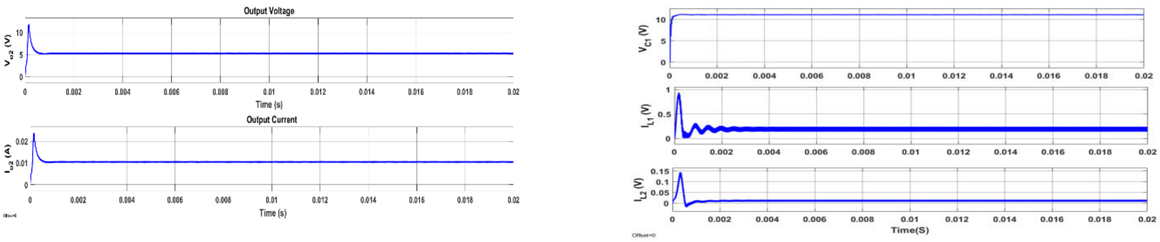


Fig. 4: Input Current i_{in}, Input Voltage V_{in}, Output Current $i_{o1}$and Output Voltage V_{o1},Output Current $i_{o2}$and Output Voltage V_{o2},Current through Inductors and voltage across Capacitor

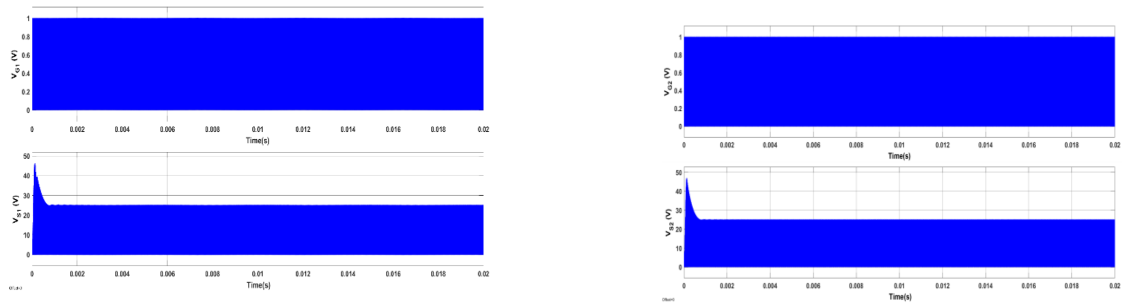
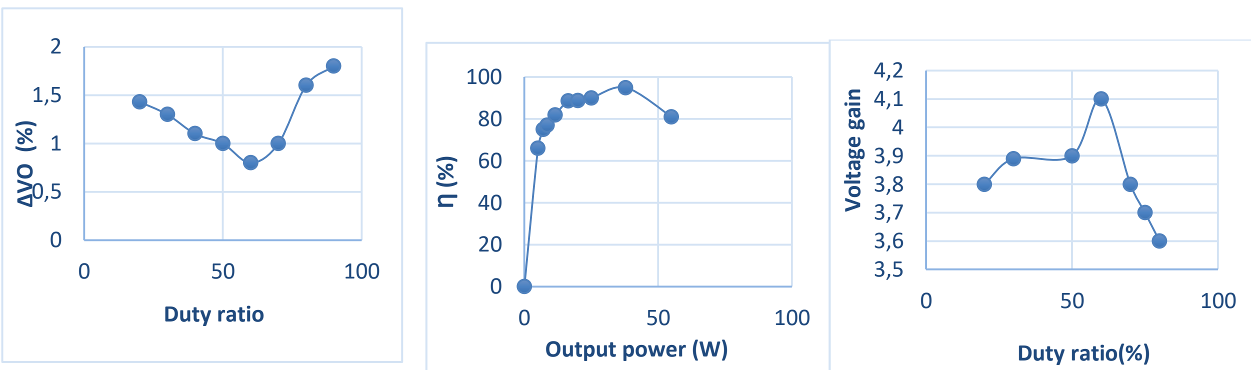


Fig5. Gate pulse and Voltage across switch V_{s1},V_{s2}

The switching frequency is chosen to be 30kHz for both switches. Step-up output voltage Vo1 measured as 49.15V and voltage ripple is 0.4V. The output current Io1 is 0.195A. Step-down output voltage Vo2 measured as 6.43V and voltage ripple is 0.23V. The output current Io2 is 0.0126A Fig.4 shows current through inductor L and voltage across capacitor VC1. The inductor current IL1 is measured as 0.8138A and IL2 is 0.3A. Voltage across capacitor VC1 is 11.93V

V. PERFORMANCE ANALYSIS

Efficiencyofapowerequipmentisdefinedatanyloadastheratioofthepoweroutputtothepowerinput.Theefficiencytells the fraction of the input power delivered to the load. Here efficiency Vs output power with R load is obtained in theFig.6(b). The converter efficiency is around 94% for 3000W output power. The plot of output voltage ripple (in %) Vsduty ratio of BDC is obtained in Fig. 6(a). It is observed that if the duty ratio is greater than or less than 0.5, the outputvoltagerippleismoreascomparedtothatofrippleat0.5dutyratioswitchedinductorbasedBDC.ThegainVsdutyratioplot is shown in Fig.6(c). According to the graph it is clear that as duty ratio increases gain also increases. From Fig.6(a)the duty ratio at 0.5 gives lowest ripple. So, at 0.5 duty ratio, switched inductor based BDC have a gain of 12. The plot of output voltage ripple (in %) Vs frequency of the converter is shown in Fig. 6(d). As the frequency decreases the output voltage ripple also decreases.



(a) (b) (c)

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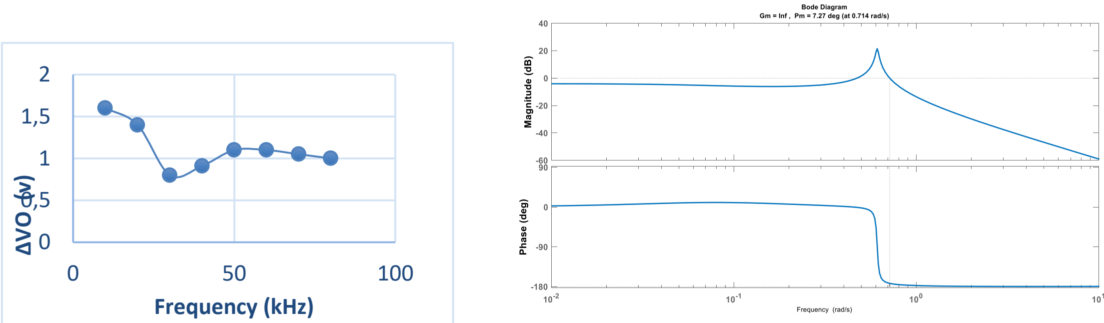

(d) (f)

Fig. 6.(a) Output Voltage Ripple Vs Duty Ratio(b)Efficiency Vs Output Power for R Load(c) GainVsDutyRatio(d) Output Voltage RippleVsFrequency, and(e)BodePlotof TheTransfer Function

From Fig.6(a)itisobservedthatthelowestrippleobtainedis0.004%ofoutputvoltage.So,at 0.004% ripple, the frequency obtained is 100KHz in the BDCs. The bode plot of system is shown in the Fig. 6(f). The system has a continuous-time transfer function. The seventh order transfer function has positive gain margin and phase margin. The gain crossover frequency (W_{gc}) and phase crossover frequency (W_{pc}) are obtained as4.1*10^3rad/sand 1.61*10^4rad/srespectively.So, the system is stable since W_{pc}>W_{gc}.

VI.CONCLUSION

The super-lift buck converter offers a high step-up conversion ratio, low switch voltage stress. The switches and diodes have relatively low voltage stresses and hence the switching and conduction losses are reduced. It achieves an improved overall efficiency and features automatic uniform current sharing. The input voltage is 12V and output voltage is 49.15V for step-up and 6.43V for step-down. The converter has an efficiency of 93% and voltage gain of 4.1. The proposed structure is applicable to a SIMO converter with different output voltage levels. Finally, it should be noted that the aforementioned design and specification of converter allow EVs to benefit from the acquired features of converter.

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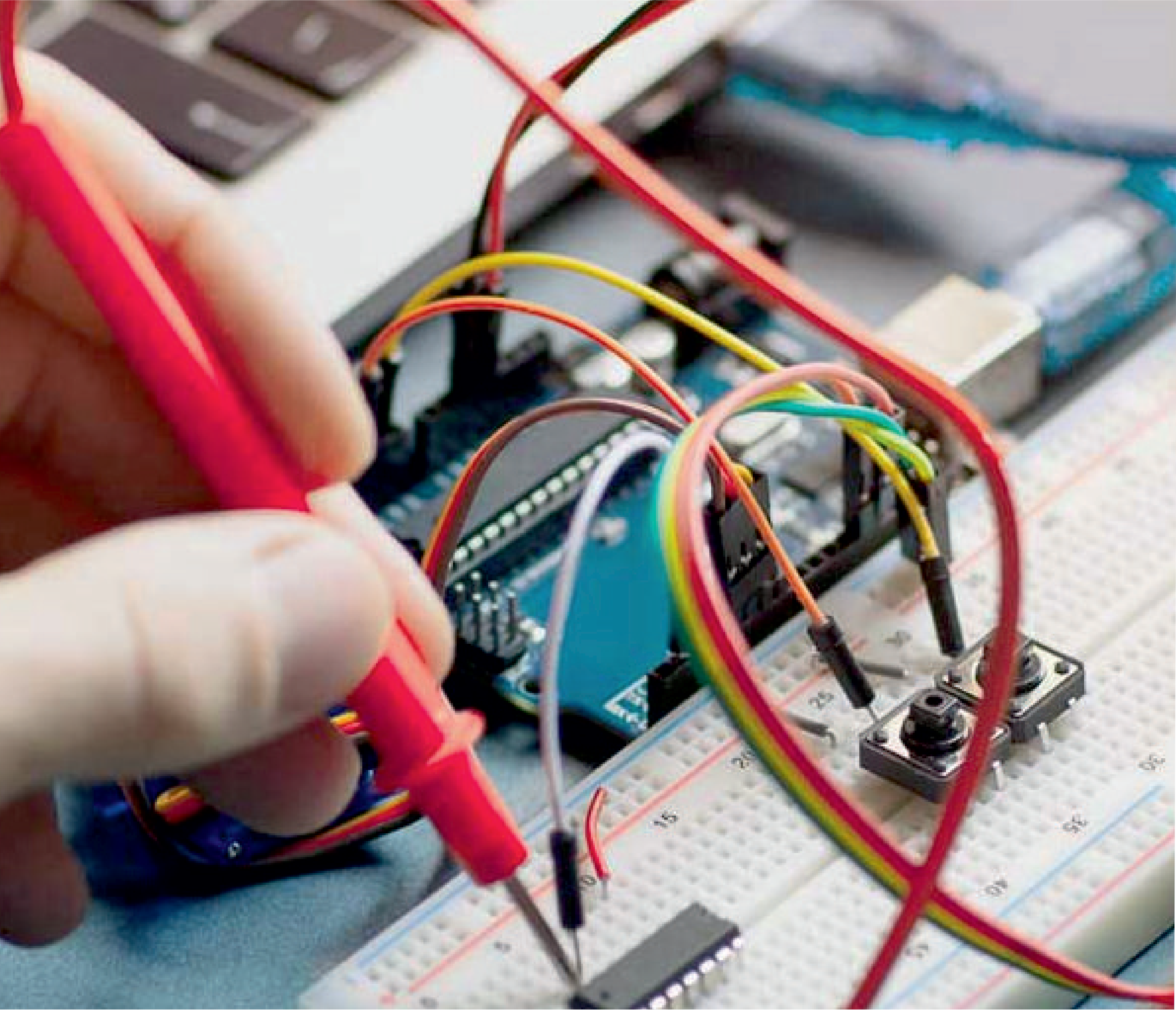

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