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Single-phase Soft-Switching AC-link Buck-Boost Inverter

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ABSTRACT: This paper proposes the implementation of ac-link buck-boost converter using soft-switching were presented in detail. the proposed inverter is an extension of DC-link buck-boost converters, which is an alternative of DC-DC Buck-Boost converter. Unlike DC-link buck-boost converters the ac-link buck-boost inverter is based on the soft switching technique. Soft-switching ac-link buck-boost converters, also known as ac-link universal power converters and partial resonant ac-link converters, The inductor current in these converters is alternating and all the switches have zero-voltage turn-on and soft turn-off of switches, which makes the control process more flexible and reliable in operation. The new proposed converter, named improved ac-link buck– boost inverter, is an extension of ac-link buck-boost inverters that requires lesser number of switches from 20 to 18. Despite reducing the number of switches, the partial resonant time during no power is transferred is as short as conventional Buck-Boost inverter configuration. The advantage of this improved configuration is the use of unidirectional switches, which can be fabricated using IGBT modules, which are more compact and more-cost effective compared to the discrete devices. The link current and voltage in this inverter are alternating, and the frequency can be as high as permitted by the switches, sampling time of micro controller. More over in this inverter galvanic isolation can be implemented by using a single phase high frequency transformer to the link. This paper presents the principle of operation of this proposed configuration and compares the efficiency and failure rates of the proposed configuration with conventional inverter. This paper evaluates the performance of the proposed inverter through simulation.

KEYWORDS: Soft-Switching, Buck–Boost Converter, Unidirectional, Bidirectional, Inverter, Galvanic Isolation, DC Electrolytic Capacitor, IGBT

I.INTRODUCTION

This paper proposes a Ac-link buck-boost inverter using soft-switching with lesser number of switches using a single controller. The converter implementation for medium and high power dc-ac and ac-dc applications were presented in detail[4]. The proposed configuration uses two bidirectional switches per leg in the converter. Power transfer from input to output is accomplished via a link inductor which is first charged from the input phases, Capacitance in parallel with the link inductor produces low turn-off losses. Turn-on is always at zero voltage as each switch swings from reverse to forward bias. Reverse recovery is with low di/dt and also is buffered due to the link capacitance.

The soft switching nature of the converter permits the use of slower switching with high link frequencies Converter operation is bi-directional and supports any input or output power factor or voltage, within the current and voltage capacity of the switches. Simulation results showing converter operation under different conditions were presented. The topology is expected to offer relatively low weight, compact and efficient power converters. Soft switching ac-link power converters is also called partial resonant power converters. Being universal the input and output of the converters may be ac, dc, single-phase or multiphase therefore these converters were configured as ac to ac, ac to dc, dc to ac and dc to dc.

The improved ac-link buck-boost inverter is an extension of conventional ac-link buck boost inverter. The three phase inverter with unidirectional and bidirectional switch configurations with photovoltaic and battery utility applications were represented in fig 1. Therefore,

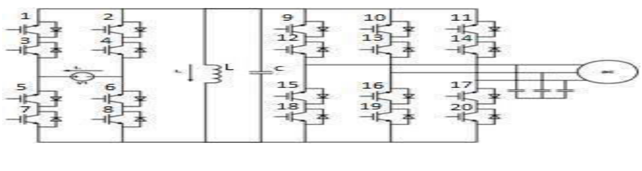

Fig. 1. Conventional AC-link buck–boost inverter

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in this inverter the frequeny of the link current and voltage is only limited but the switching characteristics and sampling time of the microcontroller, therefore the frequency will be very high which results in the compact link and filtering components. therefore by palcing a small capacitor in parallel with the link inductor benfits the inverter from soft-switching.

The altering link current and voltage in the inverter eliminates the need of dc-electrolytic capacitors in the link. Dc electrolytic capacitors are the integral parts of the dc-link ac- ac converters and the two stage bidirectional inverters. The problem associated with the dc-electrolytic capacitor is that it has high failure rates generally at high temperatures. Therefore converters containing electrolytic capacitors are expected to have shorter lifetime, one more merits of ac-link inverter is possibility of having galvanic isolation with a single-phase high frequency transformer added to it.

This method of switch reduction dosen’t lead to any switch count reduction in dc side, therefore dc side is as same as original converter. The switch modules are made of IGBT devices, there is a diode in series with each IGBT to block the reverse voltage further shown in fig 4. In the next part, the principles of the operation in the improved ac-link buck–boost inverter will be studied in detail. Section III compares the proposed inverter with the ac-link buck–boost inverter, to show the advantages and the disadvantages of this configuration. Simulation and results were presented in Section IV, and Section V summarizes the paper with a conclusion. In the coming part II detailed operation of improved AC-link buck-boost inverter is presented.

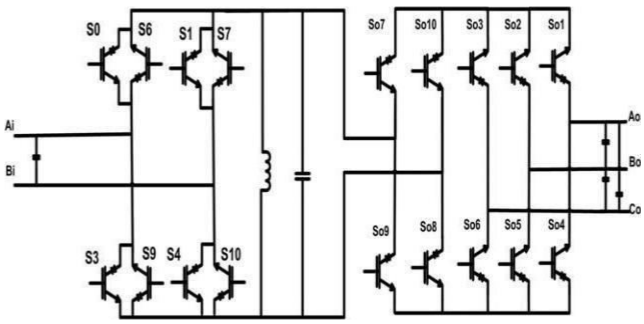
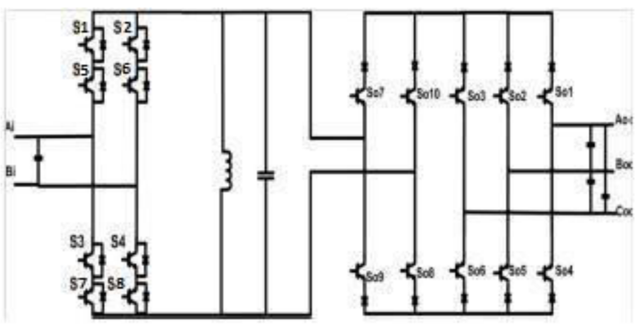


Fig 3. Proposed eighteen switch improved ac-link buck– boost inverter.

Despite of all the advantages of ac-link buck-boost inverters it has more number of switches for operation which makes the control process more complicated, in this Despite of all the advantages of ac-link buck-boost inverters it has more number of switches for operation which makes the control process more complicated, in thispaper a modified configuration of ac-link buck-boost inverter named improved ac-link buck-boost inverter with lesser number of switches is implemented. Despite of reducing the number of switches the principal of operation of the proposed configuration is same as that of the conventional buck-boost inverter. switches they can be implemented using switch modules. These modules are more compact more cost-effective compared to that of discrete devices. Despite using the unidirectional switches the improved ac-link buck-boost inverter allows the bidirectional power flow.

This method of switch reduction dosen’t lead to any switch count reduction in dc side, therefore dc side is as same as original converter. The switch modules are made of IGBT devices, there is a diode in series with each IGBT to block the reverse voltage, since conventional IGBTs can not block the reverse can be simplified further shown in fig 4. In the next part, the principles of the operation in the improved ac-link buck–boost inverter will be studied in detail. Section III compares the proposed inverter with the ac-link buck–boost inverter,



ig.4. Improved AC-link buck-boost inverter with reverse-blocking IGBTs.

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II. PROPOSED CONFIGURATION AND OPERATION

The performance of the proposed configurations is similar to that of the ac-link buck–boost inverter. The link current and voltage are exactly the same as that of the original configuration, and the partial resonance time is as short as in the original converter. As mentioned earlier the method used for reducing the number of switches does not lead to any switch count reduction at the dc side. In order to improve the efficiency, the dc side may be kept similar to the original configuration. Therefore, in this paper, we will mainly focus on the configuration shown in Fig. 3. Before studying the principles of the operation of the proposed configuration, a brief overview of the principles of operation in the ac-link buck–boost inverter shown in Fig. 1, is presented in Detail. Both converters transfer power entirely through the link inductor, which is charged through the input phases and then discharged into the output phases.

The frequency of charge/discharge is called the link frequency and is typically much higher than the output line frequency. Between each charging and discharging there is a resonating mode during which none of the switches conduct, and the LC link resonates to facilitate the soft-switching of the switches. In the ac-link buck–boost inverter, charging and discharging of the link in a reverse direction is feasible through complimentary switches located at each leg, which leads to an alternating current in the link. In the improved ac-link buck-boost inverter, there are three output phases and one charged link to be discharged into these phases. In order to have more control on the currents and minimized harmonics, the link discharging mode is split into two modes. Although there are three phase-pairs in a three-phase system, considering the polarity of the current in each phase, only two of these phase-pairs can provide a path for the current when connected to the link. Again between each charging or discharging mode there is a resonating mode, which facilitates zero voltage turn ON of the switches and their soft turn OFF.

A. Modes of Operation

The basic operating modes of the ac-link buck–boost inverter and the relevant waveforms are represented in Figs. 5 and 6, respectively. Each link cycle is divided into 12 modes, with 6 power transfer modes and 6 partial resonant modes taking place alternately. The link is energized through the input phase pairs during modes 1 and 7 and is de-energized to the output phase pairs during modes 3, 5, 9, and 11. Modes 2, 4, 6, 8, 10, and 12 are resonating modes during which no power is transferred and the link resonates.

MODE1: Before the start of mode 1, the incoming switches, which are supposed to conduct during mode 1, are turned ON (S6 and S10 in Figs. 5(a) and 6); however they do not conduct immediately, because they are reverse-biased. Once the link voltage, which is resonating before mode 1, becomes equal to the voltage across the dc side, proper switches (S6 and S10) are forward biased initiating mode 1. This implies that the turn ON of the switches occurs at zero voltage as the switches transition from reverse to forward bias. Therefore, the link is connected to the dc source via switches which charge it in the positive direction. The link charges until the dc-side current averaged over a cycle time, meets its reference value. Input-side switches are then turned OFF.

MODE2: During mode 2 none of the switches conduct. The link resonates and the link voltage decreases until it reaches zero. At this point, the incoming switches that are supposed to conduct during modes 5 and 7, are turned ON (So2, So3 and So4 in Figs 5(b) and 6); however being reverse-biased they do not conduct immediately. Once the link voltage reaches VACO (assuming $|V$ACO$|$ is lower than $|V$ABO$|$) switches So3, and So4 become forward biased and they start to conduct initiating mode 3.

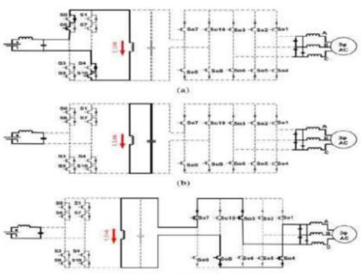

Fig.5.Behavior of the improved ac-link buck–boost inverter during different modes of operation: (a) Mode1. (b) Mode 2, Mode 4, and Mode 6. (c) Mode 3.(d) Mode 5. (e) Mode 11.

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MODE3: During mode 3, the link is discharged into the chosen phase pair until the current of phase C at the output-side averaged over a cycle meets its reference. At this point So3 will be turned OFF initiating another resonating mode was shown in fig.5(c).
For the case shown in Figs. 5(b) and 6, it swings from becomes equal to the voltage across the output phase pair AB, biased, initiating the mode 5.
MODE4: During mode 6, the link voltage swings to $-V$max, and then its absolute value starts to decrease until it reaches to maximum.
Modes 7 through 12 are similar to modes 1 through 6, except that the link charges and discharges in the reverse direction. For this, the complimentary switch on each leg is switched when compared to the ones switched during modes 1 through 6.Although the output switch bridge contains unidirectional switches, So7–So10 (referenced above as intermediate cross-over switching circuit) enable the link to conduct both positive and negative currents. Therefore, during modes 7–12, the same output switches as modes 1–6 will be conducting; however, instead of So7 and So8, switches So9 and So10 conduct during modes 9–12.

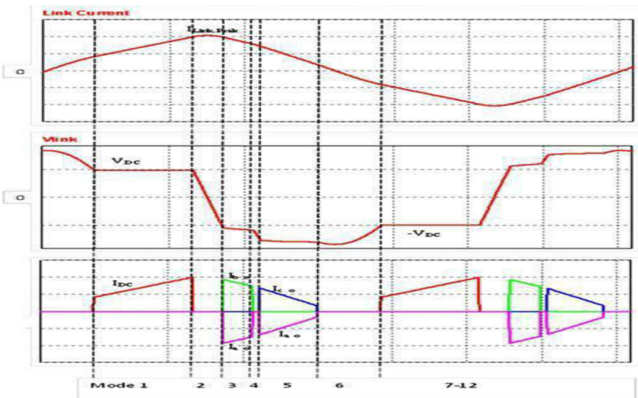

Fig.6 Link current, link voltage, and unfiltered input and output currents in the improved ac-link buck–boost inverter.

III.COMPARISION OF THE AC-LINK BUCK-BOOST INVERTER WITH IMPROVED AC-LINK BUCK-BOOST

A. Efficiency

The efficiency of the improved ac-link buck-boost inverter is compared with the different inverters from the comparison we found that the efficiency of the improved ac-link buck-boost inverter is slightly lower than the conventional model using RB IGBTs. However the efficiency of the proposed system can also be improved by using RB IGBTs in place of unidirectional IGBTs

B. Reliability

Reliability is another important criterion on which power electronics converters can be compared. To predict the reliability of a converter, it is necessary to first calculate each component**'s failure rate (λp).**
The failure rate values are obtained by multiplying the listed base failure rate values (λb) by the π factors that take into account the stresses.(1)

$$\lambda_p = \lambda_b \left(\prod_{i=1}^{n} \pi_i \right).$$

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in is the number of π factors for each component. MIL-HDBK 217 handbook lists the base failure rates for electronic devices.[16]

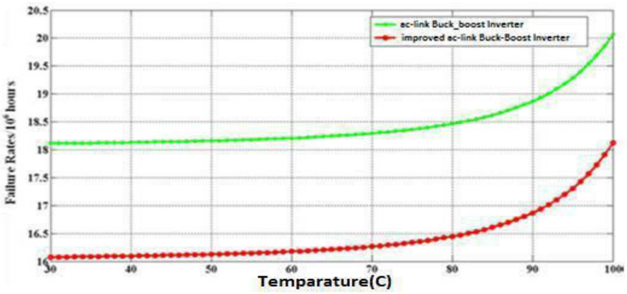

Fig 8. Failure rates of the improved ac-link buck–boost inverter and the conventional ac-link buck– boost inverter

IV. SIMULATION RESULTS

Here the performance of the bidirectional sparse ac-link buck–boost inverter will be evaluated during simulations. These results will be compared with the experimental results of the original configuration. The parameters of the simulated and tested inverters are listed in Table I.

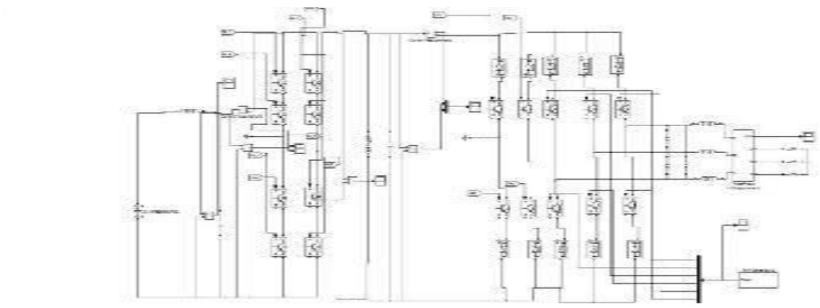

Fig 9. Simulink model

The simulink model for the improved ac-link buck-boost inverter durying dc-ac power flow is shown in Figs. 9, the simulation results corresponding to the dc–ac mode of operation was show in Fig. 10. The dc-side current and the scaled voltage is 5A and 200 V approximately,for the inverter operating at 800 W.

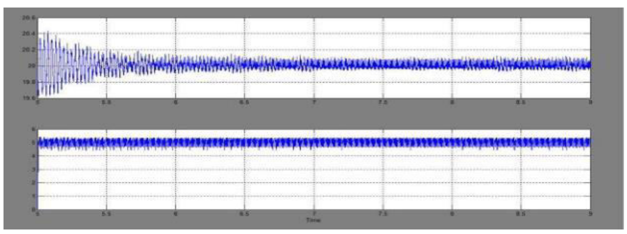

Fig 10. DC-side current and scaled voltage in the improved ac-link buck–boost inverter. (simmulation, dc–ac power flow).

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The simulink result for the link inductor for dc-ac side power flow of improved a-link buck-boost inverter is shown in the figure.1

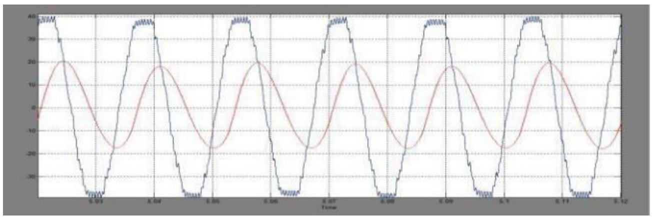

Fig 11. Link current and scaled voltage in the improved ac-link buck–boost inverter (simulation, dc– ac power flow).

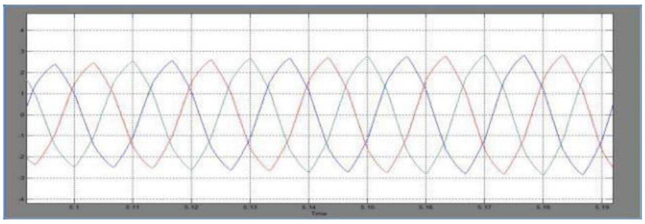

Fig. 12. AC-side currents in the improved ac-link buck– boost inverter (simulation, dc–ac power flow).

As seen in the figures.11 and 12, the peak current and the frequency of the link are 17A and 3.6 kHz, respectively. Fig. 12 shows the ac-side voltage/current for the input voltage is 200 V DC.

V.CONCLUSION

The switch current rating, the efficiency, and the failure rates of the proposed inverter were compared with those of the original configuration. The efficiency of the system is improved and failure rates of the system were decreased. It was shown that the switches in the proposed configuration should withstand

higher average current; however, the peak current they tolerate is the same as the peak current switches in the buck–boost inverter can tolerate. The characteristics of the PM synchronous motor can be improved using the proposed inverter configuration with a fuzzy controller. Though this emerging technology is at beginning stage, it will boost up with photovoltaic application in the future.

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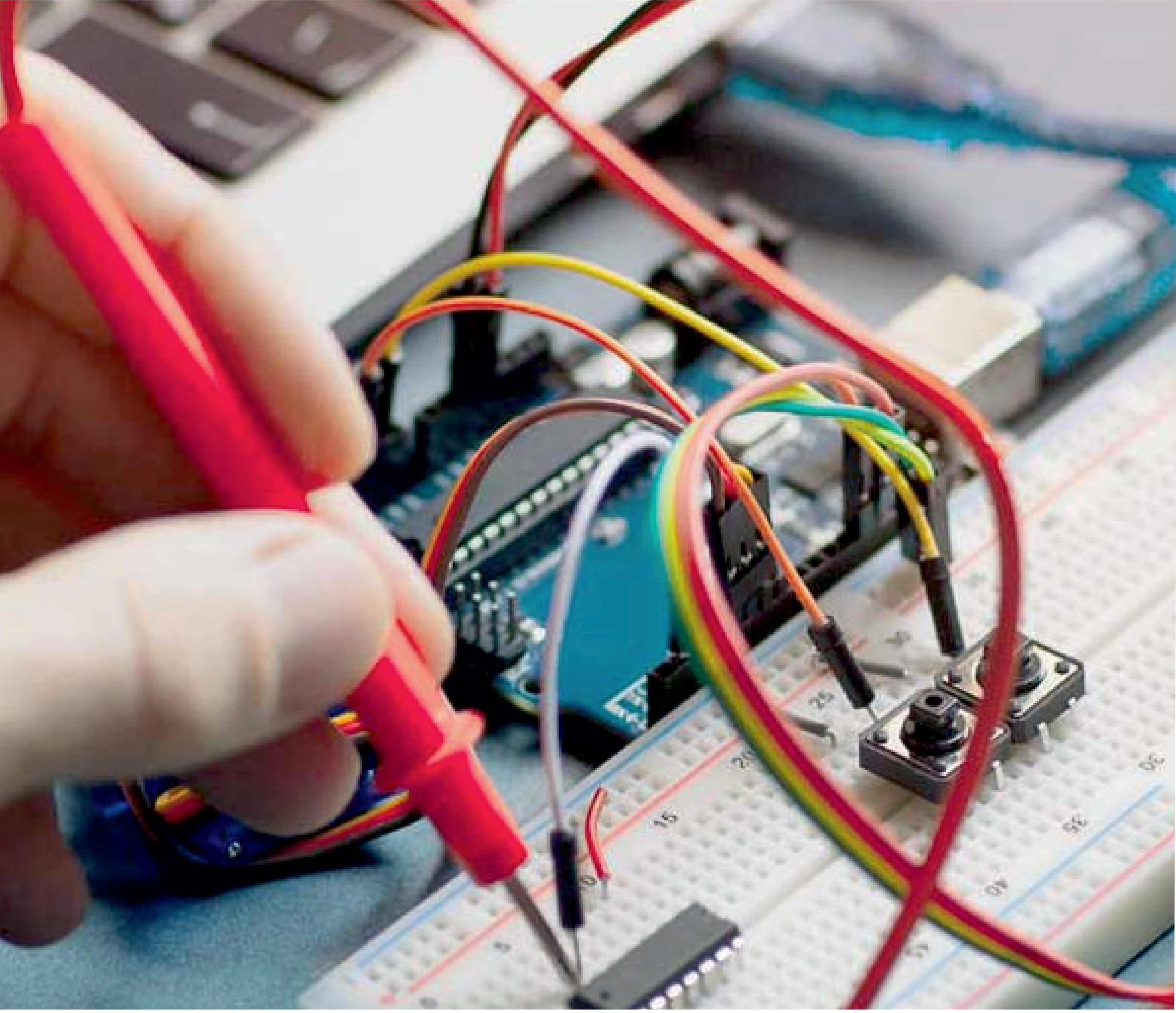

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