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Two Mode Control Scheme for Two Switch Buck-Boost DC-DC Converter

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ABSTRACT: In recent years the use of buck-boost converters are more when compared to other type of converters. When compared with the basic converters like cuk, zeta the two switch buck-boost converter (TSBB) presents less voltage losses on the switches. The two switch buck-boost converter requires fewer passive components can effectively reduce the conduction and switching losses, leading to high efficiency over a wide input voltage range.The TSBB converters has been extensively used in telecommunications, battery operated vehicles etc. with wide input voltage range. So it is thus important to improve the efficiency of TSBB converter over a high input voltage range. So in the telecommunications systems and fuel cells the TSBB converter input voltage fluctuates with output power, due to the input voltage response is not satisfactory. If the input transient voltage response is not satisfactory it creates problems on the output response of the system.so in addition to these TSBB converter we use input voltage feed forward method (IVFF) to improve the input transient response and reduces the effect of input voltage disturbances on the output of the system. These input voltage feed forward compensation is then proposed for two switch buck boost converter which realizes the automatic selections of operating modes and input voltage feed forward functions. The smooth switching between boost and buck modes is guaranteed with converter by representing its characteristics using matlab/simulink.

KEYWORDS: Input voltage feed-forward, small-signal model, two-mode control, two-switch buck-boost converter.

I.INTRODUCTION

The two-switch buck-boost (TSBB) converter, as shown in Fig. 1, is a simplified cascade connection of buck and boost converters [1]. Compared with the basic converters, which have the ability of both voltage step-up and step-down, such as inverting buck-boost, Cuk, Zeta, and SEPIC converters, the TSBB converter presents lower voltage stress of the power devices, fewer passive components, and positive output voltage [2]–[4], and it has been widely used in telecommunication systems [4], battery-powered power supplies [5], [6], fuel-cell power systems [7], [8], power factor correction (PFC) applications [9], [10], and raido frequency (RF) amplifier power supplies [11], all of which have wide input voltage range.

It is thus imperative for the TSBB converter to achieve high efficiency over the entire voltage range. Moreover, considering that the input voltages from battery and fuel cell fluctuate with the output power, and the input voltage in the PFC applications varies with the sinusoidal line voltage, a satisfactory input transient response preventing large output votlage variation in case of input voltage variation is also desired for the TSBB converter. There are two active switches in the TSBB converter, which provides the possibility of obtaining various control methods for this converter. If $Q1$ and $Q2$ are switched ON and OFF simultaneously, the TSBB converter behaves the same as the single switch buck-boost converter. This control method is called one mode control scheme [12], [13]. Q_1 and Q_2 can also be controlled in other manners. For example, when the input voltage is higher than the output voltage, Q_2 is always kept OFF, and Q_1 is controlled to regulate the output voltage, and as a result, the TSBB converter is equivalent to a buck converter, and is said to operate in *buck mode*. On the other hand, when the input voltage is lower than the output voltage, Q_1 is always kept ON, and Q_2 is controlled to regulate the output voltage, and in this case, the TSBB converter is equivalent to a boost converter, and is said to operate in *boost mode*. Such control method is called two-mode control scheme [3], [4]. Compared with one-mode control scheme, two-mode control scheme can reduce the conduction loss and switching loss effectively,

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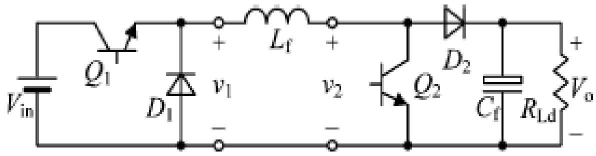

Fig. 1. Two-switch buck-boost (TSBB) converter.

Moreover, in the two-mode control scheme with automatic mode-switching, only one voltage regulator is used for both buck and boost modes, and it is often designed to have enough phase margin in boost mode by reducing the bandwidth of the control loop, thus the transient responses of this converter are deteriorated in the whole input voltage range, including both buck and boost modes. To improve the transient response of the TSBB converter, average current mode control [16], current-programmed mode control [17], [18], and voltage mode control with a two-mode proportional-integral derivative (PID) [19], Type-III (2–zeros and 3–poles) [20] compensator, or passive *RC*-type damping network [21] are employed. With these control schemes mentioned earlier, the influence of the input voltage and load disturbances on the output voltage can be well reduced, but cannot be fully eliminated. For the converter in the applications with wide input voltage variation, input voltage feed-forward (IVFF) compensation is an attractive approach for improving the transient response of the converter, for it can eliminate the effect of the input voltage disturbance on the output voltage in theory. The IVFF of the buck or boost converter can be implemented in several methods:

1) vary either the amplitude of the carrier signal [12], [14] or the value of the modulation signal [15]–[17] according to the input voltage. However, the variations of the carrier signal for the IVFF of the boost converter and the modulation signal for IVFF of the buck converter are both inversely proportional to the input voltage, which imply that the implementation of this IVFF method is complicated relatively for the TSBB converter.

2) Calculate the duty ratio [17]–[20]. Since the duty ratio calculation for the buck converter is inversely proportional to the input voltage, a little complicated realization is also required.

3) Derive the IVFF function producing zero audio susceptibility through the small-signal model . As derived in [31], the IVFF functions of buck and boost converters are both in proportion to the input voltage, and they are easy to be implemented. So, the IVFF method with derived IVFF function from the small-signal model will be adopted in this paper.

II. TWO-MODE CONTROL SCHEME WITH AUTOMATIC MODE-SWITCHING ABILITY

As shown in Fig. 1, the voltage conversion of the TSBB converter operated in continuous current mode (CCM) is [4]

$$V_0=\frac{d_1}{1-d_2}V_{in} \quad (1)$$

where d_1 and d_2 are the duty cycles of switches Q_1 and Q_2 , respectively. In the two-mode control scheme, d_1 and d_2 are controlled independently. When the input voltage is higher than the output voltage, the TSBB converter operates in *buck mode*, where $d_2 = 0$, i.e., *Q*2 is always OFF, and d_1 is controlled to regulate the output voltage; when the input voltage is lower than the output voltage, the TSBB converter operates in *boost mode*, where $d_1 = 1$, i.e., Q_1 is always ON, and d_2 is controlled to regulate the output voltage. Thus, the voltage conversion of the TSBB converter with two-mode control scheme can be written as Fig. 2 shows the TSBB converter under the two-mode control scheme based on two modulation signals and one carrier, and Fig. 3 gives the

$$V_0 = \begin{cases} d_1 V_{in}, & d_2 = 0(\, V_{in} \geq V_0) \\ \frac{V_{in}}{1-d_2}, & d_1 = 0(V_{in} < V_0) \end{cases} \quad (2)$$

key waveforms of this control scheme, where $v_{e\text{-buck}}$ and $v_{e\text{- boost}}$ are the modulation signals of Q_1 and Q_2 , respectively, and v_{saw} is the carrier. The maximum and minimum values of the carrier are *VH* and *VL* , respectively, and

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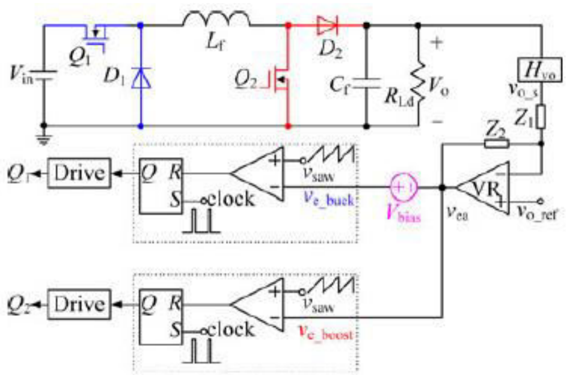

Fig. 2. TSBB converter under the two-mode control scheme

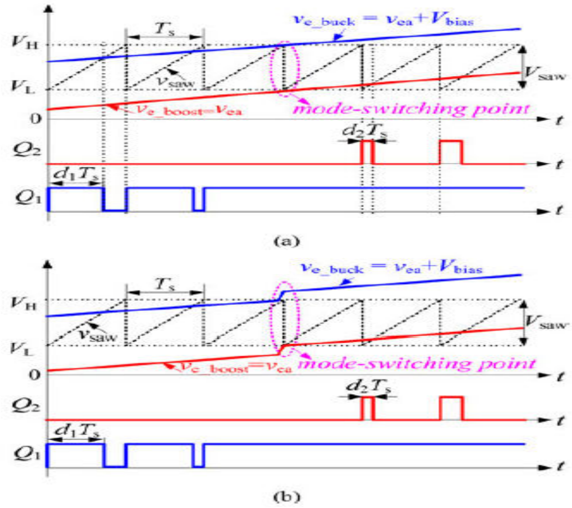

Fig. 3. Two-mode control scheme based on two modulation signals and one carrier.

(a) $V_{bias} = V_{saw}$. (b) $V_{bias} > V_{saw}$.

the peak-to-peak value of the carrier is $V_{saw} = V_H - V_L$. With the same carrier, in order to achieve the two-mode operation as described in (2), only one of $v_{e\text{-buck}}$ and $v_{e\text{-boost}}$ can intersect v_{saw} at any time. So, it is required that

$$v_{e\text{-buck}} - v_{e\text{-boost}} \geq v_{saw} \quad (3)$$

$$\begin{cases} v_{e-\text{buck}} = V_{ea} + V_{bias} \\ v_{e-\text{b00st}} = V_{ea} \end{cases} \quad (4)$$

Substituting (4) into (3) yields

$$V_{bias} \geq V_{saw}. \quad (5)$$

So, the modulation signal in (4) with $V_{bias} \geq V_{saw}$ can achieve the two-mode operation of the TSBB converter. When $V_{in} > V_o$, $v_{e\text{-buck}}$ will be within $[V_L, V_H]$, and it intersects v_{saw} and thus determines $d1$; and meanwhile, ve boost = $vea \leq ve$ buck $- V_{saw} < V_L$, and thus $d_2 = 0$. Such case corresponds to the buck mode of the TSBB converter. When $Vin < Vo$, $v_{e\text{-boost}} = v_{ea}$ will be within $[V_L, V_H]$, and it intersects $vsaw$

III. IVFF FOR TWO-MODE CONTROL SCHEME

A. Derivations of DC and Small-Signal Models of the TSBB Converter

As described in [18] and [20], in the averaged switch model of a dc–dc converter, the switch is modeled by a controlled current source with the value equaling to the average current flowing through the switch, and the diode is modeled by a controlled voltage source with the value equaling to the average voltage across the diode. With this method, the averaged switch model of the TSBB converter can be obtained, as shown in Fig. 4(a), where $iQ_1 = d_1\, iL$ and $iQ_2 = d_2\, i_L$, which are the average currents flowing through switches Q_1 and Q_2 , respectively, and $vD_1 = d1vin$ and $vD_2 = d_2 v_o$, which are the average voltages across diodes D_1 and D_2 , respectively. The average values of voltage, current, and duty

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cycle in the averaged switch model can be decomposed into their dc and ac components, so iQ_1, iQ_2, vD_1 , and vD_2 can be expressed as

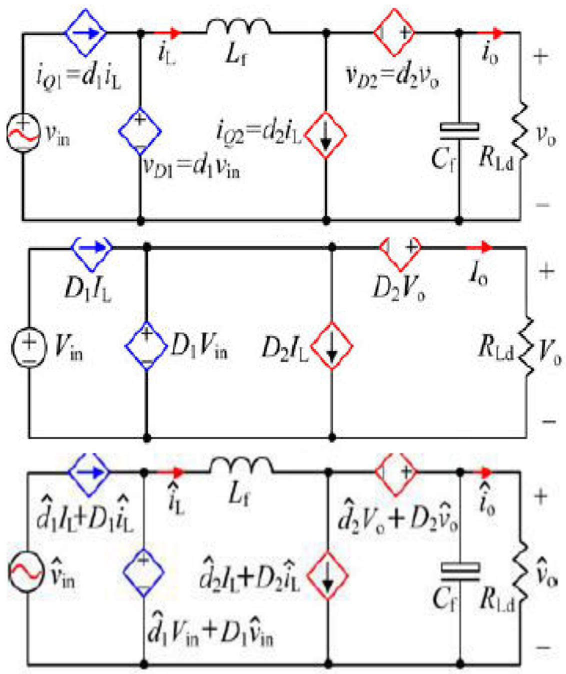
$$iQ_1 = iQ_1 + \hat{\imath}_{Q1} = (D_1+\hat{d}_1)(I_L + \hat{\imath}_L)$$
$$= D_1 I_L + D_1\hat{\imath}_L + \hat{d}_1 I_L + \hat{d}_1\hat{\imath}_L \quad (6)$$

$$iQ_2 = iQ_2 + \hat{\imath}_{Q2} = (D_2+\hat{d}_2)(I_L + \hat{\imath}_L)$$
$$= D_2 I_L + D_2\hat{\imath}_L + \hat{d}_2 I_L + \hat{d}_2\hat{\imath}_L \quad (7)$$

$$vD_1 = vD_1 + \hat{v}_{D1} = (D_1+\hat{d}_1)(V_{in} + \hat{v}_{in})$$
$$= D_1 V_{in} + D_1\hat{v}_{in} + \hat{d}_1 V_{in} + \hat{d}_1\hat{v}_{in} \quad (8)$$

$$vD_1 = vD_2 + \hat{v}_{D2} = (D_2+\hat{d}_2)(V_0 + \hat{v}_0)$$
$$= D_2 V_0 + D_2\hat{v}_0 + \hat{d}_2 V_0 + \hat{d}_1\hat{v}_0 \quad (9)$$

Where the upper-case letter denotes the dc value, and the lowercase letter with hat (^) denotes the small-signal perturbation.



(c)

Fig. 4. Models of the TSBB converter. (a) Averaged switch model. (b) DC model. (c) Small-signal model.

With small-signal assumption, the average values in (6)–(9) can be linearized by neglecting the second-order ac terms [1]. Then, the dc model of the TSBB converter can be gotten by replacing the average values in Fig. 4(a) with the dc components in (6)–(9), as depicted in Fig. 4(b). Besides, the inductor L_f is short circuit, and the capacitor C_f is open circuit in the dc model. Likely, by replacing the average values in Fig. 4(a) with the first-order ac components in (6)–(9), the small-signal model of the TSBB converter can be obtained, as illustrated in Fig. 4(c). According to (2), setting $d_2 = 0$, i.e., $D_2 = 0$, $\hat{d}_2 = 0$, and $d_1 = 1$, i.e.,$D_1 = 1$, $\hat{d}_1 = 0$ in Fig. 4(c), respectively, the small-signal models in buck and boost modes can be derived.

IV. SIMULATION RESULTS

Simulink is a software package for modeling, simulating, and analyzing dynamical systems. It supports linear and nonlinear systems, modeled in continuous time, sampled time, or a hybrid of the two. Systems can be also multi-rate, i.e., have different parts that are sampled or updated at different rates. For modeling, Simulink provides a graphical

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user interface (GUI) for building models as block diagrams, using click-and-drag mouse operations. With this interface, you can draw the models just as you would with pencil and paper (or as most textbooks depict them).

This is a far cry from previous simulation packages that require you to formulate differential equations and difference equations in a language or program. Simulink includes a comprehensive block library of sinks, sources, linear and nonlinear components, and connectors. You can also customize and create your own blocks.

Models are hierarchical, so you can build models using both top-down and bottom-up approaches. You can view the system at a high-level, then double-click on blocks to go down through the levels to see increasing levels of model detail. This approach provides insight into how a model is organized and how its parts interact.

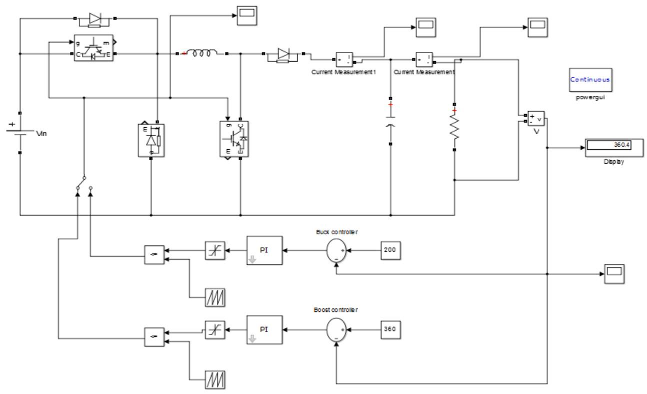

Fig.6. Boost/buck converter

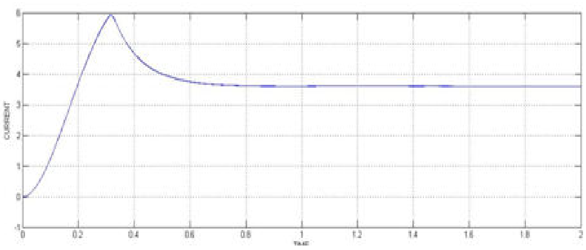

Fig.7. Boost current for converting mode

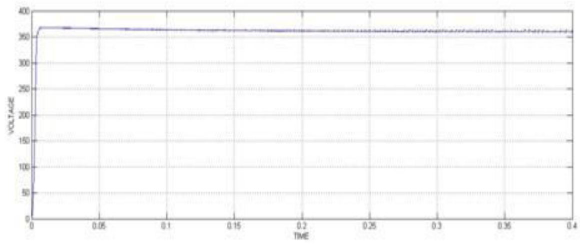

Fig.8. Boost voltage for converting mode

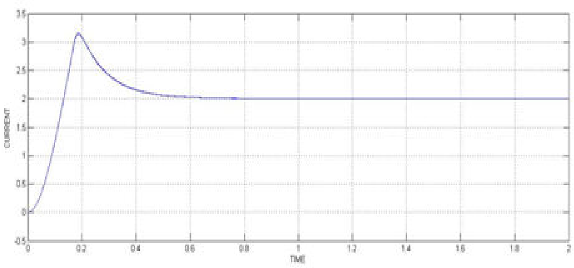

Fig.9. Buck current t for converting mode

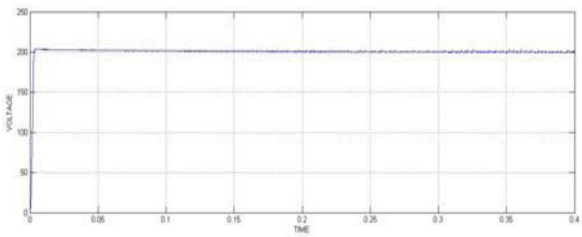

Fig.10. Buck voltage for converting mode

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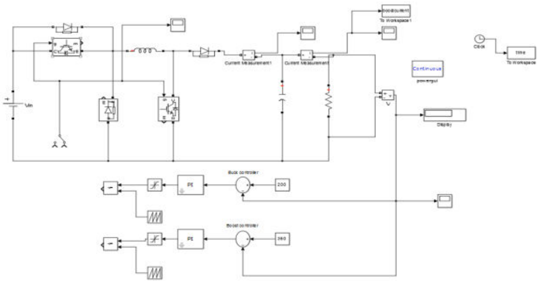


Fig.11. Boost/buck converter with out controller

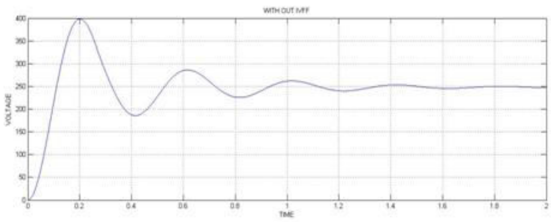


Fig.12. Voltage for converting mode

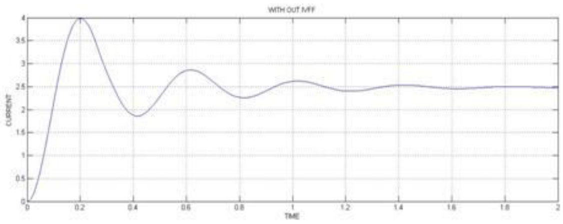
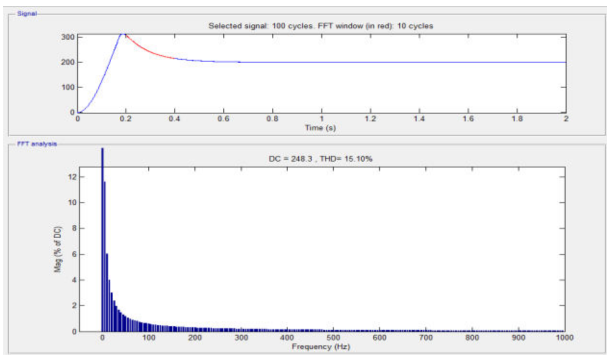


Fig.13. Current for converting mode



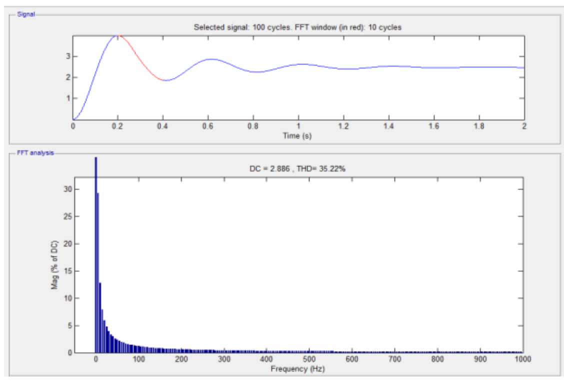


Fig.14. Fft analysis for buck boost converter with ivff.

Fig.15. Fft analysis for buck boost converter without ivff

V. CONCLUSION

The small signal model for buck boost modes are built , based on detailed derivation of IVFF function under different operating modes .IVFF compensation is proposed to achieve automatic selection of operating modes for TSBB converter. The smooth switching operation can be achieved in this proposed model without switching losses Finally 250-500V input , 360 V output and 6 kw rated power prototype model is designed and verified using MATLAB simulation. High efficiency over the whole input output range and improved input voltage transient response are achieved for TSBB converter.

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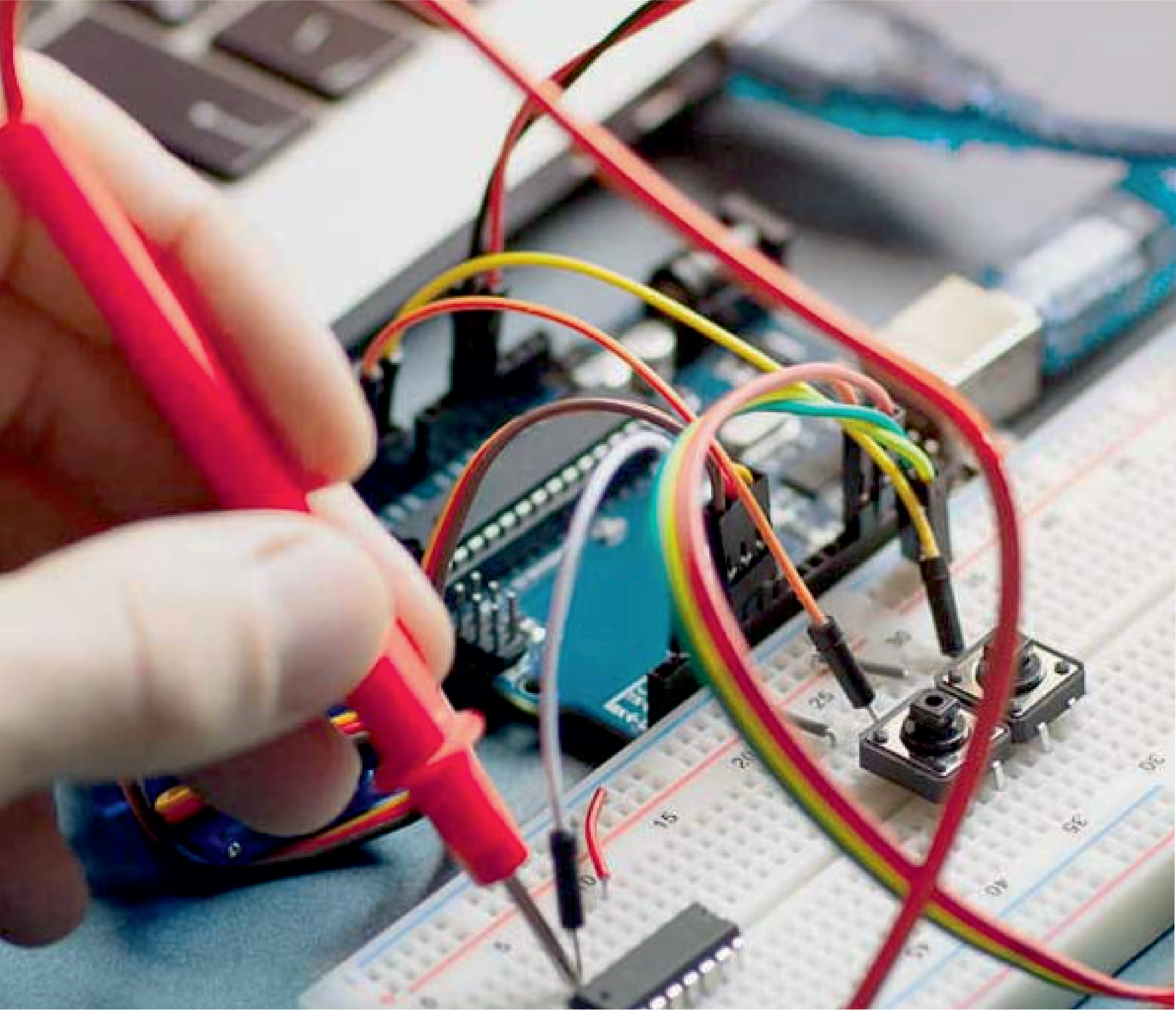

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