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Performance Analysis of Parameters Variation in PV Array

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ABSTRACT: The paper states an introduction, description and implementation of a PV cell under the variation of parameters. Analysis and observation of a different parameters variation of a PV cell are discussed here. To obtain the model for the purpose of analyzing an equivalent circuit with the consisting parameters a photo current source, a series resistor, a shunt resistor and a diode is used. The fundamental equation of PV cell is used to study the model and to analyze and best fit observation data. The model can be used in measuring and understanding the behaviour of photovoltaic cells for certain changes in PV cell parameters. A numerical method is used to analyze the parameters sensitivity of the model to achieve the expected result and to understand the deviation of changes in different parameters situation at various conditions respectively. The ideal parameters are used to study the models behaviour. It is also compared the behaviour of current-voltage and power-voltage by comparing with produced maximum power point though it is a challenge to optimize the output with real time simulation. The whole working process is also discussed and an experimental work is also done to get the closure and insight about the produced model and to decide upon the validity of the discussed model.

KEYWORDS: PV cell; module; array; Temperature, Irradiance, Efficiency, MATLAB, Simulation.

I. INTRODUCTION

One of the ways to categorize energy resources is based on a consideration of their sustainability and renewability. Fossil fuels, such as coal, oil, and natural gas, are examples of conventional energy resources that are not sustainable and non-renewable. On the other hand, biomass and biofuels, geothermal energy, hydropower, wave and tidal power, solar and wind power are types of sustainable and renewable energy sources. Then, there is also nuclear power, which is technically not renewable because it uses nuclear fuel, such as uranium, as a consumable during generation, and it is also hardly sustainable concerning the radioactive waste it creates. However, it is considered as one of the low-carbon power generation sources, similar to hydropower, solar, and wind power, hence it is sometimes still classified as a clean alternative energy source in spite of its arguable sustainability. Among all the renewable energy solutions solar energy is the fastest growing industry. Still, solar panels are not very efficient and researchers all around the world are trying to improve their efficiency and different types of solar panels are producing in the solar panel industries. The single diode solar cell model is an efficient model to analyse the different parameters variation of a PV cell and its five external and internal parameters are analyzed using the ideal values given by the industry [1]. The considered external parameters are solar irradiance and cell temperature (T). The internal parameters are series resistance R_s , shunt resistance R_{sh} and diode reverse saturation current I_s .

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II. PV CELL

In a PV cell there is an equivalent circuit what is consists of a diode, a series resistor, a current source and a shunt resistance.

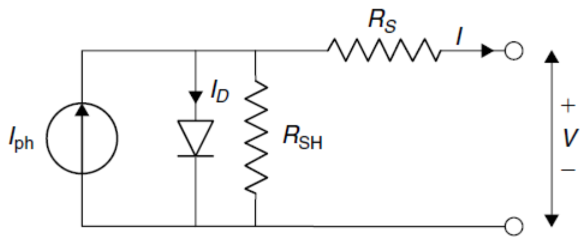

Fig. 1. PV equivalent circuit.

From the above equivalent circuit we can find the load current of the following equation.
Using Kirchhoff's Current Law:

$$I = I_{ph} - I_D - I_{sh} \tag{1}$$

where I is the output current, I_{ph} is the photocurrent, I_D is the diode current, I_{sh} is the shunt current. Using Kirchhoff's Voltage Law and Ohm's law:

$$V_D = V + I \times R_s \tag{2}$$

where V_D is the diode voltage, V is the output voltage, Rs is the series resistor. Using Ohm's Law, it may be seen that:

$$V_D = I_{sh} \times R_{sh} \tag{3}$$

where R_{sh} is the shunt resistor. Substituting Eq. (2.3) into Eq. (2.2), we have

$$I_{sh} = \frac{V_D}{R_{sh}} = \frac{V + IR_s}{R_{sh}} \tag{4}$$

From the Shockley's diode equation, we have

$$I_D = I_s \left[e^{\left(\frac{V_D}{nV_T}\right)} - 1 \right] \tag{5}$$

where I_s is the diode reverse saturation current, n is the emission coefficient/ideality factor, and V_T is the thermal voltage. The thermal voltage can be expressed as:

$$V_T = \frac{k_B T}{q} \tag{6}$$

where k_B is the Boltzmann's constant, T is the temperature of the PV cell, and q is the magnitude of the electron charge constant. I-V characteristics equation for a single PV cell using the SDM is expressed as:

$$I = I_{ph} - I_s \left[e^{\left(\frac{V_D}{nV_T}\right)} - 1 \right] - \frac{V + IR_s}{R_{sh}} \tag{7}$$

III. EFFECT OF PARAMETER VARIATION

(a) Solar Irradiance Variation Effects

With the increase of solar radiation there is increase of current-voltage (I-V) curve and its maximum point also. If we see the increase in insolation then we find Isc increases accordingly. The impact on the power-voltage curve is that while there is increase of solar radiations there is increase of P-V curve and maximum power output also. Also by increasing insolation V_{oc} increases.

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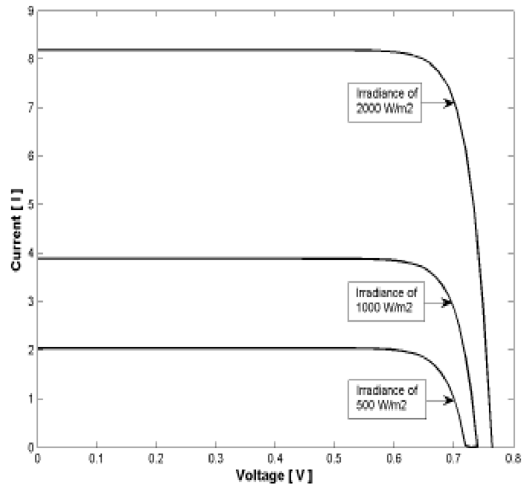

Fig. 2 I-V curve for different solar irradiance.

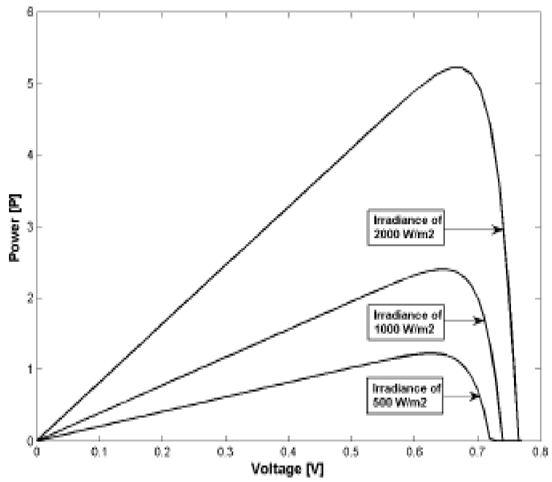

Fig. 3. P-V curve for different solar irradiance.

The light intensity or irradiance has a dominant effect on current parameters. The short circuit current and the maximum current increase linearly with increasing light intensity. This can be observed in Figure 3. Therefore, concentrating systems such as Fresnel lenses and Booster mirrors can be used to increment photocurrent, short circuit current and maximum current values of module. The cell temperature slightly affects the short circuit current, increasing it a bit with the temperature increment. All these effects can be calculated by (14):

$$(I_{sc})_{G,T} = (I_{sc})_{STC}(1+\alpha(T-T_{STC}))*\frac{G}{G_{STC}} \tag{8}$$

Where STC denotes the Standard Test Conditions ($TSTC$=25°C and $GSTC$=1000Wm^2) and α is the relative current temperature coefficient. It has been found that the series resistance decreases with increasing light intensity due to the increase in conductivity of the active layer with the increase in the light intensity. On the other hand, parallel resistance also decreases with light intensity. This decrement can be explained in terms of a combination of tunnelling and trapping of the carriers through the defect states in the space charge region of the device. Otherwise, it has been observed that module temperature has a high effect on voltage parameters. It has been found that the series resistance of mono-crystalline modules have a small increase when temperature increases, while the poly-crystalline modules show a small decrease with temperature. On the other hand, it has been found that the parallel resistance of mono-crystalline modules decrease with temperature. The parallel resistance of poly-crystalline module increase with temperature. The best way to improve the performance of solar system is maximizing the light intensity falling on the PV module and also to avoid the drop in V_{OC} and V_{mp} keeping the module temperature as low as possible.

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(b) Effect of varying Cell Temperature

If we increase the cell temperature then there is increase of short circuit current (I_{sc}) and decrease in open circuit voltage (V_{oc}). Increase in temperatures cell efficiency drops also.

$$I_s(T) = I_s \left(\frac{T}{T_{nom}}\right)^3 \exp\left[\left(\frac{T}{T_{nom}} - 1\right)\frac{E_g}{NV_t}\right] \tag{9}$$

Fig. 4. and 5 shows the V-I and P-V characteristics.

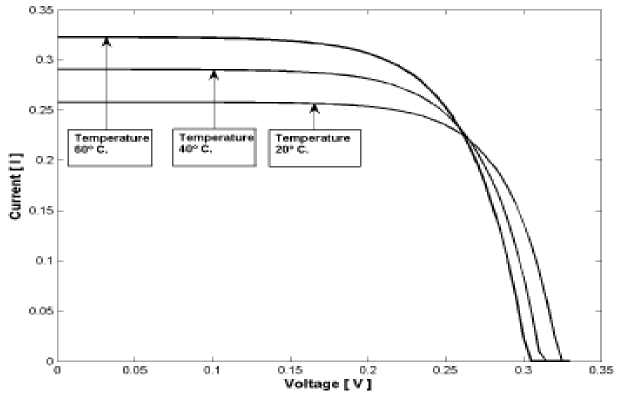

Fig. 4 I-V curve for different temperature.

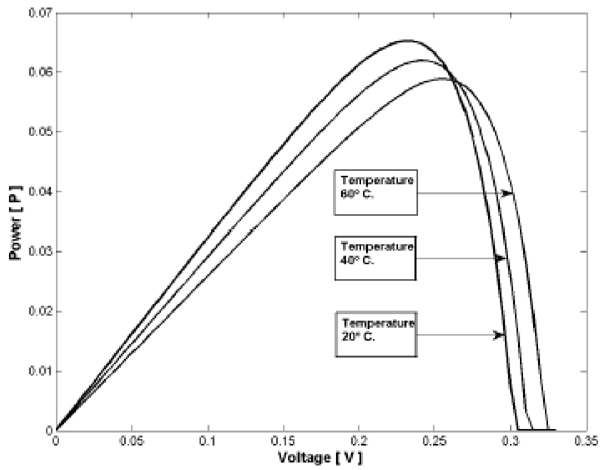

Fig. 5. P-V curve for different temperature

(c) Variations of Series Resistance R_S

R_S does not affect a solar cell at open-circuit voltage because the overall current flow through the solar cell is zero. But, the effect of RS is clearly seen near the short-circuit conditions. The combined load resistance and series resistance are in parallel with the diode in the solar cell model. As the value of R_S is increased, the voltage across it increases. This increases the voltage across the diode as well and the current through it. Since the diode current is exponential function of its voltage, a larger portion of the photonic current flows through the diode. So, the output current will decrease. Thus the current flowing through the diode R_S is not constant and varies with electrical load and illumination or percentage of shading across the cells. Series resistance is a particular problem at high current densities, for instance under concentrated light. Fig. 6 and 7 show the I-V and P-V characteristics for different values of series resistance.

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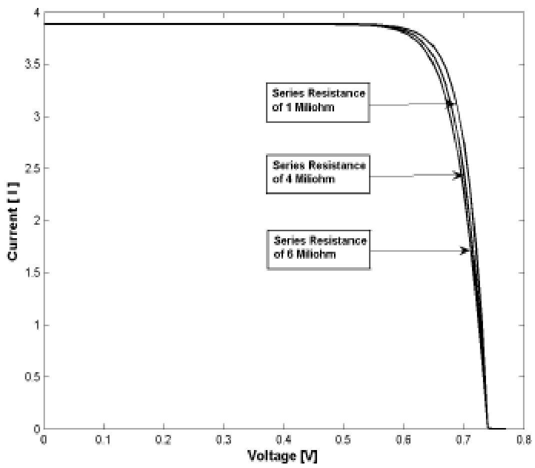

Fig.6. I-V curve for different Series Resistance

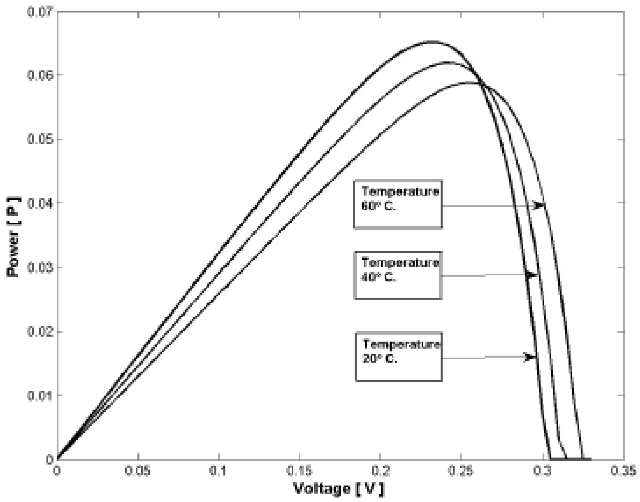

Fig. 7 P-V curve for different Series Resistance

Though series resistance in a PV circuit is very low but there is less effects of its variation. After observing with the changes it is found that the short circuit current changes slightly and open current voltage remains same. There is decrease in current-voltage curve with the increase of series resistances. With the increase of series resistances there is decrease in power-voltage (P-V) curve resulting the change in maximum power point. With the decrease of series resistances there is increase in I-V and P-V curves with increase in maximum power point. MPPT (Maximum Power Point) strongly depends on series resistances.

(d) Variations of Shunt Resistance R_{Sh}

Shunt resistance mostly arises due to

a) Manufacturing defects, rather than poor solar cell design.

b) Leakage of current through the cell, around the edges of the device and between contacts of different polarity.

The equation for a solar cell in presence of the shunt resistor (R_{sh}) is:

$$R_{sh} = \frac{V + R_s I}{\left[I_{ph} - I_s \left(\exp\left(\frac{qV + qR_{sI}}{NKT} \right) - 1 \right) I \right]} \quad (10)$$

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Shunt resistance has great impact on current-voltage curve. With the increase of shunt resistance, current-voltage (I-V) increases because while shunt resistance increases short circuit current remains almost same but open circuit voltage increases. It increases fill factor also. But the infinity value for shunt gives the best output.

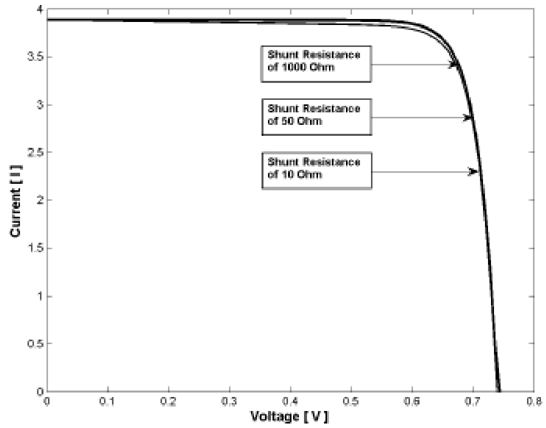

Fig. 8. I-V curve for different Shunt Resistance.

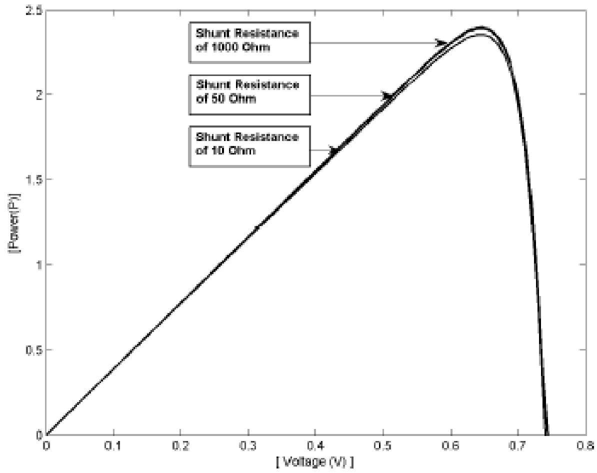

Fig. 9. P-V curve for different Shunt Resistance.

Shunt resistance must be good enough to obtain the maximum power output of a PV cell. Shunt resistance is used to measure high currents and it is connected in parallelly. With the increase of shunt resistance power-voltage (P-V) increases and it increases maximum power output also. But the infinity value for shunt gives the best output. With the decrease of shunt resistances power output also decreases [8]. As can be seen in Figure 8, the effect of shunt resistance R_{SH} is more prominent at the open circuit conditions than at the short circuit. The shunt resistance appears in parallel with the series combination of series resistance and load resistance. As the shunt resistance is reduced it reduces the overall output resistance. Thus the voltage drop across it and the parallel diode in the solar cell model decreases. This causes reduction in the output voltage across the load. The I-V curves deteriorate with decrease in shunt resistance RSH.

(d) Shading of solar cells

Since the maximum voltage given by a solar cell is approximately 0.65V, cells are connected in series in order to collect higher voltage or in parallel to generate higher current, forming PV modules with the desired output. When one of the cells is partially shadowed, it will produce less current than the rest of the cells in the string, as the photo-current goes in the reverse direction. The other cells will try to push more current through the poor cell than it delivers. This is however not possible, since in this case the cell acts as a diode in the reverse direction. Then the current of this cell will limit the current of the whole string. The conventional solution to mitigate shading problem are the bypass diodes.

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There are some newer solutions for minimizing the impact of shading, as DC-DC optimizers or module inverters. As a result of shading, multiple local MPP appear in the power curve, Figure 10.

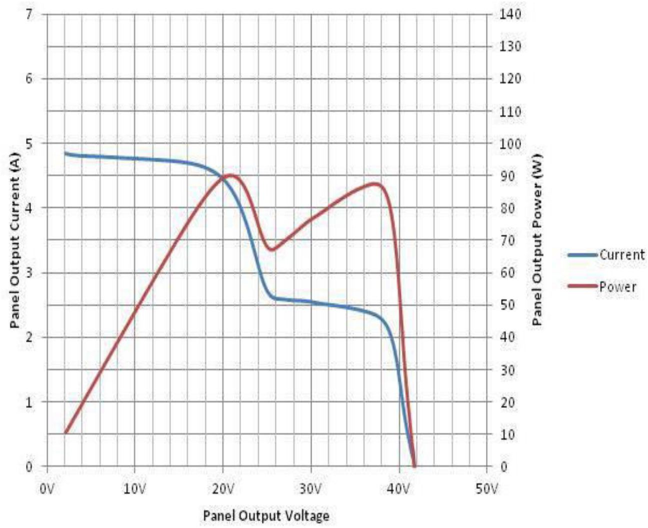

Figure 10. I-V and P-V curves with multiples local MPP due to shading

Therefore, to obtain the global MPP, a Maximum Power Point Tracker (MPPT) which can track the global power point is necessary. The DC-DC optimizers and module inverters usually incorporate this function.

(e) Bypass diode

In order to avoid the shading problem, the conventional solution is to install bypass diodes. A bypass diode is connected in parallel, but with opposite polarity. Under normal operation, each solar cell will be forward biased and therefore the bypass diode will be reverse biased and will be an open circuit which will not conduct. However, if a solar cell is reverse biased due to a mismatch in short-circuit current between several series connected cells as a consequence of shading, for instance, then the bypass diode conducts, thus allowing part of the current from the unshaded solar cells to flow in the external circuit. Figure 11 shows five bypass diodes connected in parallel with five cells in series connected.

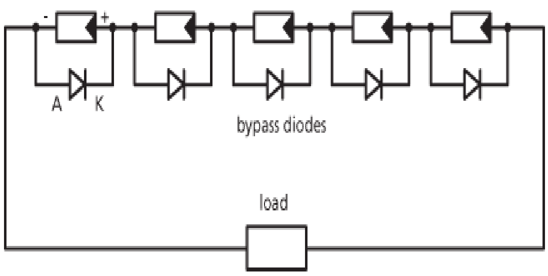

Figure 11: Bypass diodes installed in five solar cells

In practice, one bypass diode per solar cell is generally too expensive and instead bypass diodes are usually placed across groups of solar cells. Generally, for a solar cell string of n cells being equipped with one bypass diode, the absolute value of the breakdown voltage, Vbr, of a reverse biased solar cell must be greater than n up to n+1 times 0.5V. This value is the equivalent to the voltage in the MPP of the rest of the cells in series which are not shadowed (n-1) plus the voltage of a silicon bypass diode that is usually between 0.5 and 1V. Figure 17 illustrates a string of n cells connected with a bypass diode through which is circulating a current $Ibypass$. Considering that the voltage increment in each cell and the voltage drop in the bypass diode is 0.5V, the shadowed cell has the following voltage drop :

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$$\Delta V = (n-1)0.5 - (-0.5)V = 0.5nV \quad (11)$$

Because of that fact, V_{br} of a reverse biased solar cell must be greater than n up to n+1 times 0.5 V, not to achieve the breakdown value which will generate serious damages in the cell.

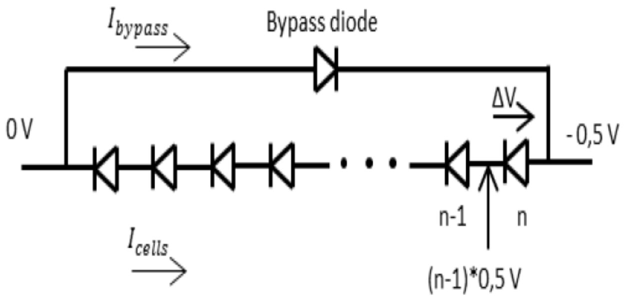

Figure 12: Current through bypass diode when a cell is shaded

If the V_{br} is higher than this value, the current will be lower than the maximum that the un-shadowed cells can generate and the power output will probably be lower than the maximum.

IV. CONCLUSION

This paper discuss by using the fundamental circuit equations of a solar photovoltaic cell. It is clear that the characterization of the solar photovoltaic cell by using different parameters and it shows the great effects of the parameters variation [4]. The changes for current, voltage and power with the maximum power point (MPPT) output are represented in the figures. PV cell presents different behaviors depending on the internal and external parameters. It is very unpredictable and unimaginable about what may happen for a slight change of a parameter and it is not possible to know without observing the current-voltage and power-voltage curve of a PV cell. In future different solutions can be proposed to overcome the shortcomings to improve the efficiency.

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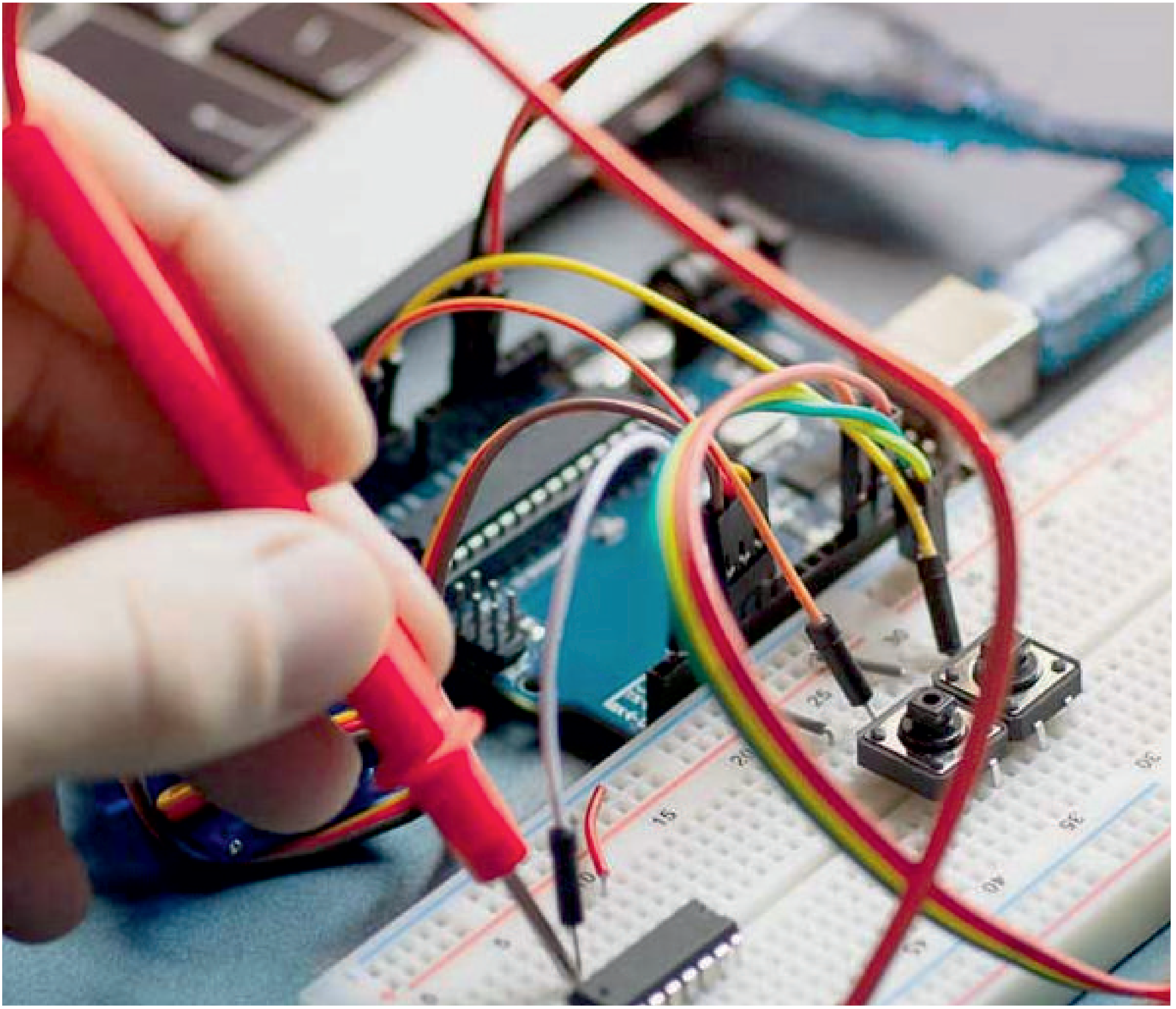

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