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A Review of Single Phase Flyback Inverter Topologies for PV Applications

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ABSTRACT: In the recent year's solar energy become a popular source of renewable energy source(RES). So photovoltaic system based inverter topologies have become most popular due its high optimization and more flexibility in the design process. This review paper mainly focuses on different fly-back inverter topologies, which are used in photovoltaic(PV) modules for power conversion purposes. Nowadays fly-back topologies have become one of the most used and growing inverter technology for small-scale to medium scale and also for large scale PV applications. The inverters used for photovoltaic systems are classified into different categories based on power processing stages, based on number of cells used for interleaving and whether they used transformers for its operation. These different fly-back inverter topologies have been presented, compared with their operating principles, life time, ratings. At last, some of the topologies selected as best solution for particular application either single PV module or multiple PV modules.

KEYWORDS: Photovoltaic(PV), Renewable energy resources(RES's), Discontinuous conduction mode(DCM), Micro inverter, Fly-back inverter, Boundary conduction mode(BCM), Grid-connected systems, Maximum power point(MPP).

I.INTRODUCTION

The electrical energy generated by photovoltaic system is supplied to utility grid or to the load is getting more and more attention towards solar energy, when entire world's power demand is increasing day by day. There is not much PV modules have been installed so far into the grid because of its higher cost when compared to other traditional sources such as oil, coal, hydro power, wind energy, gas etc., When solid state devices started evolving and became popular, the usage of PV systems increased rapidly and now they are used for integrationwith grid connected or used as standalone applications. So from the above reference, it will clearly show that there is considerable reduction in the cost of PV modules, inverters. Therefore, it is very important to make use of PV modules for extracting solar energy with a suitable inverter topology.

For grid-connected or directly supply to end users power conversions by using PV energy grouped into few types of configurations, such as centralized, string, multi-string, AC-module configurations. Centralized configuration is used for large scale PV plants (three phase), string configuration is for small and medium scale PV systems (single phase and three phase), multi-string configuration is mostly applicable for small scale to large scale PV applications and AC modules are preferably used for small scale applications (commonly single phase). Now a day's lot of research work has been carried out on the different inverter topologies and control techniques. Among the various topologies fly-back topology is widely used because of its simple structure, low cost, ease of control, higher efficiency and due to this it is best suited for PV applications. The following below figures [11] shows the grid-connected PV module configurations.

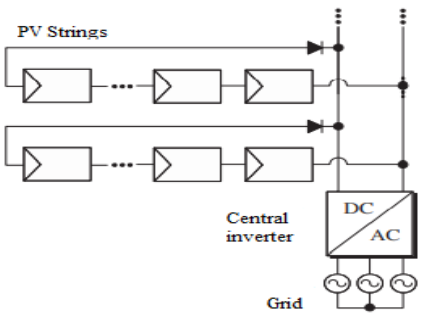

Fig. 1(a). Centralized configuration.

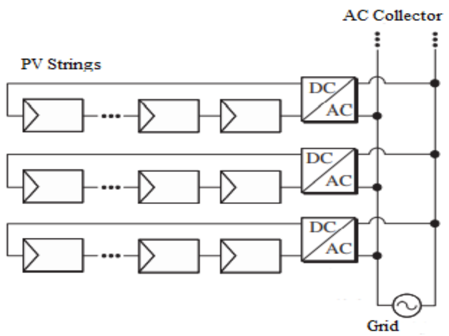

Fig. 1(b). String configuration.

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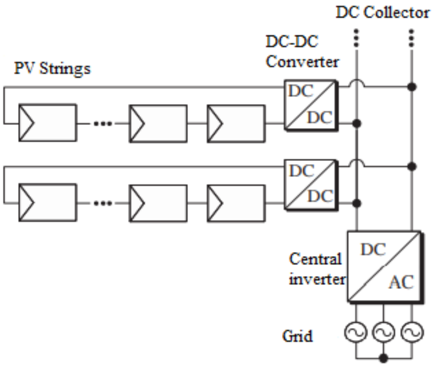

Fig. 1(c). Multi string configuration.

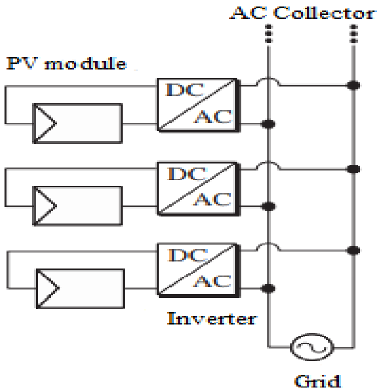

Fig. 1(d). AC module configuration.

II.SPCIFICATIONS AND STANDARDS

Inverters should be interfacing with PV modules such that both generating side (PV Panel) and at load side there should be balance, then only proper interfacing will take between the source and grid side. For successful operation of PV module at MPP and another one is to inject sinusoidal current into grid. There are some demands which are defined by grid, PV module(s) and also by operator(owner) or user. Some of the demands required for the grid connection between the PV system and the grid, some of the standards given by utility companies must be obeyed. In the future international standards IEC61727 [3], other one is EN61000-3-2 [4] and IEEE1547 [5] and US National Electric Code (NEC) 690 are useful in considering for normal operation. All these standards deal with problems like power quality, island detection operation, grounding and other some queries. The IEEE [5] and IEC [3] standards will limit the maximum allowable injected dc current into the grid. The main purpose of this process is to avoid the saturation of distributed transformers.

TABLE I. Some of the important standards deal with interconnections of PV and grid.

ISSUE	IEC67172[3]	IEEE1547[5]
Nominal Power	10kW	30kW
Harmonic currents (order-h) limits	(3-4) 4.0% (11-15) 2.0% (17-21) 1.5% (23-33) 0.6%	(2-10) 4.0% (11-16) 2.0% (17-22) 1.5% (23-34) 0.6% (>35) 0.3%
	Even harmonics in this case will be less than 25% of odd harmonic limits listed.	
Maximum current THD	5.0%	
Power factor at 50% rated power	0.9	-
DC current injection	Less than 1.0% of rated output current.	Less than 0.5% of rated output current.
Voltage range for normal operation	85% - 110% (196V-253V)	88% - 110% (97V-121V)
Frequency range for normal operation	50 ± 1 Hz	59.3 Hz to 60.5 Hz

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Some of the demands defined for photovoltaic module(s) were like, the MPP voltage range for these modules normally in the between 23-38V at generation of power nearly 160W and open circuit voltage should be less than 45V. Nowadays most of the PV modules are monocrystalline or multi-crystalline silicon modules. According to NEC690 standard [6] PV module should be grounded and monitored for ground faults. Some other demands given by owner or user, that is it should be cost effective, durability and reliable (long time operational). Also PV panel manufacturers gives offer of warranty about 25 years with an 80% initial efficiency and material with service validity of 5 years.

III. DIFFERENT FLYBACK INVERTER TOPOLOGIES

We can see different fly-back inverter topologies based on their connection, operating procedures and controlling methods they are varies. Among many of them here we study some of the most commonly used topologies for PV applications.

Topology 1: - In this fly-back topology [7] as shown in fig. 2 power is drawn from PV module through a capacitor as a power train in a switching manner to feed the grid. The main reason of the capacitor is to support PV module voltage and drain its power when the circuit is momentarily inactive to increase the power yield. To obtain MPP the primary current is controlled in such a way that secondary current waveform shall be sinusoidal waveform. From the circuit diagram in the figure 2 consists of two transformers and four switches which are used to work separately. Switch SW1 is simultaneously turned on with SW3 along with the transformer during the positive half cycle of grid period and other two switches are disabled during this period. When controller detects negative half cycle of grid period, the switches namely SW2 and SW4 will be switched on and remaining two will be disabled.

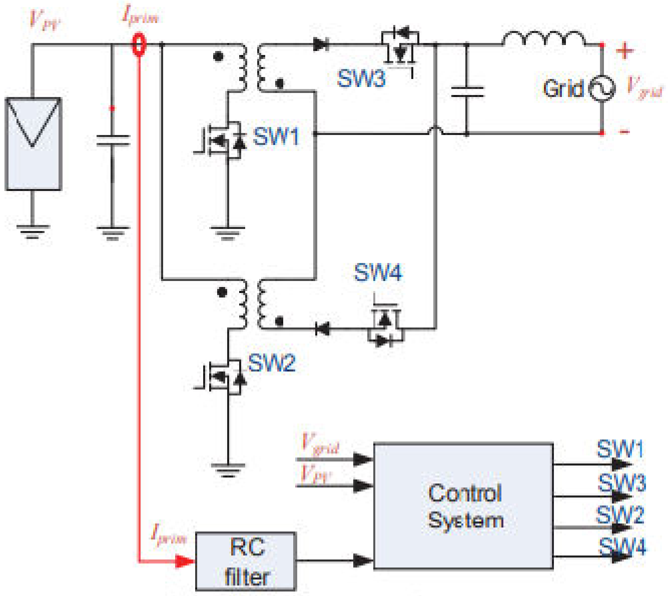

Fig. 2. Fly-back micro-inverter topology.

Topology 2: - The interleaved fly-back inverter [8] as shown in figure 3 consists of two fly-back converters and full bridge inverter. The working principle is same as the conventional fly-back inverter. Each fly-back converter is phase shifted 180^{o} in each switching cycle. This interleaving operation is can be achieved with double switching frequency, so current ripples in the secondary get minimized. In the figure 3 there are two main power switches S1 and S2, diodes D1 and D2 are used for rectification purpose. Np1 and Np2 are the primary winding turns and Ns1 and Ns2 are secondary winding turns of fly-back converter. There are another four switches S3, S4, S5 and S6 of full bridge inverter. These will operate when S3 and S6 will tuned on during positive half cycle and S4 and S5 will turned on during the negative half cycle of grid period. This interleaved fly-back inverter operated with two different control techniques, they are boundary conduction mode (BCM) and discontinuous conduction mode (DCM). Here another control strategy is used along with DCM, because during DCM operation high current will causes more stress on the devices and it will further lead to more power losses and lesser efficiency. So, to overcome this problem operate the inverter in such a way that during peak currents operate using BCM and during lower peaks operate with DCM. From the combination of both these control techniques, operate the entire inverter over a half period like 2-phase BCM modulation technique and 1-phase DCM modulation at the same time simultaneously.

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So by doing this procedure, we can get better efficiency of BCM during peak currents and similarly DCM operation during lower currents. Because of this control strategy it will improve the overall efficiency and also reduces considerable amount of %THD. In the DCM mode of operation turn on and turn off time of each switching period is given below equations (1) & (2).

$T_{on} = \frac{L_p I_p}{V_{dc}}$.............. (1)

$T_{off} = \frac{L_s I_s}{v_g(t)}$............ (2)

In the BCM mode the turn on and turn off time are calculated by using following equations (3) & (4),

$T_{on} = \frac{L_m \times i_{ref}}{v_i}$.......... (3)

$T_{off} = \frac{n \times L_m \times i_{ref}}{v_o}$....... (4)

Where n is turns ratio of flyback transformer, i_{ref} is current reference signal and Lm is magnetizing inductance.

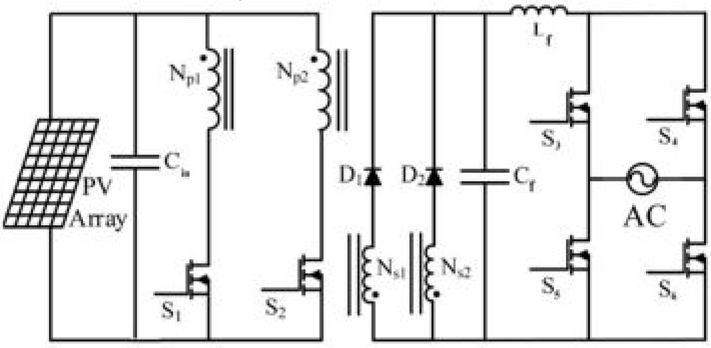

Fig. 3. Interleaved fly-back inverter.

Topology 3: - The below figure 4 shows the micro inverter system [9] with PV module as source of supply. This topology consists of interleaved fly-back converter, whose two different converters are connected in parallel both sides of input and output. Each one of these fly-back converters are separately named as converter-1 and converter-2. During first converter operation only one of the two converters are operating actually. In the second converter operation both the converters are operating actively and will take part in power conversion stages. From the PV panel to dc-dc converter circuit, then unfolding circuit (full bridge inverter). The MOSFET based power switches of fly-back converter operated with sinusoidal pulse width modulation (SPWM) technique using peak control method. So pulses are generated for switches to operate accordingly, further these will be phase shifted to reduce the filtering. The output current obtained from the converter after filter is sine wave shape, which is being after produces good quality (lower THD) sinusoidal grid current. Here there is an another way of operating converters depending on the load requirements, like when there is light load one-converter operation is enough, for higher loading condition two-converter operation will take place.

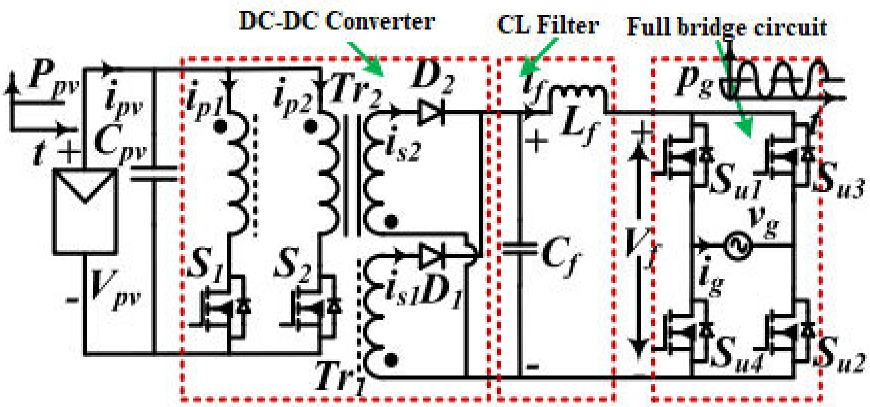

Fig. 4. Interleaved converter based micro inverter.

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Topology 4: -The figure 5 shows the basic circuit topology of the fly-back converter, which consists of one main power switch (MOSFET) in the primary side and a diode, capacitor with a flyback transformer on the secondary side. Input to this circuit is maybe unregulated dc source or we can use PV as a source of supply voltage. The ripples in the dc voltage is much lower frequency and this ripple waveform repeats twice the ac mains supply frequency. Fly-back converter operates at much higher frequency in the range of 50-100kHz, for this purpose it is mandatory to select the switching device such that it will operate fast switching. Due to this reason it is obvious that MOSFET is most suitable switching device for fast switching operation.

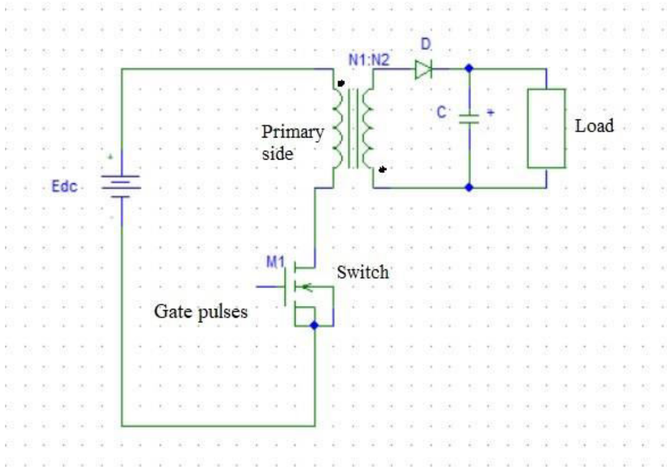

Fig. 5. Basic fly-back converter.

From the above figure we can thee that fly-back transformer is different from that of normal conventional transformer operationally. The design of this such that windings of both primary as well as secondary have good coupling to achieve nearly same magnetic flux for smooth and safe operation. This fly-back transformer provides voltage isolation between both input and output circuitry for better matching. While normal transformers under loading condition both primary and secondary windings simultaneously conduct current, in such a way that ampere-turns of primary will balance the opposition in secondary winding with nearly or same ampere-turns. It can be operated basically with two different modes of operation, they are continuous conduction mode (CCM) and discontinuous conduction mode (DCM). There are several advantage of DCM over CCM mode of operation, such as it will give fast dynamic response, good stability in all operating environments, absence of reverse recovery issue, less turn on losses, smaller in size and easy to control. Apart from this, it has few disadvantages like higher farm factor compared to CCM which leads to power losses. So to overcome this problem we are connecting devices in parallel that is, interleaving two or more flyback converters will help to reduce the losses.

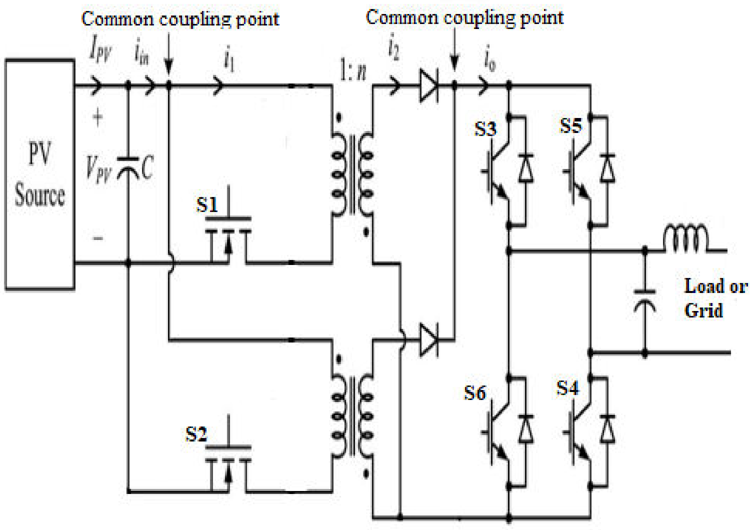

Fig. 6. Two cell interleaved flyback inverter topology.

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Figure 6 shows the two cell interleaved flyback inverter topology [10], which is modified version of basic circuit topology shown in figure 5, by connecting two cells parallel through a decoupling capacitor at the input side. Further it is fitted with the two flyback transformers connected parallel with two different main switches, and at the load side it consists of a full bridge inverter circuit for unfolding and a low-pass filter to reduce the harmonics for sinusoidal current waveform at the grid or load side. By increasing the number of turns in both primary and secondary of the flyback transformer, we can increase the voltage level at the output. Instead of connecting the magnetizing inductance we can directly convert the voltage, which can be seen from the figure 6 modified by removing the magnetizing inductance. To start with operation, it is more or less similar to basic circuit as explained in the previous figure 5. The main switches S1 and S2 turned on simultaneously in the primary side, then current starts flow from source (here PV is selected as source) through flyback transformer, decoupling capacitor and energy is stored in the form magnetic field. When the switches are in on state, no there is no current flows in secondary due to position and polarities of diodes in the secondary side. Energy is transferred to secondary when the main switches are turned off, current starts flowing in secondary, further it flows through the unfolding full bridge inverter circuit through low pass filter to grid load to provide required sinusoidal current with lesser harmonics. Therefore, this topology acts as voltage controlled current source. This circuit topology operates in the DCM mode for its ease of operation, flexibility and for stable operation.

IV. CONCLUSION

In this review various flyback topologies are discussed based on different types of connections, type of transformers used and how they operate. This paper has also covered the some of the standards related to interconnection of PV system and grid applications that should fulfil. All these standard will be focussing on the how much amount of dc current injection into grid, what should be the minimum percentage total harmonic distortion (%THD) for safe and good working condition and also some the requirements by user or owners such as low cost, higher efficiency and long lifespan. From the above all reviews we can say that interleaved flyback inverter topology practically used at high power as centralized/central type PV inverters. Here it covers how they controlled using some of the basic operating techniques easily, like discontinuous mode of operation in flyback topology and also there is advancement in the development of AC modules with their own dc-ac inverter at the grid side. In addition, there is an another way control technique which will increase the overall efficiency is that, the combination of both BCM as well as DCM modes of operation. By proper use of these techniques with topology shown in figure 6 will improve the overall efficiency reasonably higher percentage compare to use of single control technique.

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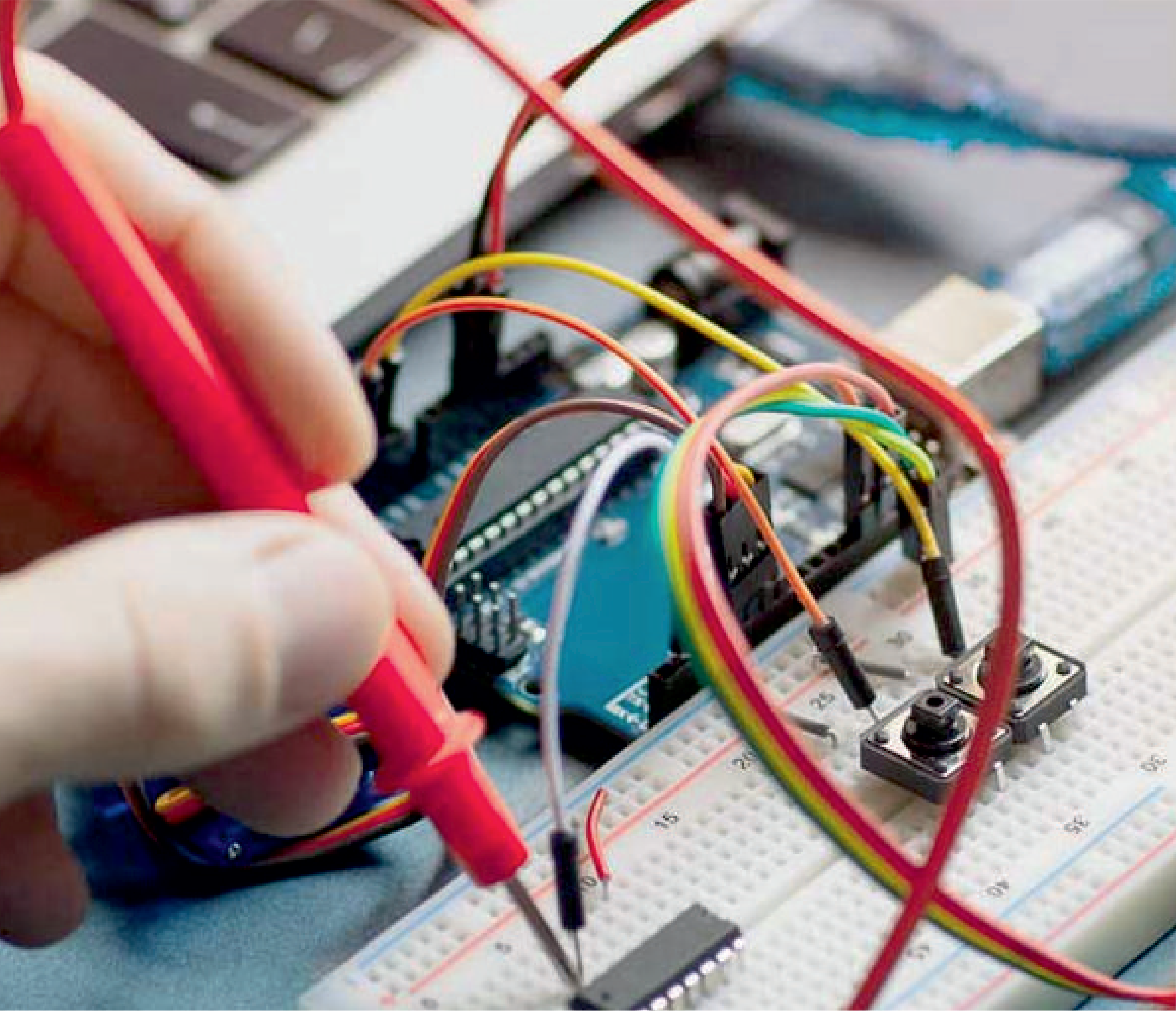

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