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A Review on Microgrid Energy Management Systems with an Advanced Control Schemes

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ABSTRACT: The power industry is getting a major leap towards productively extracting power from the various resources known as Renewable Energy sources (RES). From the last decade, continual efforts are being made to extract the maximum energy is obtain using advanced control techniques of RES in comparison with the conventional source of energy. The various problems are the intermittent nature of RES, inconsistency of energy production, poor reliability in terms of stability, and power quality issues associated with RES in comparison with conventional sources of energy. These problems can be avoided with the help of the integration of an ESS with the combination of renewable energy sources (i.e., solar and wind energy). The concurrent energy management of these sources to cope with load side demand along with better accuracy is a crucial consideration. An efficient, as well as safe controlling algorithm with an Energy management system (EMS), is essential to share energy from microgrid (MG) technology to the power system. In this paper, a brief analysis of main EMS techniques is extensively reviewed and its typical applications with their sorting for Micro Grid is presented for an advanced control technique of an EMS.

KEYWORDS: Energy management system (EMS), Renewable energy sources (RES), Distributed generators (DG), Artificial neural network (ANN), Particle swarm optimization (PSO).

I. INTRODUCTION

Renewable resources help to protect the environment. Due to growth in power demand causes the use of Distributed generators at the main grid has been increased. The incorporation of DG is a difficult task. As a consequence, the MG concept is becoming more well known. MG structure is explored [1], which highlights the AC as well as DC technologies used in MG. Many other projects for the configuration, control, governance, as well as implementation of MGs have been carried out around the world in recent years. The integration of Microgrid with EMS aims to reduce servicing, running, and fuel consumption. Energy management seems to be essential to maintain system voltage and frequency, which must be properly designed. In [2] introduces the evolution of MG testbeds around the world. Multigeneration sources are coupled in a microgrid and system management is required to ensure that electricity is delivered to the load without interruption. Management can occur in several ways, including management at supply-side, demand-side, power, and energy management. The overall governance of MG is composed of several layers; EMS decentralized control systems, several converters or inverters, power production sources, multiple loads, and interaction with many other power sources. EMS is the most emphasized of these control techniques because effective management of energy from varied processes must be maintained, so when which sources ought to be ON to meet demand should be regulated [3] Furthermore, battery management is critical since it serves as the backbone of the entire system in an emergency.

EMS is a combination of hardware and software that allows for the monitoring and control of power-producing units and unusual loads, as well as interface with other power clusters, explored [4] MGs, are recommended to feature three levels of controls in the early descriptions of MG structure is explained [5] power electronic controllers, protection systems, and energy management. An example of power electronic control in MGs is the coordinated control of bidirectional converters in an AC-DC hybrid MG described [6]. Another example is the method presented in [7] for decentralized regulation of interactions between several energy sources in an islanded MG bus without mutual

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communication. A novel scheme comprising a Rolling Horizon and MPC was demonstrated by the EMSs. Various studies use one or both of these approaches to solve the dispatch problem in power systems. The author in [8] uses a receding horizon MPC to adopt a multi-level approach to regulating distributed sources and storage MPC. In diverse circumstances, studies on how to best schedule the dispatch of MG resources have been conducted. The author in [9] presents a two-horizon scheduling approach using MILP to optimally plan energy resources in residential MG. Another author has developed a distributed technique for reducing operating expenses in MGs by calculating an optimal power flow (OPF) [10], with a stochastic OPF problem. This technique aims to reconcile demand and supply for real-time, as averse to electricity cost-cutting explored in prevailing work. The design approach in the articles creates instantaneous power values for a single MG system, but the approach given in the paper determines temporally averaged power flow values in circuits of MGs. In this paper, power conditioning approaches are studied for performance analysis. The EMS schemes are series-connected and shunt-connected systems that improve the voltage stability in transmission lines and provide a reduction in losses along with enhanced power quality.

II. MICROGRID

MGs are identified as combined DERs and ESS that form a grid feedings various dispersed loads at lower voltage system operated in a grid-connected or standalone mode [11]. Fig.1 explained basic MG architecture. It has two DG sources, an ESS, and both ac-dc loads, along with PHEV. MG buses are of two kinds:

- DC bus - The DC bus connects the DG sources, storage device, and dc loads.
- AC bus- Connects ac loads to the electric grid.

The following infrastructure is required by MG:

- RES/ DG
- Power Converting Systems
- Distribution Lines
- Monitoring Devices Along with Instruments
- Proper control functioning

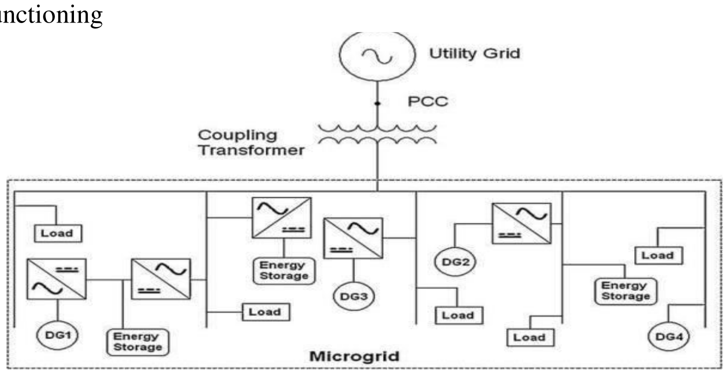

Fig.1. Basic MG Architecture

MG is made up of various distributed generation sources linked to the utility grid through a single point. The MG energy management phase with an array of functions, including HMI modules, control, and data collecting, predictive modeling, and optimization [29].

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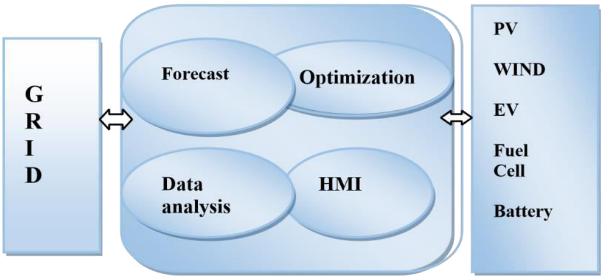

Fig. 2. MG Energy Management

III. ENERGY MANAGEMENTSCHEMES

Energy management techniques are essential for the proper operation of MG in both grid-connected as well as standalone states, that determines the output power of DG. In [12] the EMS schemes are categorized as follows in general.

A. SUPERVISORY CONTROL-BASED ENERGY MANAGEMENT SCHEME

COMMUNICATION-BASED ENERGY MANAGEMENT SCHEME

The system information is conveyed in this scheme to determine the operating point of each DG in the MG. The best communication method is chosen depending on the distances between power sources, the level of security, the cost, and the technologies available, which include fiber optics, microwave, infrared, PLC, and/or wireless radio networks. There are two types of energy management schemes: centralized and decentralized. These two schemes are combined to provide a centralized and decentralized scheme [13].

1.1. Centralized Energy Management Scheme

Fig.3. shows centralized EMS. The operating points of the DGs are determined by a single control center in this arrangement. The measured signals are received and the DGs' operating points are set based on the objectives and limits for lowering system operation and maintenance costs, reducing environmental impact, increasing system efficiency, and so on. After making decisions, the DG control systems receive the control signals. The biggest disadvantages are the high computational load and the risk of the system collapsing if communication fails. This approach, on the other hand, can accomplish competitive results.

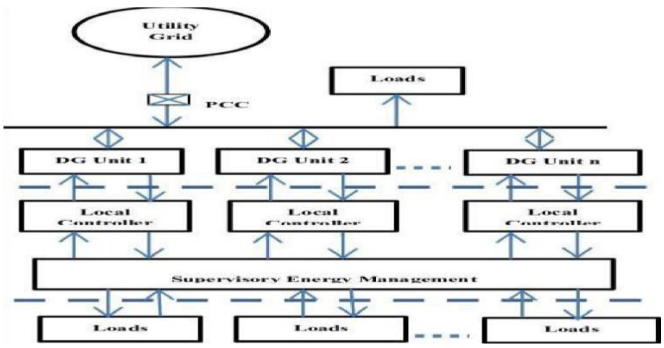

Fig.3.Centralized Energy Management Scheme.

1.2. Decentralized Energy Management Scheme

In this architecture, all of the controllers are connected via a communication bus, which is used to exchange data amongst DG controllers. All of the local controllers are also connected to all of the loads.

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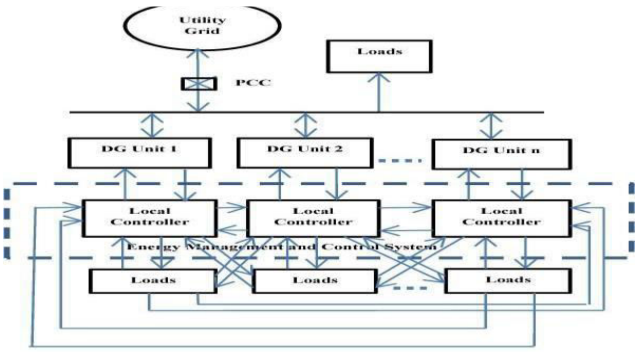

Fig.4. Decentralized Energy Management Scheme.

Fig.4. shows the decentralized energy management strategy. This information is used to establish the DG operating points [14]. The compute requirements are lowered under this technique, and the system's modularity is improved.

COMMUNICATION-LESS ENERGY MANAGEMENT SCHEME

While communication is difficult or expensive the DG unit has to work independently. Energy sources are having their controller devoid of communication links through further controllers as shown in Fig.5. The advantages of such a scheme are

a) No communication prerequisite
b) Expandable control scheme.

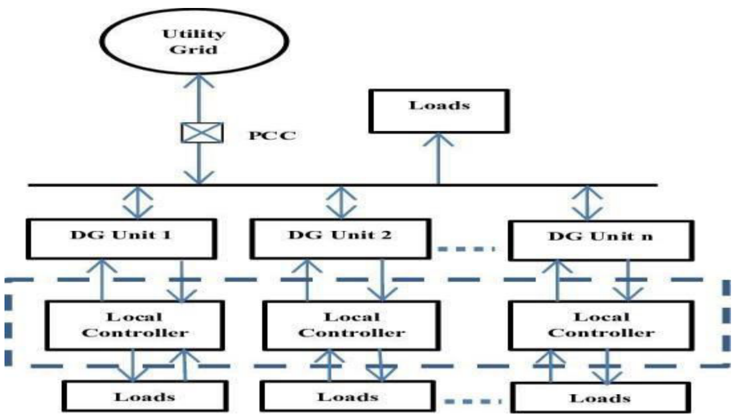

Fig.5. Communication-Less Centralized Energy Management Scheme

B. OPERATING MODE-BASED ENERGY MANAGEMENT SCHEME

1.Stand-Alone Mode

The use of a hybrid system can lower the total cost for a system of areas where energy from the sun and wind are plentiful. A sampling with time-series signals at intervals is demonstrated using linear short-term forecasting for a hybrid system incorporating these sources [15]. There are two versions for microgrid; grid linked mode and standalone mode. It is linked by a grid to provide consumers with a consistent and steady power supply, that works in this mode for lots of time [16] a unique double-layer synchronized control scheme for microgrid power management, which comprises of two layers: a) scheduling layer and b) dispatch layer. The scheduling layer chooses the most cost-effective operation as per predicting data. Conversely, the dispatch layer delivers configurable units as per real-time

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data. The discrepancy between predicting and real-time data is resolved to utilize two-layer coordinated control to accomplish economic as w
well as stability goals. In IEMS, unit commitment along with optimal power flow restrictions are presented [17], which uses model predictive control to characterize the inaccuracy in renewable output & power demand. When the suggested approach was compared to DEMS, IEMS had a lower running cost and makes better use of storage and some other hybrid sources. A renewable-based DC MG is made up of many generation sources, an energy backup system, with loads that can be self-contained or linked to a grid and configured to satisfy load requirements for rural and remote locations [18].

2.Grid Connected

MG, which is composed of distributed sources for energy, distributed sources, including load, is intended to fulfill rising power requirements. MG can operate in both grid-connected as well as island mode while maintaining frequency deviation following EN50160 standard. To achieve the necessary output, numerous power electronics components such as converters and inverters are used. Different architectural approaches for solar have been scrutinized to present to collect maximum power from PV. However, research is being conducted to a large extent using other RES. Fig.6.shows a block schematic for MG connected to the main grid incorporating residential load. Wind and solar are RES employed here, with a battery as either a backup. The algorithm is created having droop characteristics in consideration for active plus reactive power exchange amongst parallel resources.

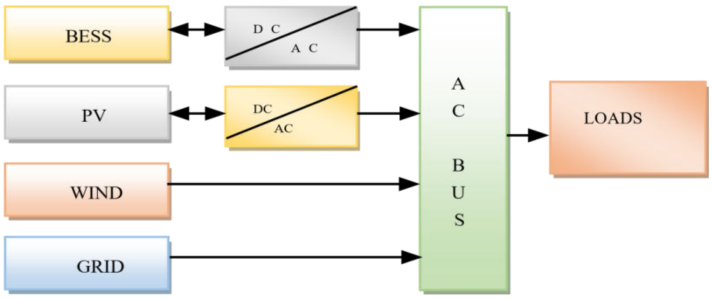

Fig.6. Block diagram Grid-Connected Micro Grid

Basic EMS approaches are controllers that address conditions, characteristics such as power demand, fluctuations, as well as intermittency of RES technologies for a short amount of time. These low-level algorithms ignore variables such as the SC's state charge, the battery's dynamic responsiveness, power demand, even wind profile, among others. As a result, basic level algorithms presume that ESS will always operate at maximum capacity. Because of the nonlinear nature of SC and battery technologies during their charge/discharge operations, and also time fluctuation for wind as well as power demand profiles, EMS techniques are unable to efficiently exchange electric power across the ESS devices under consideration. Furthermore, due to the aforementioned factors, effective mitigation of RES variations and intermittency necessitates the adoption of EMS approaches along with advanced system algorithms allowing the synchronization of all power system elements to optimize the benefits of HESS. Fig.6.depicts the advanced EMS approaches, which are separated into two categories: ruled-based and optimization-based on the rule-based procedures are classified as deterministic as well as fuzzy logic, whereas the optimized techniques are classified as online or offline. Fig.7. shows a schematic representation that is used as a reference to demonstrate a classification based on multiple EMS methodologies in [19-20].

V. CLASSIFICATION OF EMS

.

A. BASIC EMS TECHNIQUES

Voltage drop control is one of the most commonly used algorithms to regulate energy in ESS devices, according to sources. Furthermore, the voltage drop control technique has provided the foundation for Advanced EMS techniques. With one or two PI control interfaces, the strategy seeks to generalize the voltage drop control technique to manage the energy in a battery or SC, as shown in Fig. 8. EMS technique involves regulating VDC via an SC or a battery, using an

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exterior voltage control loop (interface PI) and/or an inner current control loop to control ISC but rather a battery current in [21-22]. According to [23], adding a linear filter with a set time constant between the external voltage control loop

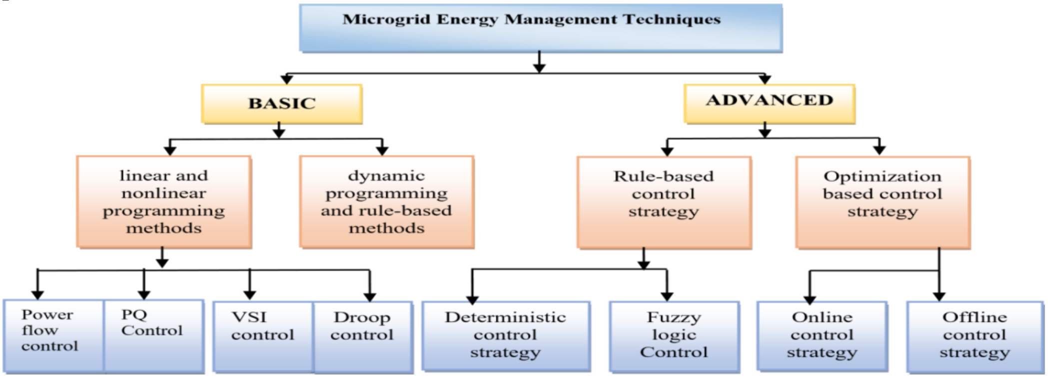

Fig.7. Classification Of Energy Management Techniques

and the inner current control loop improves the sharing of low and high-frequency power components in the HESS system. This is termed as Linear Filtering EMS approach, and it may isolate the higher and lower major elements and send them to the battery along with SC, respectively, to aid alleviate concerns linked to load's power consumption, intermittency, and uncertainty of wind energy. Furthermore, during the electric charge/discharge operation of ESS devices, the LF EMS approach lowers and smoothest peak current. As a result of the latter, the battery life is improved, as well as the dc-bus voltage is more stable. The performance of the external voltage control loop process, as well as the difference between VDC Ref and the nominal VDC, can be seen in fig.7. which helps to keep the dc-bus voltage within safe operating limits. This process generates the necessary current for the Hybrid ESS system to inject I comp into the dc-bus voltage.

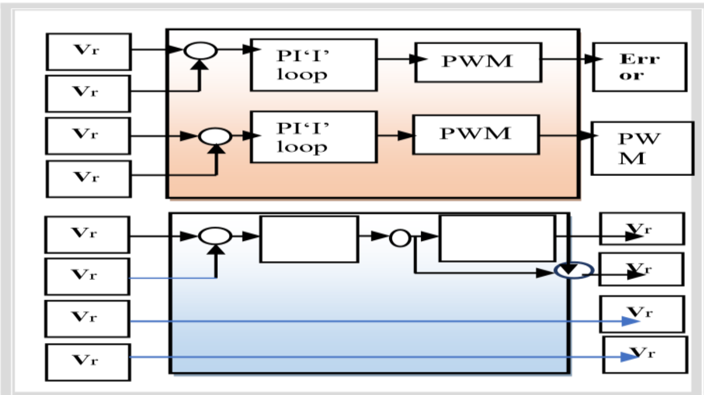

Fig.8. Block Diagram of Voltage Drop EMS Technique with A Linear Filter

Due to the variations and variability of renewable energy sources, as well as the power load profile, compensated current will have both low and high-frequency power components. A Low-frequency current is required to inject or absorb the dc-bus voltage by the battery when LF is used in compensating current.

B.ADVANCED EMS TECHNIQUES

1. Deterministic EMS Technique

The TCS, PW, and ST EMS approaches all agree that the control algorithm is built on rules that take into account one or more established design parameters, such as the battery and SC's superior and inferior thresholds, maximum charge/discharge rate, PDEM, PGEN, and so on. Furthermore, these methods make use of the benefits of voltage drop and linear filtering approaches. As a result, the power electric system, ESS devices, and control interfaces are better coordinated and share power. In Fig.5.the Linear Filtering EMS approach is used [24].

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2. Fuzzy Logic EMS Technique

In hybrid ESS systems, fuzzy logic has been widely employed to control and manage energy. This technique determines reference values for voltage and current control interfaces as well as updating values such as the LF constant [25]. It can also be utilized to perform supervisory control functions, such as multiplexing reference values computed using the LF EMS approach or reference voltages [26]. One or more of the electrical parameters described earlier in the previous section are frequently taken into account when establishing rules for the FL EMS approach. FL controller is made up of membership functions, which are mathematical models that allow you to describe the ambiguity of everyday language through trial and error.

3. Optimization of Online/ Offline EMS Technique

primarily at achieving optimal resource scheduling [27]. It is based on cutting-edge information technology and can improve the administration of distributed energy sources and storage systems in [28]. The following goals are usually included in a microgrid optimization problem:

- To boost up generators' output power at a certain moment
- To diminish the micro grid's running expenses
- To enhance the lifespan of energy storage device
- To curtail the environmental costs

The findings of optimization off-line EMS approaches can be utilized to train artificial intelligence models like Artificial neural networks (ANN) [30], and Support Vector Machine (SVM) [31]. Once they are online, the Artificial Intelligence can compute the battery and SC's reference values, as well as generalize new variables that were not considered during the training phase. These methods can also be utilized as control interfaces. Techniques such as Neuro-Fuzzy [32], Model predictive control (MPC) [33], and RTA [34] are included in this classification shows an application of the ANN EMS approach to a HESS system with a semiactive topology. The optimization offline technique allows for a considerably more efficient generation of new rules, as well as assigning values to predetermined electric parameters in the Deterministic and FL EMS procedures. Some battery objectives, such as life cycle, efficiency, and output current peaks, are evaluated during the design process to optimize and/or decrease their magnitudes. The load demand profile and the power profile generated by the renewable source are frequently taken into account by offline EMS techniques. So that this scheme is best among the other scheme, which is also easy to implement. Partial Swarm Optimization [29], for example, falls into this category. Linear Programming, Genetic Algorithm, and Dynamic Programming are all terms for much the same thing. The core approach of PSO, LP, GA, and DP when compared to the other controllers, as shown in Table1 and Table2.

Table2: Comparison of Time Domain

EMS Control ➡ / Techniques / Attributes ⬇	Drop voltage & LF	TCS PW & ST	Fuzzy Logic Control	PSO, GA, LP, DP.	ANN MPC SVM Neuro -fuzzy
Implementation complexity	Low	Medium	High	High	High
Consider Degradation of ESS	No	Yes	Yes	Yes	Yes
Power system coordination	No	Yes	Yes	Yes	Yes

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Table2: Comparison of Time Domain

Time Domain ⬇ **Attributes**	**EMS Control Techniques**			
	Without Controll	**PID**	**Fuzzy**	**ANFIS With a Derivative Algorithm**
Delay Time(s)	8	6	4	3.5
Rise Time(s)	0.813	4.21	6.81	0.63
Settling Time(s)	38	27	25	8
Peak Overshoot (%)	32.157	11.8	0.5	0.02
Steady State Error	0.75	0	0	0

V. CONCLUSION

This paper provides a comprehensive overview of recent research into the various energy management strategies for microgrids, including classical, heuristic, and intelligent algorithms. In addition, this paper includes a brief overview of microgrid architecture, distinct microgrid classifications, microgrid components, communication technologies used, standards accessible for implementation, and auxiliary services necessary in the microgrid. The various techniques are compared in Table1 and Table2. based on the time domain, implementation complexity, degradation of the energy storage system, and power system coordination, as well as the reduction of stabilization times, deviations, oscillations, and/or transients. As a result, MG energy management becomes a multi-objective optimization issue with major limitations such as economics, technology, and emissions. Prospects, solutions, and opportunities of the objective functions of the EMS employing efficient strategies are the main topics covered in this review. The strategies are considered to identify global solutions to the system's operations based on their practicability, appropriateness, and tractability. The goals of microgrid energy management are determined by the manner of operation, which can be centralized, decentralized, or distributed, as well as a number of economic limitations and the dynamic nature of dispatchable energy sources.

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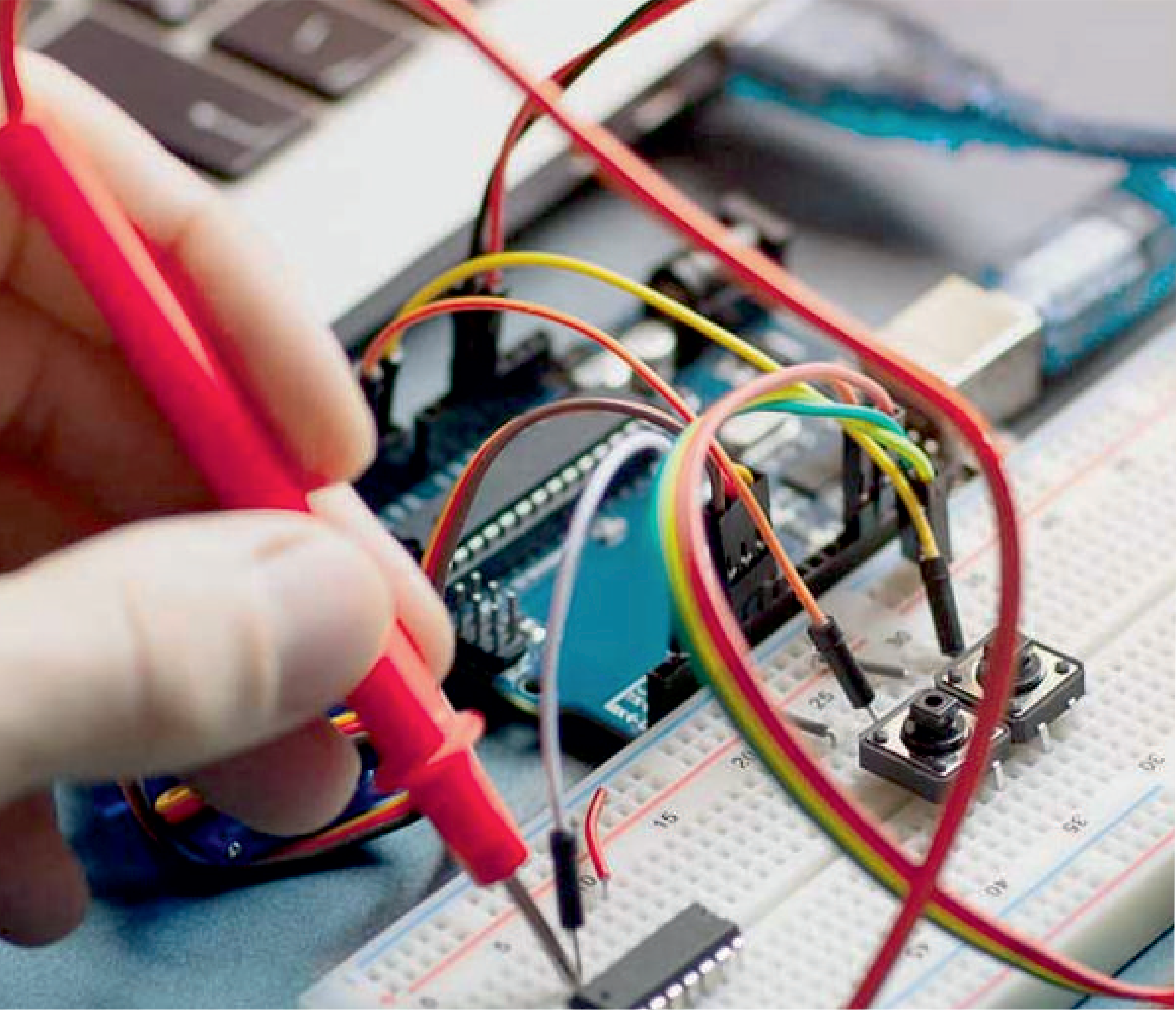

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