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# Reducing the Effect of Geomagnetic Induced Current on Power System Installations using Genetic Algorithm

**Ejimofor Chijioke[1], Eke James[2], Eneh I.I[3]**

PG Student [Power Systems], Dept. of EEE, Enugu State University of Science and Technology, Enugu, Nigeria[1]

Professor, Dept. of EEE, Enugu State University of Science and Technology, Enugu, Nigeria[2]

Professor, Dept. of EEE, Enugu State University of Science and Technology, Enugu, Nigeria[3]

**ABSTRACT**: This work has the singular aim to develop a working model for reducing the effect of geomagnetic induced current on power system installations using genetic algorithm deducible from the developed GIC-transmission line model. Figure 1.1 shows the general description of a sample transmission line and the presence of GIC. In simulating GIC in power systems, derivation of field strength is required. However only field strength of the geoelectric field at injection points approximate is possible to obtain at points such as grounded transformers. Geomagnetic induced current (GIC) is a ground end manifestation associated with the space weather perturbations that should be greatly taken into account by the society. Although the GICs implication to the power system is not regular, it can cause large scale of system failure. In equatorial region, the power system is considered safe since the most intense of geomagnetic storm happened in high latitude. However, the internal damage due to GICs which finally led to the South African power system failure has totally changed the normal perception. Therefore, a preliminary investigation on the GICs activity in equatorial region is performed to understand the space weather impact to the power system. Time derivative of the horizontal magnetic field component (dB/dt) is done to indicate the GICs activity value based on Faraday's law. All the reported power failures are compiled to produce the threshold value of dB/dt, which possibly cause the harmful effect to the system. It has been shown that one can accurately estimate the geoelectric field components (Ex, Ey) from the strength of the geomagnetic field (Bx, By) and knowledge of the local ground conductivity. This is of practical interest since the magnetic field fluctuations are easier to measure than the actual geoelectric field strength. Here x and y is in the horizontal plane of the ground and the x-axis is northward pointing and the y-axis is eastward pointing

**KEYWORDS*:*** Geomagnetic data (GMD) ; Corona mass ejections (CMEs) ;Electric field (E), Geomagnetic induced current (GIC); Magnetic field component (dB/dt), plug setting multiplier (PSM), Over-current relays (OCRs)

## I.INTRODUCTION

The space weather perturbation is believed to affect the ground-based technology system in term of theoretical and experimental approached. The space weather perturbation mentioned above is the geomagnetically induced current (GIC). These GIC flow into the transformer architecture of the bulk power system through the winding where the current in the winding might be increased. More current formed in the winding, more magnetic flux might be generated and the core might be received a partial saturation on the part of the transformer. The partial saturation is believed to damage the working principle of the transformer. The AC waveform might be misinterpreted, the protective relays might be desperation and drives to trip out the power transmission line. More so, affected by that, the stability problem, the voltage drop, also the power blackout moment is possible to occur. Rapidly mentioned the famous event in 1989 which is the Hydro - Quebec power transmission blackout and the society suffered for nine hours without electricity .The stimulation of the bulk power system enhances the consideration of awareness to identify to what extent the GIC can be impactful to the power transmission system. The rate of the change of the total magnetic field (dB/dt) normally used to identify the GIC level at high latitude region . The magnitude of dB/dt (nT/min) exceeding 30 nT was indicated the occurrence of the GIC. The high latitude regions are the one that achieves a high possibility that affected by the GIC event due to the auroral electrojet current as a driving mechanism. Previously, the dB/dt value during Hydro – Quebec power transmission is approximately 479 nT/min. Some of GIC cases, there was produced not only occurring due to the substorm, but the sudden impulse (SI) and the storm sudden commencement (SSC) also encourage the GIC

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to occur. Some information about the dB/dt value are not depending on the substorm as a single caused, but the SI event and the SSC had prepared the evidence that the value of dB/dt can still be high enough to penetrate in the power transmission system. This has been discussed by a great number of authors in literature, they proposed a model on how the ionospheric current penetrates in the lithosphere by applying the concept of Lorentz force. It has been reported that substations situated at the ends and at the corners of long transmission lines are prone to maximum GIC magnitudes. These are the substations which are only connected to one substation on one end and a transmission line on the other end. However, a number of the study was done in a region close to the auroral zone and may not necessarily agree with regions far from the auroral zone. An investigation was done on the Namibian network and reported that south northerly lines appeared to be more susceptible to GICs than the east-westerly lines.The method had been used previously is by determining the time derivative of the horizontal component as conducted to determine the GIC phenomena. Meanwhile, other studies are done by calculation approached. In addition, the on-site measurement that needs an equipment that must be conducted under the transmission line that operated with high voltage also had been used. However, the space weather perturbation that drives GIC during the descending, peak, and ascending phases of the solar cycle is still questionable due to the different mode of solar activity.

Traditionally, transmission lines protection has been done with the aid of relays. From the earliest types which were manually actuated to the present day where highly automated relays are commonly being used in numerous ways. The optimal coordination of primary and backup over-current relays (OCRs) scheme has become one of the main challenges in modern MV-distribution networks (DN) owing to the multi-looped structure and the increased penetration of interment nature-DGs with large-share capacities. The changeable operational topologies of microgrids in modern DN have increased the computational burden to obtain the optimal setting of OCRs. The discrimination time of OCRs scheme may be no longer sufficient or even unmanageable to provide reliable performance in the islanded and grid-connected operational modes. The numerous previously reported optimization techniques employed for OCR coordination may have some limitations/drawbacks regarding OCRs coordination and their framework. Therefore, this study provides a well-defined analytical examination of the limitations in the tripping characteristics of manufactured OCRs. A new constraint taking into consideration maximum plug setting multiplier (PSM) was proposed to improve the optimization techniques. Moreover, enhance the complementary with industrial OCRs tripping characteristics with the optimization techniques in term of coordination time interval.

This work focuses on the transmission aspect of the electrical power value chain and considers primarily the protection of the system during faulty conditions of either overcurrent type or …with the underlying goal of mitigation. When simulating GIC in power systems one needs to approximate field strength of the geoelectric field at injection points, such as grounded transformers. It has been shown that one can accurately estimate the geoelectric field components from the strength of the geomagnetic field and knowledge of the local ground conductivity. This is of practical interest since the magnetic field fluctuations are easier to measure than the actual geoelectric field strength. Here x and y is in the horizontal plane of the ground and the x-axis is northward pointing and the y-axis is eastward pointing. Therefore, this study aims to observe and estimate the value of GIC by designing a GMD detection framework to setup optimization algorithm using evolutionary approach of genetic algorithm (GA).

## II.LITERATURE SURVEY

(Abuhussein et al., 2021)investigate the adverse effect of GICs on power transformers and the impact of the GIC-produced harmonics on transformers' operation. The experiments are carried out via MATLAB/SIMULINK, and the testing considered three primary high-voltage levels, 765 kV, 500 kV, and 230 kV, to verify transformer susceptibility to GICs based on voltage levels. Shell and core types were also considered to screen the effect of the transformer core type on the excitation current and the reactive power demand during a GIC. Finally, this paper analyses the harmonics content and the voltage unbalance in the system during GIC for the listed voltage levels and core types.

The findings of this paper conclude that: 1) high-voltage (HV) and extra-high-voltage (EHV) shell-type transformers are more susceptible to GIC than low-voltage or core-type transformers in terms of the amount of dc current required to saturate them and the quantity of harmonics produced; 2) transformers withdraw more reactive power as the magnitude of the GIC increases; 3) negative-sequence harmonics are the most prominent in the event of GIC; 4) the 2nd harmonic, which is also a negative-sequence harmonic generated by GICs, has the greatest magnitude compared to other harmonic orders, which explains the detrimental effect of GICs Propagating to the delta-side (isolated side) of a transformer; 5) although shell-type transformers are more vulnerable to GIC, core-type transformers during GIC will cause a higher voltage unbalance based on the calculated voltage unbalance factor (VUF).

(Zmnako et al., 2020) deal with study and enhanced understanding of GIC phenomena is the key to advancing the awareness of its effects and behavior on the whole power system. In this review work, we have summarized the chain of GIC events starting from the Sun to the ground technological infrastructures on Earth, and we provided the

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most common techniques to calculate GIC on power systems in separate stages. The presented historical events are clear examples of the impacts and severe GMDs on electrical power systems, and even the flow of even a small GIC value will cause a half-cycle of saturation in a large power transformer. We can note that from this review, the severity of GIC is not limited to power systems in high-latitude countries. Moreover, it can also cause problems in mid-low latitude regions. Additionally, the GIC value is strongly dependent on the network topology, transformer types, geoelectric field orientation and resistances, which have a strong influence on the GIC generated by the geoelectric field. The result is that the GIC value and severity are different from one system to another, even within the same region. In addition, we can note that similar GIC effects can be caused by nuclear detonation at a high altitude above the Earth's surface, which can affect any nearby power systems around the world. Therefore, the severity of GIC is not limited to only solar activity and high-latitude regions. Finally, from the review of GIC blocking devices, we can summarize that these devices have several issues, and they can be costly if great care is not considered. Strongly undesirable issues and costs can be incurred if they are installed without GIC analysis on the power system.

(Farah et al., 2019) enumerate how the threshold of dB/dt has been identified during the reported power system failure due to GIC. The findings in this study deduce that the power network in equatorial region has possibly suffered by GIC since the dB/dt during geomagnetic storm events, exceeded

the threshold value of 51nT/min, especially the region situated near to the magnetic equator (0o MLAT). Furthermore, the analysis on the maximum dB/dt occurrence in this region also reveals that high number of intense GIC activity occurred during dayside. However, the implementation on GIC measurement at transformer is very important to identify the real value of the current flow in the ground technological systems that are associated with space weather effects. From the GIC measurement, it will also justify the induced current value that can pose the technical

problem in the power system. Since the GIC value is not solely dependent on the space weather effect, this site experiment can access other possible factors that contribute the intense equatorial GIC, such as the subsurface conductivity and the design of the power network topology.

(Yiqiu et al., 2018) studied the impact of GIC on power system grids. It makes the claim that the impacts of GICs on steady state voltage stability are now well-known. However, less is known about the impacts of GICs on power system transient stability, especially in the presence of contingencies. It proposed and applied a different metric to investigate the impacts of GMDs on power system transient stability by applying different single element contingencies to a 10k-bus synthetic network in the presence of time-invariant GMDs. Several case studies are presented as examples of the potential effects of GMDs. The results show that GMDs can alter power system transient margin. Therefore, relevant transient stability studies may need to be conducted to ensure secure power system operations under the effect of GMDs. The claim of static or time invariant GMD used here is also called into question considering the true nature of the GMD phenomena which is time varying. Improved models capturing this variability will therefore play a better role at making the aforementioned analysis more robust.

(Greg et al., 2017)emphasized the need for more realistic models of the earth impedance for studies of induced voltages from geomagnetic events. To this end, 3D impedance models were advised as against the easier but less realistic 1D impedance models. Empirical data used here confirmed the suitability of 3D data utilization over 1D data with 3-Dimpedances producing substantially more spatial variance in the calculated voltages, with recorded voltages being an order of magnitude different, both higher and lower, than the voltages calculated utilizing regional 1-D impedances. Case in point was the March 1989 geomagnetic storm, during which 62 transmission lines exceeded 100 V when utilizing empirical 3-D impedances, whereas 16 transmission lines exceeded 100 V when utilizing regional 1-D impedances. This demonstrated the importance of using realistic impedances to understand and quantify the impact that a geomagnetic storm has on power grids. However, a number of issues remain to be explored, such as, whether significant local differences get spatially smoothed when an integration along a power transmission line is performed to calculate the voltage across the transmission line. Long electric power transmission lines can pass over significant variations in Earth’s electrical conductivity structure, which requires the use of multiple different impedance tensors to model the spatial variations in geoelectric fields near the surface of the Earth.

In all, my research is based on using the intelligent technique of GA to reduce the effect of GIC in power system installations, which introduces the randomness into the proposed model to overcome the problem of data overfilling, enhanced modelling and optimization, handles stochastic nature of the GIC system. It is difficult to have a structured mathematical formulation of GIC detector framework, hence GA models it.

Finally, GA was used in GIC detection framework because space weather perturbation is stochastic, undeterministic, random and noisy. Thus my research is based on designing a GIC-GA detection framework that detects GIC event and isolates the power system network. The GIC model will be embedded in the software configuration of power system network to detect, prevent and isolate power equipment like high power system transformers from GIC event.

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## III.PROPOSED MEHODOLOGY AND DISCUSSION

Fundamentally, the GIC phenomena is an electromagnetic phenomena. Therefore, it is guided by Maxwell's laws which have previously been discussed in section 2 and recalled here also.

$$\nabla . E = \frac{\rho}{\varepsilon_0} \tag{3.0}$$

$$\nabla . B = 0 \tag{3.1}$$

$$\nabla x E = -\partial B / \partial t \tag{3.2}$$

$$\nabla x B = \mu_0 j + \mu_0 \varepsilon_0 \, \partial E / \partial t \tag{3.3}$$

Where $\nabla .$ and $\nabla x$ represents the div and curl of the electric and magnetic fields respectively.
In the form (3.0)-(3.3), Maxwell's equations are (microscopically) always valid. However, charges and currents are macroscopically usually divided into different types, and additional fields are introduced. The electric D field is related to E and the magnetic H field is related to B by constitutive equations, which are usually assumed to be linear and simple as follows

$$D = \varepsilon_0 E \tag{3.4}$$

$$H = B / \mu_0 \tag{3.5}$$

where μ and ε are the permeability and permittivity of the medium. The usual assumption in connection with geo-electromagnetic studies is that $\mu = \mu 0$. Macroscopically, we can write Maxwell's equations similarly to (1)-(4) but μ0 and ε0 are replaced by μ and ε, and the charge density ρ = ρfree and the current density j = jfree should only refer to charges moving freely in the medium. An additional constitutive equation needed in the geophysical part is the Ohm's law that relates jfree and E

$$j_{free} = \sigma E \tag{3.6}$$

where σ is the conductivity of the medium. What is still required for solving the geophysical part are the continuity conditions that enable moving from one medium to another. Usually we utilize the continuity of the tangential components of the E and H fields when moving across a boundary (Pirjola., 2012).
The GIC is usually computed from the electric and magnetic field data using the formulas

$$E_x(w) = \frac{Z(w) B_y(w)}{\mu_0}, \tag{3.7}$$

$$E_x(w) = \frac{Z(w) B_y(w)}{\mu_0}, \tag{3.8}$$

$$\frac{dB}{dt} = \left( \left( \frac{dBx}{dt} \right)^2 + \left( \frac{dBy}{dt} \right)^2 \right)^{1/2} \tag{3.9}$$

The resulting GIC has been calculated as a function of the various electric field components by the formula

$$GIC = aEx(t) + bEy(t) + \varepsilon(t) \tag{3.10}$$

In an alternative approach, if only local GIC flowing through, for example, individual node of power transmission system is needed, in this instance, application can be made of a simple linear relation where the noise term ε(t) is ignored

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$$GIC = aEx + bEy \tag{3.11}$$

where (Ex, Ey) are the horizontal components of the geoelectric field and (a, b) the system parameters. (a, b) that depend on the topology and electrical characteristics of the conductor system under investigation can be derived for individual locations by using information about the full conductor system or by inverting the parameters from GIC and ground magnetic field observations. The linear relation in Eq. (3.11) has been shown in numerous studies to hold to a good approximation in many situations of interest. The typical values for (a, b) are in the range between 0-200 A·km/V. The driver of GIC is the geoelectric field (the electric field at the surface of the earth) integrated along the length of each transmission line which can be represented by a dc voltage source:

$$V_{dc} = \oint \vec{E}\vec{dl} \tag{3.12}$$

Where E is the geoelectric field induced as a result of the GIC and dl is the transmission line segment under consideration. Finally Vdc completes the definition as the induced voltage in the transmission line. The electric field E will be considered the resolved field given by

$$E = \sqrt{\left(E_x^2 + E_y^2\right)} \text{ = Cost function} \tag{3.13}$$

## IV.EXPERIMENTAL RESULTS WITH TABLES/FIGURES

The GIC expression which is used for computation is made possible by utilizing the measured magnetic field data from the Center for Atmospheric Research (CAR) NASRDA, Abuja magnetometer station. The resulting electric field values were also computed in the axes of the earth's plane (Ex and Ey) for this and stored accordingly in an excel file .Some of the obtainedresults are presented in this section.

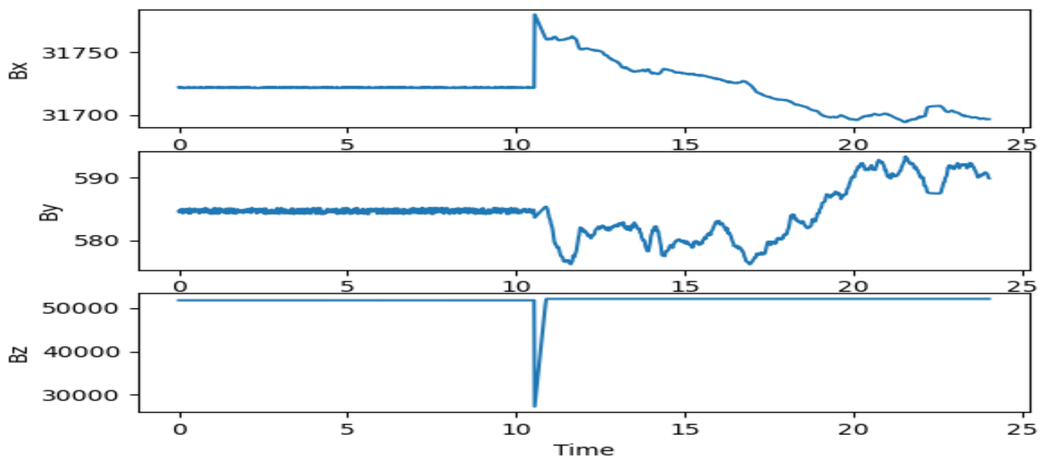


Figure 3.1 Plot of Bx,By,and Bz with respect to time

The next set of results show the changes in the magnetic field with time or magnetic field derivative

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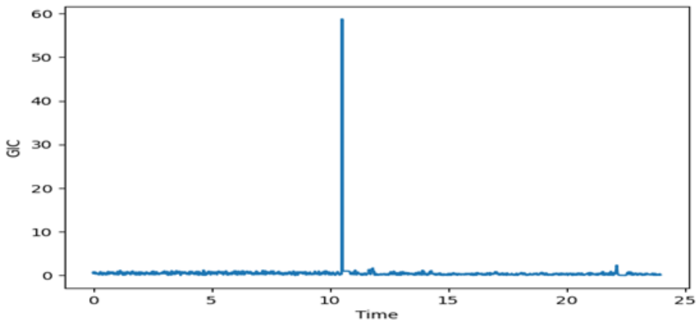


Figure 3.2 Plot of GIC with respect to time

Finally the first GIC computation showing the induced currents as a function of the changes in magnetic field is given in Figure 3.2 above. Using the electric field equations for GIC computation, the following plots were obtained with the parameter set given in table 1 below:

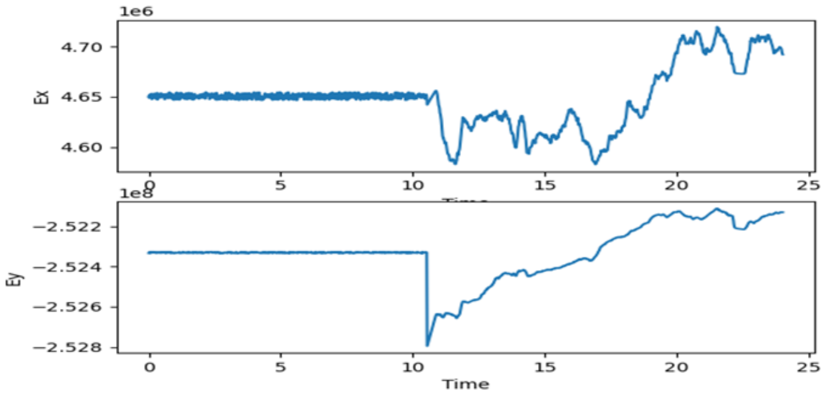


Figure 3.3 Shows electric field component in the earth's plane as a function of time

Table 3.1 Plot parameters

| s/n | Z_im | a | B | Gaussian noise |
|---|---|---|---|---|
| 1 | 0.01 | 0.5 | 0.717 | 0.00987564 |

Figure 3.3 renders the Electric field component in the earth's plane as a function of time. The resulting GIC which was computed from the electric field values and using the parameters in table 3.1 is shown in figure 3.4 below. ComputationGIC result from the electric field obtained from the cost function

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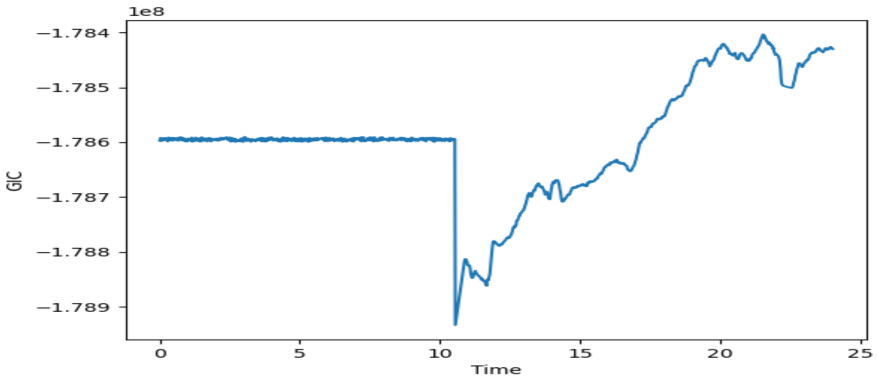


Figure 3.4. GIC plot from the conditioned electric field components

## V.RESULT AND DISCUSSION

The need to mitigate the impact of the GIC currents on the transmission system demands that a metric be available for decision making by the controllers in the power system network. The GIC has been resolved into the DC component of the induced geoelectric fields E, this parameter can be correctly used to measure the magnitude of the GIC on the power system. Overall, the aim will be to minimize this parameter within the framework of an optimization problem. To frame this minimization problem, the following assumptions/facts are employed;

- Minimize Vdc subject to the magnitude of electric field E, being less than an acceptable threshold ρ, which is to be defined by the power system controller.
- This threshold is defined by the acceptable range of values that can be assumed by the equation:

$$E = \sqrt{\left(E_x^2 + E_y^2\right)}$$

## VI.CONCLUSION

The main aim of this section is to generate a model that can harness the threshold GIC value obtained from the cost function equation (see equation 3.13) which I call GA optimizer. Thus designing a GIC detection framework with GA optimization algorithm becomes vital and as my topic shows. In order to model with the nonlinear model, the data set was also divided into 3. The first part was used to train the data; the second part was used as a test data while the last set of data was used to validate the model. Genetic Algorithm was able to successfully identify a model that fitted the given data with relative efficiency and robustness solely because it can uniquely search for the ideal and globally optimal solution fairly accurately from a host of candidate solution. The main work here is formulating an optimization problem having the working model as the objective function to be minimizes subject to constrains.

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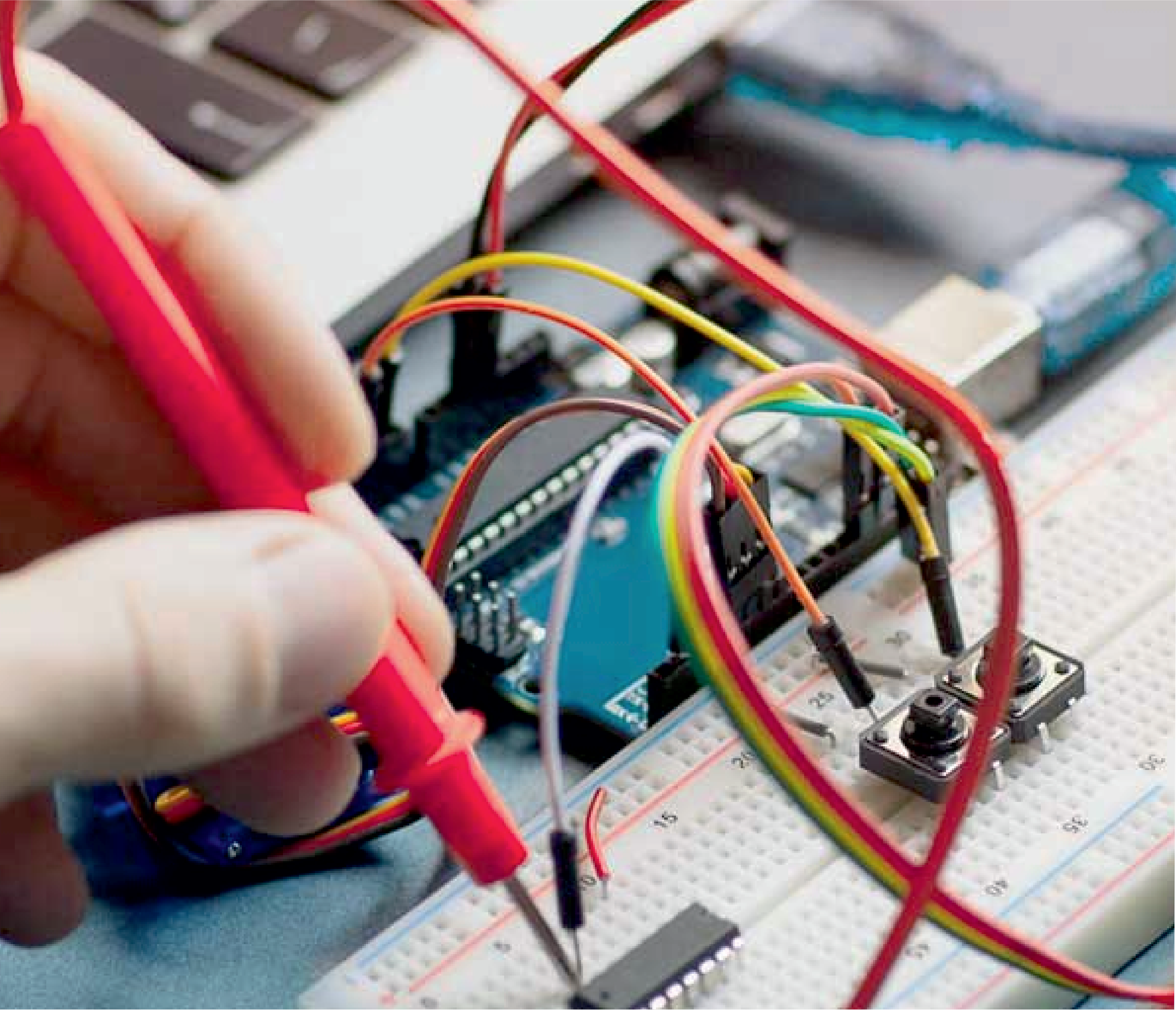

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