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Dynamic Voltage Restores Using Renewable Energy

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Abstract: This work proposes a kind of voltage insertion into the grid through a dynamic voltage restorer (DVR) to compensate sagged and distorted voltage applied to sensitive load. The control to dynamically restore voltages applied to sensitive loads generates only voltage with the elemental frequency. The proposed method has the advantage of generates an easy waveform to compensate only the sag, this enables a extended battery lifetime of the DVR. As a consequence, restoration of the fundamental voltage, besides recomposing it to its nominal value, also attenuates the extent of THD within the load. Thus, this method also improves the facility quality of the system. A recursive least-squares is included to the system to estimate the harmonic components that compose the distorted voltage to be restored, instead of using filtering on the waveform.
In addition, the RLS doesn't contain delays, common to filters, which improves the performance of the system used. it's important to spotlight these harmonic components are not compensated by the restorer device. Their estimation has the function of reconstituting the distorted voltage digitally in the DSP. Simulation and experimental results are presented.

I. INTRODUCTION

ALthough the electrical power transmission and distribution systems have achieved a high level of reliability, electrical disturbances can't be entirely avoided. Some loadsmay not withstand disturbances in their voltage supply dueto economic or safety constraints, then the standard of suchelectrical power is of paramount importance.

In the scope of electricity quality, among the disturbancesthat affect the standard of electrical energy, thoseassociated with short-term duration are theforemost frequent inenergy systems. The impact of voltage disturbances in nationaleconomies, several surveyon costs that were administered bydifferent entities during last years. Among all disturbances,voltage sags have the very best occurrence frequency [1].
Another important disturbance within the quality of electricalenergy is that the incidence of harmonics on power grid componentsand loads. Harmonics are produced by nonlinearequipment, like discharge furnaces, variable speed drivesand loads which use power electronics. Harmonics can causedefects in computer-controlled loads, transformer overheatingand failed capacitor among other problems [2]. the assemblyof pulsating torques and overheating in rotating machinery
cans also are attributed to harmonics [3].

Among some alternatives made to make sure the standard ofpower supply for the load, the DVR has proven efficientand profitable [4], [5]. This equipment protects critical loadsagainst mains voltage disturbances by imposing, throughtransformers serial with the load, compensation voltagelevels such the load is protected and maintains sinusoidalvoltages with constant frequency.

The primary function of a dynamic transformer is toprotect critical loads from voltage sags and swells [6], [7].However, these systems have their performance compromisedin the presence of voltages with harmonic distortions [8], [9].Then, DVR applications were developed to mitigate the consequencesof harmonic distortions and voltage sags [10]–[12]. However,harmonic distortions are a permanent regime problem. In thisway, the DVR shouldn't correct them as this is able to even beacting permanently, reducing the battery life.

This paper discusses the utilization of the harmonic estimationtechnique to estimate the elemental and harmonics in systemswith voltage sags and harmonic distortions and performsonly the restoration on the elemental component of thedistorted voltage. For this, it's necessary to continuouslymonitor the signals of the

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facility system and ensure fast andaccurate responses to signal amplitude and phase. From thisonline estimate, the control will act to correct only the voltagesag and, thus, ensure a extended battery life for the DVR.

II. ESTIMATION OF THE GRID VOLTAGE WITH HARMONIC DISTORTION

In this section, an algorithm to calculate amplitude and phase of distorted AC voltage is described. the elemental component:

$$v(t) = V_{p1}\cos(\omega_1 t + \phi_1) \tag{1}$$

can be estimated by:

$$v(t) = X_1^c \cos(\omega t) + X_1^s \sin(\omega t) \tag{2}$$

or

$$v(t) = \begin{bmatrix}\cos(\omega t) & \sin(\omega t)\end{bmatrix}\begin{bmatrix}X_1^c \\ X_1^s\end{bmatrix} \tag{3}$$

$$v(t) = \varphi\theta \tag{4}$$

where X_1 are the amplitudes to be estimated. In this representation, the amplitudes are functions of V_p and ϕ and described as:

$$X_1^c = V_{p1}\cos\phi_1 \tag{5}$$

$$X_1^s = -V_{p1}\sin\phi_1. \tag{6}$$

Equations (5) and (6) are linear with respect to $v(t)$. Thus, a linear estimation algorithm can be used. In this work, is used a weighted recursive least-squares (RLS) algorithm, where X_m^c and X_m^s relates to the parameters V_p and ϕ by:

$$V_{p1} = \sqrt{(X_1^c)^2 + (X_1^s)^2} \tag{7}$$

$$\phi_1 = -\arctan(X_1^s / X_1^c). \tag{8}$$

For multiple harmonics, the voltage $v(t)$ can be written as follows:

$$v(t) = V_{p1}\cos(\omega_1 t + \phi_1) + V_{p2}\cos(\omega_2 t + \phi_2) + V_{p3}\cos(\omega_3 t + \phi_3) + ... + V_{pn}\cos(\omega_n t + \phi_n) \tag{9}$$

in which *Vpn* is the amplitude of the *nth*-harmonic and *φn* is the phase-angle.

The matrices φ and θ must be expanded to the form:

$$\varphi = \begin{bmatrix}\cos(\omega_1 t_1) & \sin(\omega_1 t_1) & \dots & \cos(\omega_n t_1) & \sin(\omega_n t_1) \\ \cos(\omega_1 t_2) & \sin(\omega_1 t_2) & \dots & \cos(\omega_n t_2) & \sin(\omega_n t_2) \\ \vdots & \vdots & \vdots & \vdots & \vdots\end{bmatrix} \tag{10}$$

and

$$\theta = \begin{bmatrix}X_1^c & X_1^s & X_2^c & X_2^s & \dots & X_k^c & X_k^s\end{bmatrix}^T \tag{11}$$

$$e[n] = v[n] - \widehat{v}[n]. \tag{12}$$

The use of the RLS algorithm allows the estimation of the parameters in (11). Thus, the amplitudes and phases of the voltage components are often determined by (7) and(8) respectively. during this way, the worth of the voltage visestimated. For each instant tn, a mistake of the estimated signal are oftencalculated by:

$$\widehat{\theta}_n = \widehat{\theta}_{n-1} + \mathbf{P}_n \varphi e[n], \qquad (13)$$

The required parameter θ can be estimated by the following equation:

$$\mathbf{P}_n = \mathbf{P}_{n-1} - \frac{\mathbf{P}_{n-1}\varphi\varphi^T\mathbf{P}_{n-1}}{1+\varphi^T\mathbf{P}_{n-1}\varphi}. \qquad (14)$$

and P*n* is the covariance matrix to be updated by:

$$v(t) = v_{pcc}(t) - Ri(t) - L\frac{d}{dt}i(t) + u(t). \qquad (15)$$

These equations are initialized by taking some initial valuesfor the estimate at instants n, v(n) and Pn . The covariancematriz Pn is typically initialized by Pn = αI, where α may be alarge number and that i is that the unit matrix .

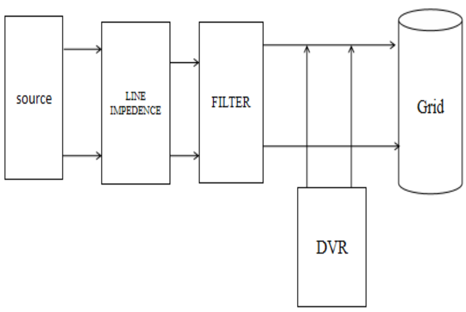
The RLS algorithm loop consists of solve the equations (12),(13) and (14). The RLS has the advantage doesn't containdelays, common to filters, which improves the performance ofthe system used.

III. MODEL AND STYLE OF THE DVR SYSTEM

The architecture of the system is shown in Fig.1. this is often an single-phase equivalent circuit to electrical grid compensation scheme to sensitive load. The DVR is found between the grid and therefore the sensitive equipment. The DVR consists of a DCAC converter supported IGBTs, an influence storage system, LCfilters and a transformer to inject the voltage at the output of the DVR. The grid voltage, vpcc, is applied on the purpose of common coupling (PCC). the present i provides the sensitive load. The DVR voltage is u and v is that the load voltage. The parameters related to the coupling transform are the resistance R and inductance L. the info acquisition and control system is additionally shown in Fig.1.

The system consists of a sensor to live the load voltage,

a measured voltage estimation block, another to calculate the reference voltage for the controller and therefore the controller block.The control action is shipped to the inverter.



BLOCK DIAGRAM

IV. DVR VOLTAGE INJECTION METHOD

This work proposes a way to compensate voltage sagsin systems with harmonic distortion. the tactic consistsof maintaining the pre-sag voltage level by injecting onlyvoltage with the elemental frequency (16). As a result, theDVR compensates sags and reduces the harmonic distortionlevel at the elemental frequency f0 .
To maintain the amplitude of the reference voltage, vref
pcc ,the DVR must know the amplitude of the sagged voltage, vf0 .However, the voltage may be a distorted sagged signal described asfollows:
The amplitude of the distorted signal are going to be the sum ofthe values of every harmonic component. With this, is feasibleobtain the amplitude of the elemental component of thesagged signal, vf0 , and thus calculate the voltage (18) thatmust be injected by the DVR.
The voltage phase injected by the DVR must be an equivalentas the fundamental component of the grid voltage and isestimated using the RLS algorithm proposed. during this way, thevoltage injected by the DVR and therefore the grid voltage need to besynchronized. To synchronize the voltages it's necessary toestimate a phase of the load voltageillustrates an example of the amplitude determination(18) injected by the DVR. Example of voltage sag with harmonic distortion.
This method of voltage injection only compensate the
sagged voltage in distorted voltage systems, these harmoniccomponents aren't compensated by the restorer device. Then,the proposed method has the advantage of generates an easywaveform to compensate only the sag, this enables a extendedbattery lifetime of the DVR. As a consequence, restoration of thefundamental voltage, besides recomposing it to its nominalvalue, also attenuates the extent of THD within the load. Thesestatements are validated within the next sections.

V. SIMULATION RESULTS

The simulations results discussed during this paper are carriedout through a Simulink platform. A load voltage compensationsystem was simulated and therefore the grid voltage used was that ofFig. 2. this is often a voltage sag with harmonic distortion. Thisvoltage contains the odd harmonic components until the 13thand is taken into account the standard voltage within the phase. it's wont toanalyze the performance of proposed compensation methods.The scenario tested may be a voltage sag with harmonic distortions in one among the phases. The sag of 40% starts at 20 msand ends at 80 ms. As shown within the Fig. 3, the load voltage iscompensated and fewer distorted than the pre-sag voltage. TheTHD of the pre-sag voltage is 33% and at the instant of theDVR operation is reduced to 17%. Thus the DVR restored thedip voltage and improved the standard of the waveform. Thefundamental component of the voltage was restored and as aconsequence the THD was reduced.
Then, the proposed method was compared with other compensation method for systems with harmonic distortion andvoltage sag. within the method described by [11], [12], the DVRcompensates the sag and mitigate all the consequences of harmonicdistortion. The compensation of all distortion effects requires moreactive power than that utilized in the tactic proposed during thispaper. additionally to the very fact that harmonic distortions arepermanent regime problems and would require the continualoperation of the equipment, which isn't capable the DVRas the dc-bus is supplied by batteries that only withstand shortduration voltage variations.

the comparison of the active DVR powers used in the [11],[12] method, P2, and the method proposed in this paper, P1.The curves ofthat during fault, in the method proposed isused a lower active power to compensate the voltagesagged satisfactorily.

VI. EXPERIMENTAL RESULTS

The experimental platform shown in Fig.6 was wont toverify the simulation results and to validate the compensationmethod proposed during this work. The DVR setup consists oftransformers, LC filters, inverters and a digital signal controller. the most device of the setup may be a four-leg DC-ACSemikron power converter supported IGBTs controlled bythe digital signal controller (DSC) TMS320F28335. The dataacquisition system consists of Hall effect voltage sensors. Alltests were performed in banks of power resistors.A sag voltage generator was wont to produce sag andharmonic distortion to be regulated by the DVR controlsystem. the experimental grid voltage on theoscilloscope screen. an equivalent scenario of the simulation isverified, the reference voltage is about to 380 V and a sag of40% is produced in one among the phases. This grid voltage isconsidered the standard sagged voltage wont to analyze theperformance of proposed compensation methods.

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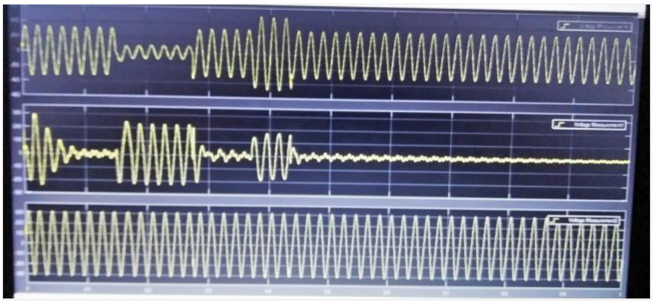
This is acritical scenario because it contains two different power qualityproblems.the grid voltage sagged,the voltage injectedby the DVR and therefore the load voltage. The controlled curve showsthat the rated value is achieved from the restoration only ofthe fundamental component.

As the voltage sag compensation is merely performed withthe fundamental component, as shown in Fig. 9(a), the loadvoltage becomes less distorted,addition to injecting an easy sinusoidal signal, THD is additionallyreduced and therefore the load voltage quality is improved.



OUTPUT WAVEFORM

The action of the DVR mitigates the interferences ofthe harmonics, during this way the grid voltage is restored to asinusoidal form. Thus, the proposed method had an efficientresponse and was validated.

The reference voltage level was maintained at theload and only the elemental component was preserved. Theresult of DVR action, seen in Fig. 11(a), shows that to wipesoff the harmonic components of the load voltage it's necessaryto inject a voltage with a non-sinusoidal shape.

VII. CONCLUSIONS

This paper proposes a voltage injection method for theDVR and therefore the use of the recursive least-squares technique.The proposed method is in a position to mitigate the voltage sags insystems with harmonic distortion from the grid by injectingonly voltage with the elemental frequency. This developedmethod corrects sags with less active power than the tacticused for compensating entire distortion effect. the utilization of themethod described during this work still improves the THD ofthe signal compared to the pre-sag condition. simulations andexperiments including these distortions were wont to verify theproposed system. The result shows the efficiency of the DVRto mitigate voltage sag in systems with harmonic distortion.

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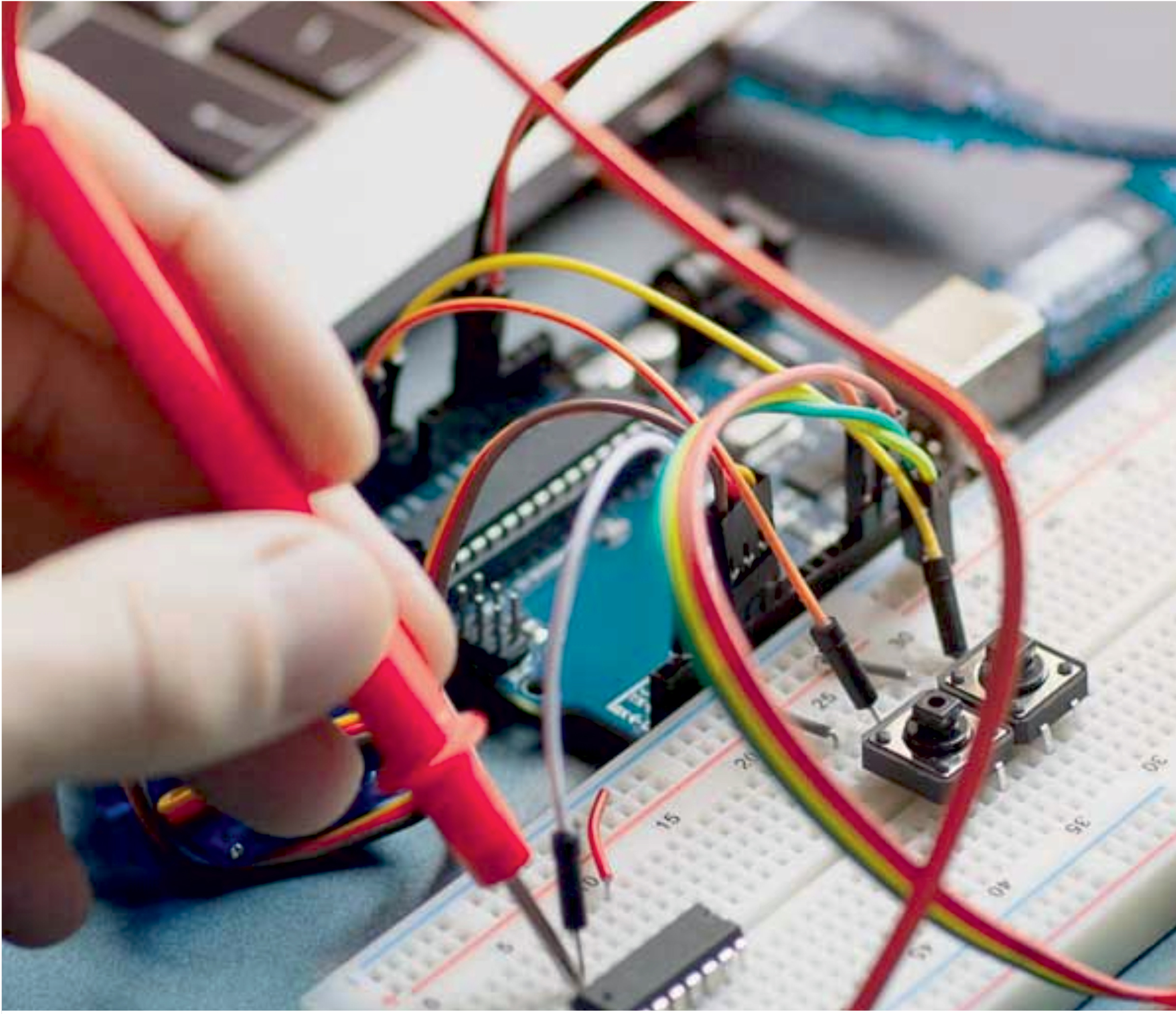

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