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Mitigation of Voltage Sag and Swell Using PWM Based Autotransformer in Power System

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ABSTRACT: This paper proposes a novel distribution-level voltage control scheme that can compensate voltage sag and swell conditions in three-phase power systems. The proposed scheme employs a Pulse width modulation switched auto transformer voltage sag compensator based on an ac-ac converter. During a disturbance like voltage sag, this proposed scheme supplies the missing voltage and helps in maintaining the rated voltage at the terminals of the critical load. Voltage sag is literally one of power quality problem and it become severe to industrial customers. Voltage sag can cause miss operation to several sensitive electronic equipment's. The proposed method performs typical functions and has advantages such as power factor correction, voltage sag and swell elimination, voltage flicker reduction and protection capability in fault situations. In addition, it has other benefits such as light weight, low volume and elimination of hazardous liquid dielectrics. This paper presents modeling and analysis of PWM switched autotransformer that can compensate during voltage sag and swell conditions. The proposed system has less number of switching devices and has good compensating capability in comparison to commonly used compensators. Simulation analysis of three-phase compensator is performed in MATLAB/SIMULINK and performance analysis of the system is presented for various levels of sag and swell.

KEYWORDS: Power Quality, Voltage Sag, switched auto transformer, voltage swell, Pulse Width Modulation (PWM),

I. INTRODUCTION

The electric power technique is considered to be composed of three functional blocks generation, transmission and distribution and reliable power system, the generation unit must produce adequate power to meet customer's demand, the transmission systems must transport bulk power over long distances without overloading must deliver electric power to each customer's premises from bulk power. The distribution system locates the end of power system and is connected to the customer directly, so the power quality mainly depends on distribution. power quality issues have become an increasing concern. Poor distribution power quality results in power disruption for the user and huge economical losses due to the interruption of production processes Many power quality surveys have been done, which show that voltage sags have been identified as the most serious power quality problem facing industrial customers today. Voltage sag is a momentary decrease of the voltage RMS value with the duration of half a cycle up to many cycles. Voltage sags are given a great deal of attention because of the wide usage of voltage-sensitive loads such as adjustable speed drives (ASD), process control equipment, and computers. Sag can cause serious problem to sensitive loads that use voltage-sensitive components such as adjustable speed drives, process control equipment, and computers In order to increase the reliability of a power distribution system, many methods of solving power quality problems, especially voltage sag, have been suggested. Existing methods of voltage sag mitigation using gate turn-off switches for pulse width modulation (PWM) need at least two switches per phase. In an effort to achieve the advantages of a fast response time, but at a significantly lower cost, the PWM switched autotransformer is proposed here. The proposed system has only one PWM switch per phase with no energy storage, which is a very low cost solution for voltage sag mitigation. Any power electronic switch for a high voltage application is expensive, and the peripheral circuits such as gate drivers and power supplies are even more expensive than the device itself. The overall cost of power electronics-based equipment is nearly linearly dependent on the overall number of switches in the circuit topology. Hence, this paper suggests a scheme that uses only one PWM switch with no energy storage.

One of the most popular topologies for voltage-sag compensators is the dynamic voltage restorer (DVR), which requires a voltage-source inverter (VSI) for the line-injection of series voltage, an injection transformer, and a dc link. Main disadvantages of this topology is its inability to compensate long-duration voltage sags, requires more energy storage devices, thereby increasing cost.

A new mitigation device for voltage sag is proposed in [1] using PWM-switched autotransformer. The performance of the compensator for various sag conditions is presented. This paper presents mitigating device for voltage sags/swells disturbances using PWM-switched autotransformer. Here the control circuit based on RMS voltage is used to identify the sag and swell disturbances. This compensator has less switching devices and hence reduced gate drive circuit size, but has the capability to supply the required undistorted load voltage and currents. It has only one switching device per phase and no energy storage device. Simulation of the compensator is performed using MATLAB/SIMULINK and performance results are presented.

II. PROPOSED SYSTEM CONFIGURATION

The proposed device for mitigation of voltage sag and swell in the system consists of an AC-AC PWM switched power electronic device connected to an autotransformer in series with the load.

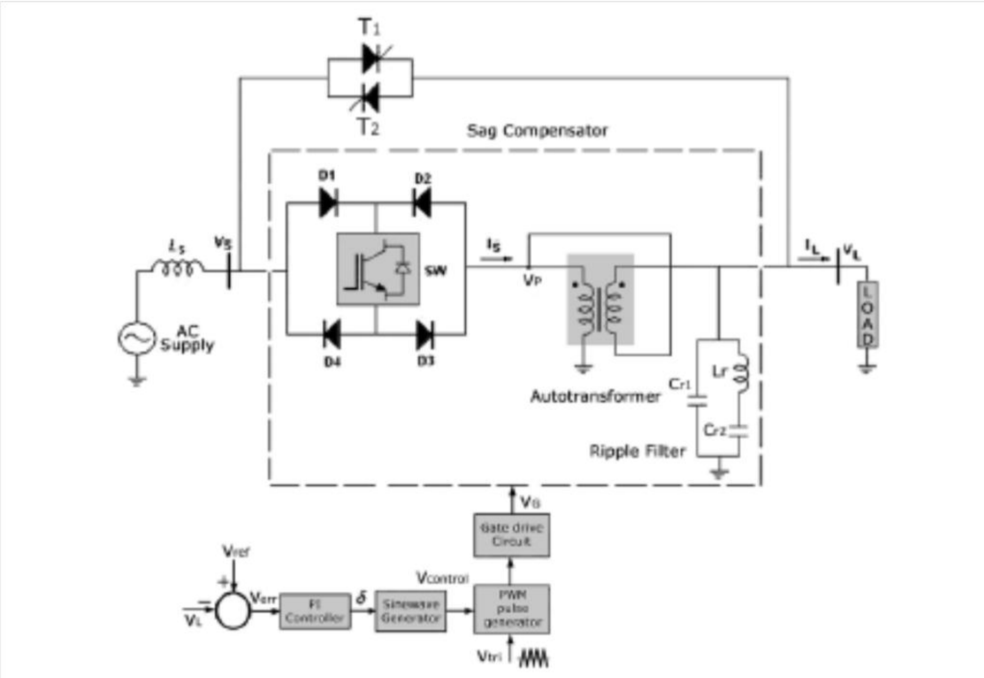

Fig.1. Voltage sag mitigating device with PWM switched auto-transformer

Fig.1 shows the single phase circuit configuration of the mitigating device and the control circuit logic used in the system. It consists of a single PWM insulated gate bipolar transistor (IGBT) switch in a bridge configuration, a bypass switch, an autotransformer, and voltage controller. The auto transformer is controlled by a PWM operated power electronic switch. The single-phase diagram of a power system network with a PWM switched auto transformer used for voltage sag mitigation is shown in Fig. 1. The circuit contains the following components-

• **An IGBT Switch:** This switch is operated based on the pulses generated by the PWM generator and controls the auto transformer operation.

• **Auto-Transformer:** It is used to boost the voltage so that the load voltage remains constant irrespective of the variations in the supply voltage. It is controlled by the IGBT switch.

• **Ripple Filter:** The output voltage given by the auto-transformer contains harmonics along with the fundamental component. Thus, these harmonics should be filtered out to maintain the THD for the given system voltage at the load should be within the IEEE standard norms. Therefore, a ripple filter is used at the output of the auto-transformer.

• **Bypass Switch:** There is a bypass switch made of SCR's connected in antiparallel. This switch is used to bypass the auto-transformer during the normal operation. During voltage sag condition, this switch remains off and autotransformer operates.

Principle of control Strategy operation

To maintain the load voltage constant an IGBT is used as power electronic device to inject the error voltage into the line. Four power diodes (D1 to D4) connected to IGBT switch (SW) controls the direction of power flow and connected in ac voltage controller configuration with a suitable control circuit maintains constant rms load voltage. In this scheme sinusoidal PWM pulse technique is used. RMS value of the load voltage V_L is calculated and compared with the reference rms voltage V_{ref}. During normal condition the power flow is through the anti parallel thyristors. Output filters containing a main capacitor filter and a notch filter are used at the output side to filter out the switching noise and reduce harmonics. During this normal condition, $V_L = V_{ref}$ and the error voltage V_{err} is zero. The gate pulses are blocked to IGBT. The main aim of the control strategy is to control the pulses generated to the IGBT switch such that the auto-transformer generates desired voltage to mitigate the voltage sag. The RMS value of the load voltage is compared with a reference value (Vref). Under normal operating conditions there is no error and no pulses are generated to the IGBT switch and auto-transformer do not work. When there is voltage sag then an error occurs and based on the error value PWM generator generates pulses to the IGBT switch. Accordingly, the auto-transformer operates and the load voltage is maintained constant [7]. The block diagram of the control Strategy is shown in Fig. 2.

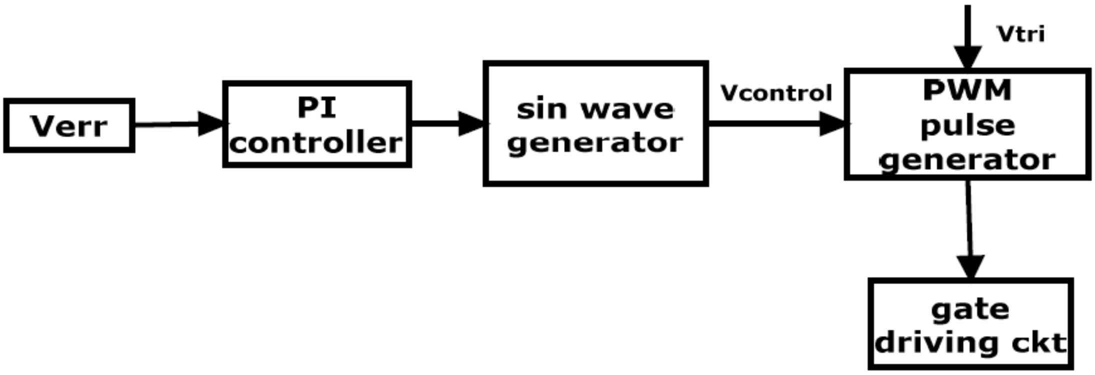

Fig.2. Block Diagram of Control Circuit

The voltage error is passed through a PI controller and it generates a phase angle δ.With this phase angle a control voltage is generated [7] using sine wave generator by using equation.

$$V_{control} = m_a \sin(\omega t + \delta)$$

Where m_a is the modulation index

The magnitude of the control voltage is dependent on the phase angle δ. The phase angle is proportional to the degree of disturbance [7]. Here the voltage which has been generated called control voltage is compared with the triangular voltage V_{tri} for the causeto generate the pulses which can be fed to the IGBT switch. In this way the autotransformer is controlled to mitigate the voltage sag.

VOLTAGE SAG COMPENSATION

The ac converter methodology is employed for realizing the voltage sag compensator. This paper considers the voltage mitigation scheme that use only one shunt type PWM switch for output voltage control as shown in Fig. The autotransformer shown in Fig. is used in the proposed system to boost the input voltage instead of a two winding transformer. Switch IGBT is on the primary side of the autotransformer. Realizing the voltage sag compensator. This paper considers the voltage mitigation scheme that use only one shunt type PWM switch for output voltage control as shown in Fig. The autotransformer shown in Fig. is used in the proposed system to boost the input voltage instead of a two winding transformer. Switch IGBT is on the primary side of the autotransformer.

$$\frac{V_L}{V_P} = \alpha = \frac{I_S}{I_L} = \frac{N_1 + N_2}{N_1}$$

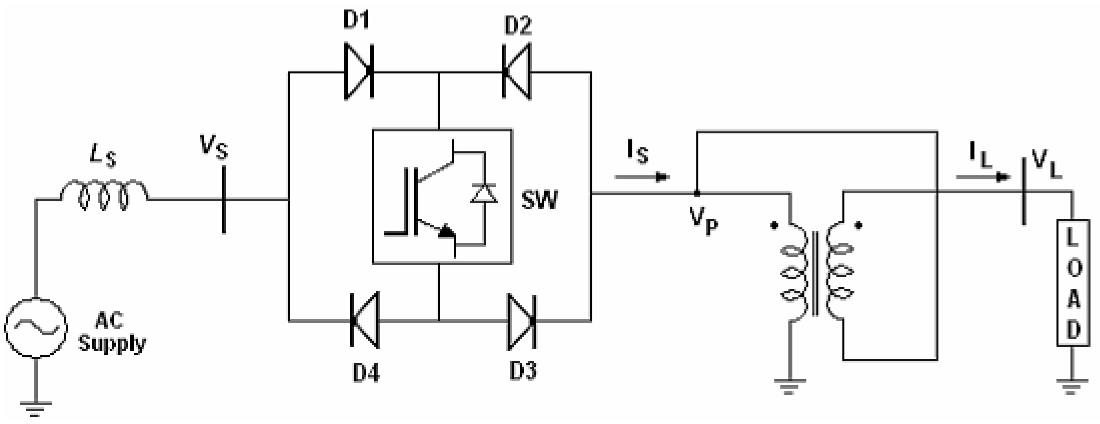

Fig2. Voltage sag/sell mitigating device

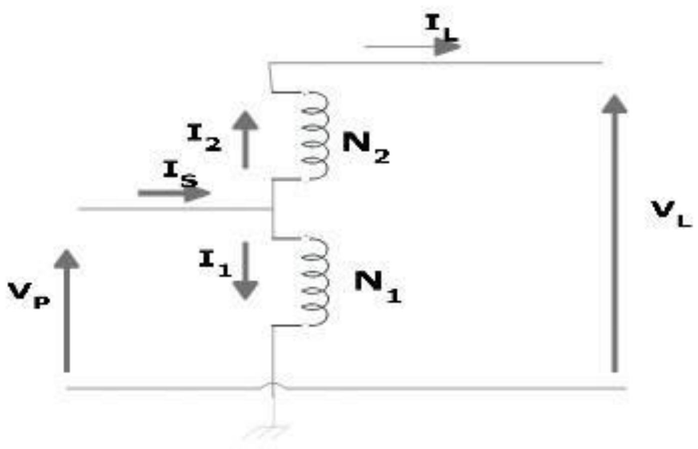

Fig3.Voltage and current relations in an autotransformer

The autotransformer in Fig. 3 does not offer electrical isolation between primary side and secondary side but has advantages of high efficiency with small volume. An transformer with N_1 : N_2 = 1 : 1 ratio is used as an autotransformer to boost the voltage on the load side when sag is detected. With this the device can mitigate up to 50% voltage sag during the sag period. As the turns ratio equals 1:2 in autotransformer mode, the magnitude of the load current I_L (high voltage side) is the same as that of the primary current I_1 (low voltage side). From Eq. (2), it is clear that $V_L = 2V_P$ and IS = $2I_L$. The switch is located in the autotransformer's primary side and the magnitude of the switch current equals the load current. The voltage cross the switch in the off-state is equal to the magnitude of the input voltage. When sag is detected by the voltage controller, IGBT switched ON and is regulated by the PWM pulses. The primary voltage V_P is such that the load voltage on the secondary of autotransformer is the desired rms voltage.

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IV. MATLAB SIMULINK MODEL

The system parameters used for simulation with an auto-transformer are shown in Table-I.

Table-I System parameters used for Autotransformer simulation

Supply	**3-Phase100 MVA, 11kV, 60 Hz , AC supply**
Autotransformer	**Primary: 6.35 kV, 100MVA, 60 Hz** **Secondary: 6.35KV ,100 MVA, 60 Hz**
Ripple filter at output of Autotransformer	**Lr = 200 mH** **Cr1 = Cr2 = 100µF**
Load Active Power	**10KW**
Load Reactive Power	**10KVAr**

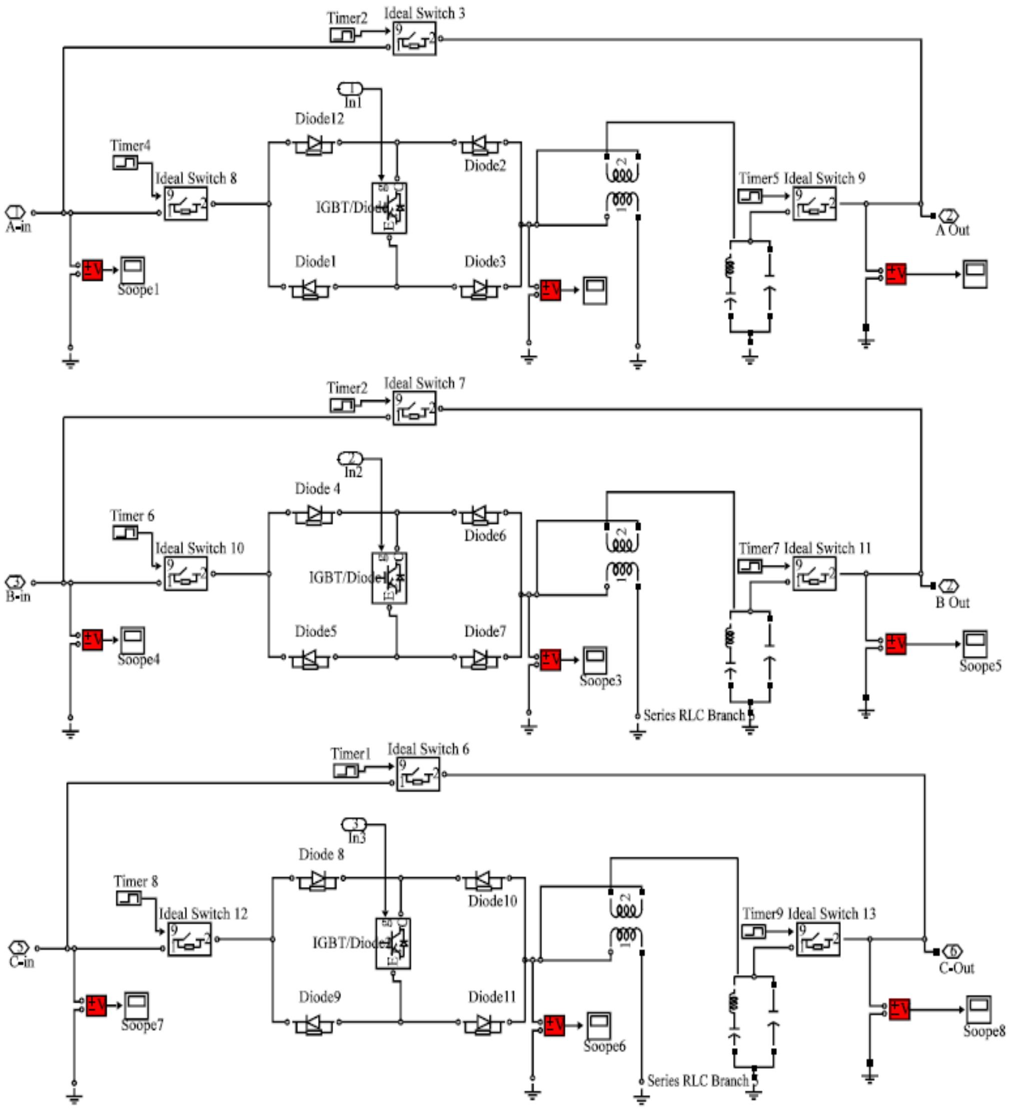

Fig. 4. MATLAB/SIMULINK model of a 3-PWM Switched autotransformer

RESULT ANALYSIS

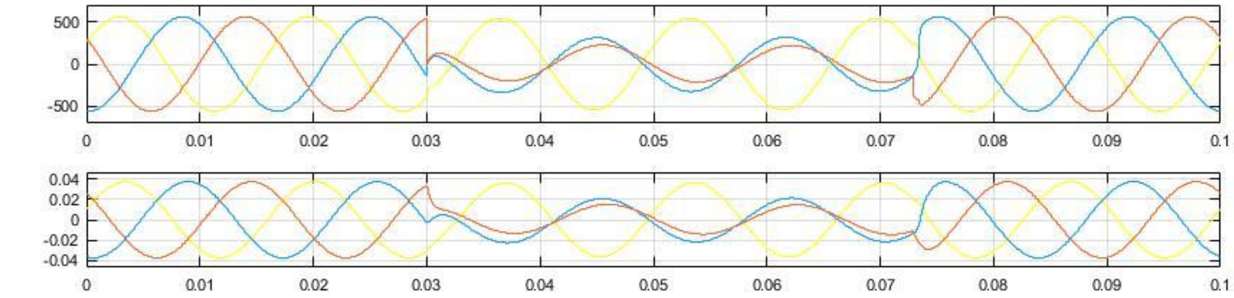

Fig 5 Load voltage and current with LLG fault

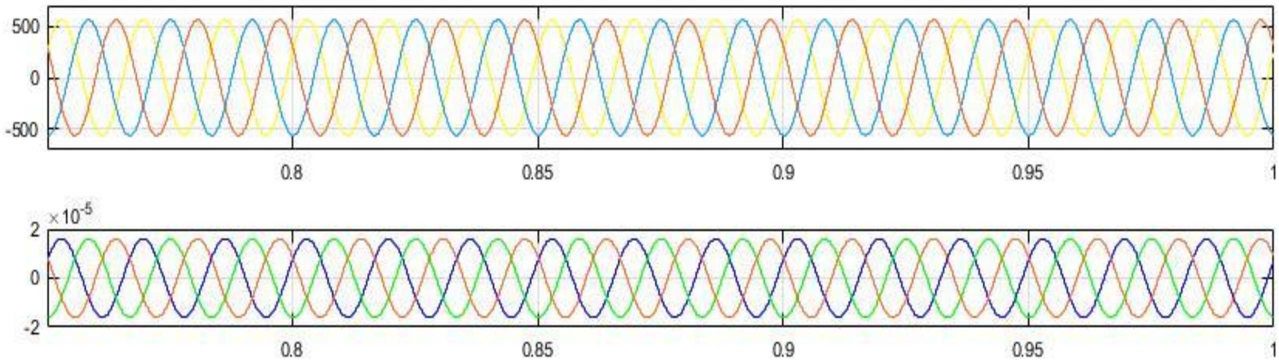

Fig 6 Load voltage and current with PWM switched autotransformer

Voltage sag is created in the system from 0.03s to 0.07s and the auto transformer acts during this period to mitigate the voltage sag. The voltage at PCC when sag is created is shown in Fig.5. The voltage at the load bus after compensation is shown in Fig.6.itclearly illustrates that the auto transformer is efficient in mitigating the voltage sag by reducing the load voltage harmonics to a great extent.

V. CONCLUSION

A new voltage sag compensator based on PWM switched autotransformer has been presented in this paper. Control circuit based on rms voltage reference is discussed. The proposed technique could identify the disturbance and capable of mitigating the disturbance by maintaining the load voltage at desired magnitude within limits. The proposed technique is simple and only one IGBT switch per phase is required. Hence the system is more simple and economical compared to commonly used DVR or STATCOM. Simulation analysis is performed for voltage sag for three phase system and simulation results verify that the proposed device is effective in compensating the voltage sag disturbances.

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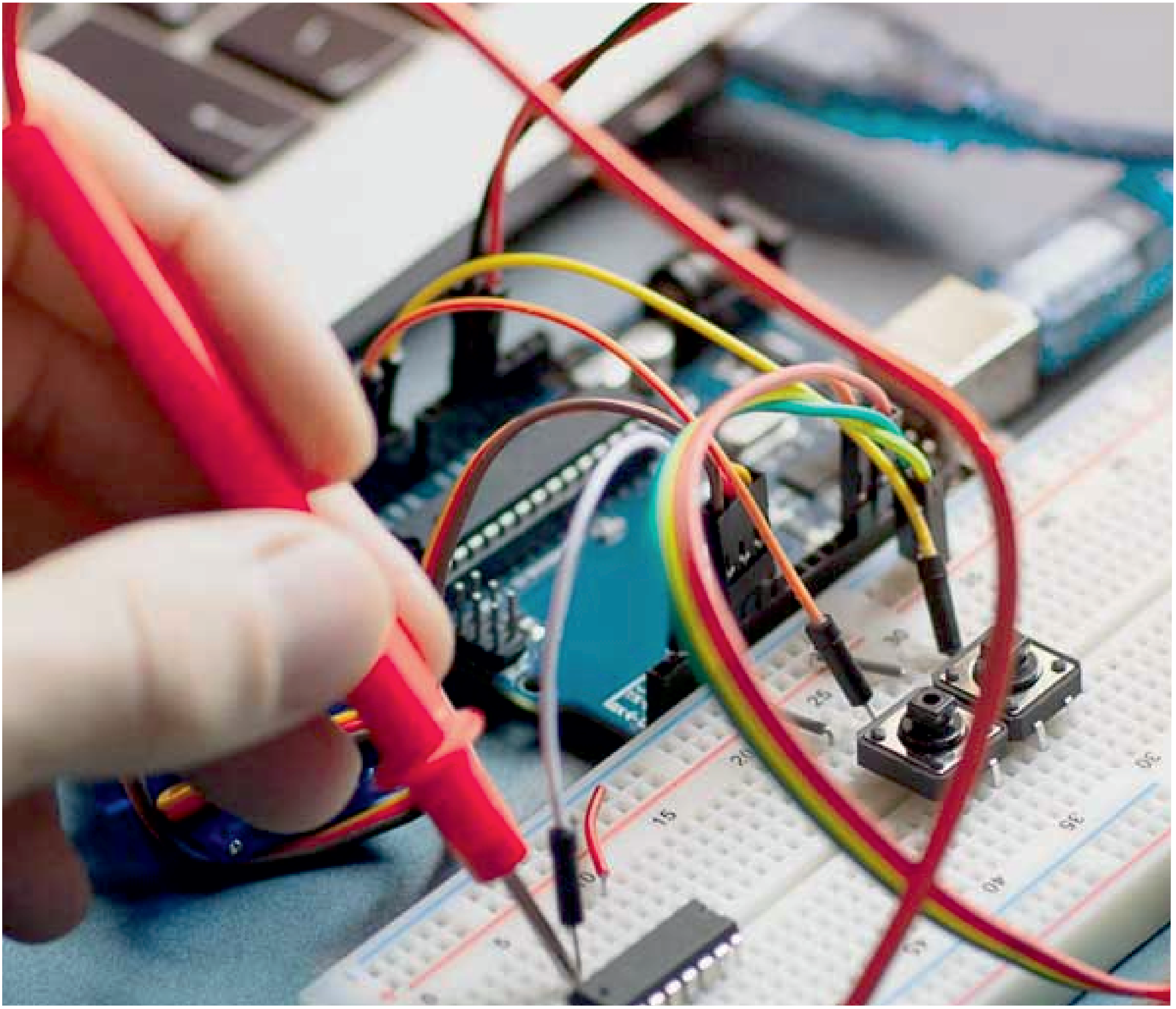

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