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Comparative Analysis of Load Flow in a 500 kV Power System using UPFC and SATCOM

Priyanka Boudh, Pro.Devendra Dohare

Research Scholar, Department of Instrumentation & Control Engineering, MPCT, Gwalior, India

Professor, Department of Instrumentation & Control Engineering, MPCT, Gwalior, India

ABSTRACT: Modern power systems require advanced solutions for efficient and reliable control. The Unified Power Flow Controller (UPFC), part of the Flexible AC Transmission Systems (FACTS) family, offers significant benefits but is often hindered by communication limitations. This research introduces a novel UPFC design integrated with Satellite Communications (SATCOM) to enhance its performance across complex power networks. By utilizing SATCOM's extensive coverage and reliability, the UPFC-SATCOM system enables real-time communication, ensuring faster and more accurate control actions, thereby improving system efficiency and stability.

In this paper, the UPFC-SATCOM system was designed and implemented using MATLAB/Simulink for simulation. Results demonstrated its effectiveness in managing power flow, maintaining voltage stability, and responding dynamically to network changes. The advantages of SATCOM over traditional methods, such as speed and reliability, were highlighted. This research lays the groundwork for future integration of advanced communication technologies with power system controllers, showcasing the feasibility and benefits of the UPFC-SATCOM system for modern grids.

KEYWORDS: Static Synchronous Compensator, UPFC**,** transmission system

I. INTRODUCTION

The Unified Power Flow Controller (UPFC) stands at the forefront of modern power system control technologies, providing dynamic and flexible solutions for enhancing the controllability and optimizing the operation of electrical power systems. The UPFC, a member of the Flexible AC Transmission Systems (FACTS) family, combines the functionalities of series and shunt compensation to manage power flows on the transmission network. It has been widely recognized for its ability to control voltage magnitude, phase angle, and impedance, thus offering unparalleled control over power flow and improving the stability and efficiency of power systems.

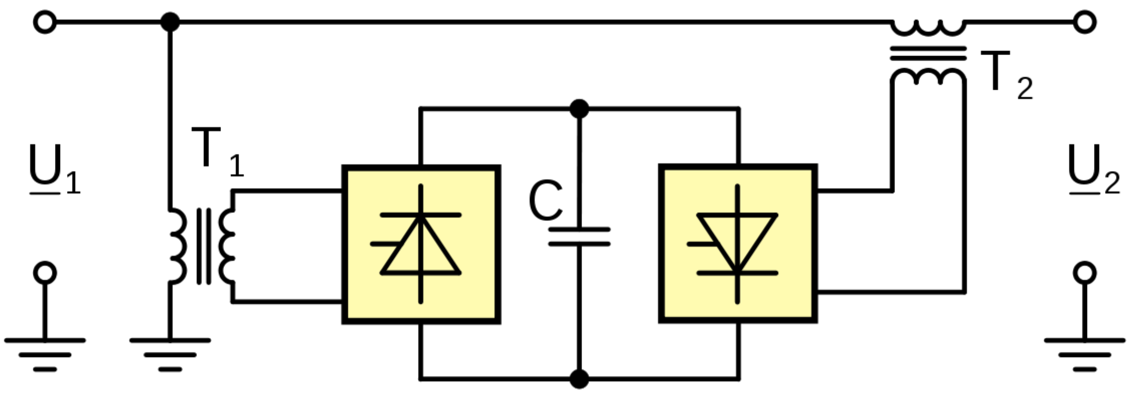

Figure 1: Block diagram of a unified power flow controller

However, the traditional implementation of UPFCs faces several challenges, particularly in terms of real-time communication and coordination across vast and complex power networks. The integration of advanced communication technologies is essential to overcome these hurdles and fully exploit the potential of UPFCs. This research explores the incorporation of Static Synchronous Compensator (STATCOM). (SATCOM) with UPFC to

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address these challenges. SATCOM, with its extensive coverage and reliability, offers a robust communication backbone capable of supporting real-time data transmission and control signals over large geographical areas.

The Unified Power Flow Controller (UPFC), a prominent member of the Flexible AC Transmission Systems (FACTS) family, is widely recognized for its ability to manage power flow, regulate voltage, and improve system stability. By integrating series and shunt compensation, the UPFC offers unparalleled control over power system parameters. However, effectively modeling and simulating the UPFC's impact on load flow studies remains a challenging task due to its complex operation and interaction with other system components.

This research paper focuses on load flow studies incorporating a UPFC power injection model using the Static Synchronous Compensator (STATCOM). The STATCOM, another key FACTS device, provides dynamic voltage support and reactive power compensation, further enhancing the capabilities of the UPFC. By combining the UPFC with STATCOM, this study aims to develop a comprehensive power injection model that accurately represents the behavior of these devices in load flow analyses.

The proposed model is implemented and tested using Matlab Simulink to evaluate its effectiveness in various scenarios. This paper presents the methodology, simulation results, and a detailed analysis of the UPFC-STATCOM power injection model's performance in load flow studies. The findings highlight the benefits and potential challenges of integrating these advanced devices into power systems, offering valuable insights for future research and practical applications.

The successful implementation of the UPFC-STATCOM power injection model in load flow studies is expected to provide significant improvements in power system planning and operation, ensuring more reliable and efficient electricity delivery. This research contributes to the ongoing efforts to modernize power grids by leveraging advanced technologies and enhancing the analytical tools available to engineers and system operators.

II. MATERIAL AND METHODS

A Unified Power Flow Controller (UPFC) is used to control the power flow in a 500 kV transmission system. The UPFC located at the left end of the 75-km line L2, between the 500 kV buses B1 and B2, is used to control the active and reactive powers flowing through bus B2 while controlling voltage at bus B1. It consists of two 100-MVA, three-level, 48-pulse GTO-based converters, one connected in shunt at bus B1 and one connected in series between buses B1 and B2. The shunt and series converters can exchange power through a DC bus. The series converter can inject a maximum of 10% of nominal line-to-ground voltage (28.87 kV) in series with line L2.

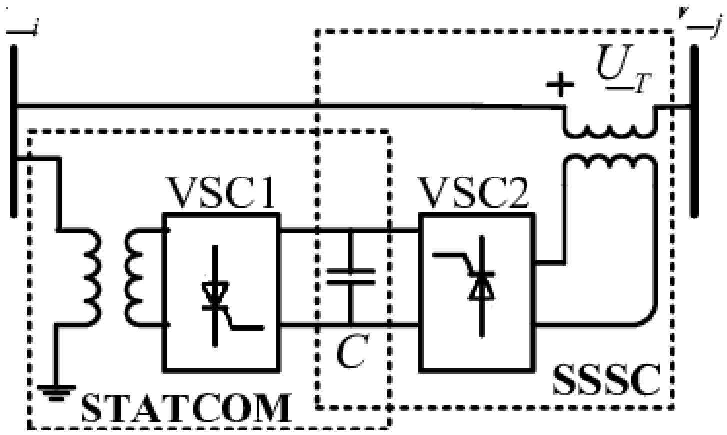

Figure 2: A basic structure of UPFC, STATCOM and SSSC

This pair of converters can be operated in three modes:

1. Unified Power Flow Controller (UPFC) mode, when the shunt and series converters are interconnected through the DC bus. When the disconnect switches between the DC buses of the shunt and series converter are opened, two additional modes are available:
2. Shunt converter operating as a Static Synchronous Compensator (STATCOM) controlling voltage at bus B1

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3. Series converter operating as a Static Synchronous Series Capacitor (SSSC) controlling injected voltage, while keeping injected voltage in quadrature with current.

The mode of operation as well as the reference voltage and reference power values can be changed by means of the "UPFC GUI" block in the proposed Simulink blockset.

The principle of operation of the harmonic neutralized converters is explained in another example entitled "Three-phase 48-pulse GTO converter". This power_48pulsegtoconverter model is accessible in the Power Electronics Models library of examples. When the two converters are operated in UPFC mode, the shunt converter operates as a STATCOM. It controls the bus B1 voltage by controlling the absorbed or generated reactive power while also allowing active power transfer to the series converter through the DC bus. The reactive power variation is obtained by varying the DC bus voltage. The four three-level shunt converters operate at a constant conduction angle (Sigma= 180-7.5 = 172.5 degrees), thus generating a quasi-sinusoidal 48-step voltage waveform. The first significant harmonics are the 47th and the 49th.
When operating in UPFC mode, the magnitude of the series injected voltage is varied by varying the Sigma conduction angle, therefore generating higher harmonic contents than the shunt converter. As illustrated in this example, when the series converter operates in SSSC mode it generates a "true" 48-pulse waveform.

The natural power flow through bus B2 when zero voltage is generated by the series converter (zero voltage on converter side of the four converter transformers) is P=+870 MW and Q=-70 Mvar. In UPFC mode, both the magnitude and phase angle and the series injected voltage can be varied, thus allowing control of P and Q. The UPFC controllable region is obtained by keeping the injected voltage to its maximum value (0.1 pu) and varying its phase angle from zero to 360 degrees. To see the resulting P-Q trajectory, double click the "Show UPFC Controllable Region". Any point located inside the PQ elliptic region can be obtained in UPFC mode.

III. SIMULATION RESULT

After successful implementation, we have simulated the proposed system in Simulink. The simulation result along with discussion is being presented in this section. The entire designed subsystem in Simulink is shown below.

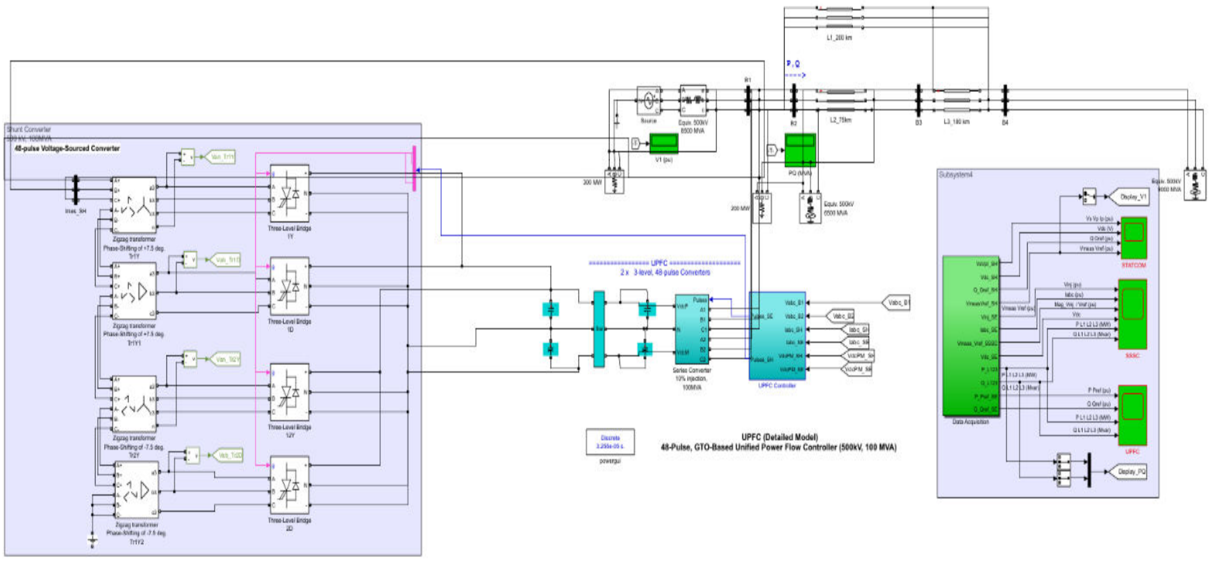

Figure 3: Proposed system model in Simulink

A. Power control in UPFC mode

Open the UPFC GUI block menu. The GUI allows you to choose the operation mode (UPFC, STATCOM or SSSC) as well as the P_{ref}/Q_{ref} reference powers and/or V_{ref} reference voltage settings. Also, in order to observe the dynamic response of the control system, the GUI allows you to specify a step change of any reference value at a specific time.

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Make sure that the operation mode is set to "UPFC (Power Flow Control)". The reference active and reactive powers are specified in the last two lines of the GUI menu. Initially, Pref= +8.7 pu/100MVA (+870 MW) and Qref=-0.6 pu/100MVA (-60 Mvar). At t=0.25 sec Pref is changed to +10 pu (+1000MW). Then, at t=0.5 sec, Qref is changed to +0.7 pu (+70 Mvar). The reference voltage of the shunt converter (specified in the 2nd line of the GUI) will be kept constant at Vref=1 pu during the whole simulation (Step Time=0.3*100> Simulation stop time (0.8 sec). When the UPFC is in power control mode, the changes in STATCOM reference reactive power and in SSSC injected voltage (specified respectively in 1st and 3rd line of the GUI) as are not used.

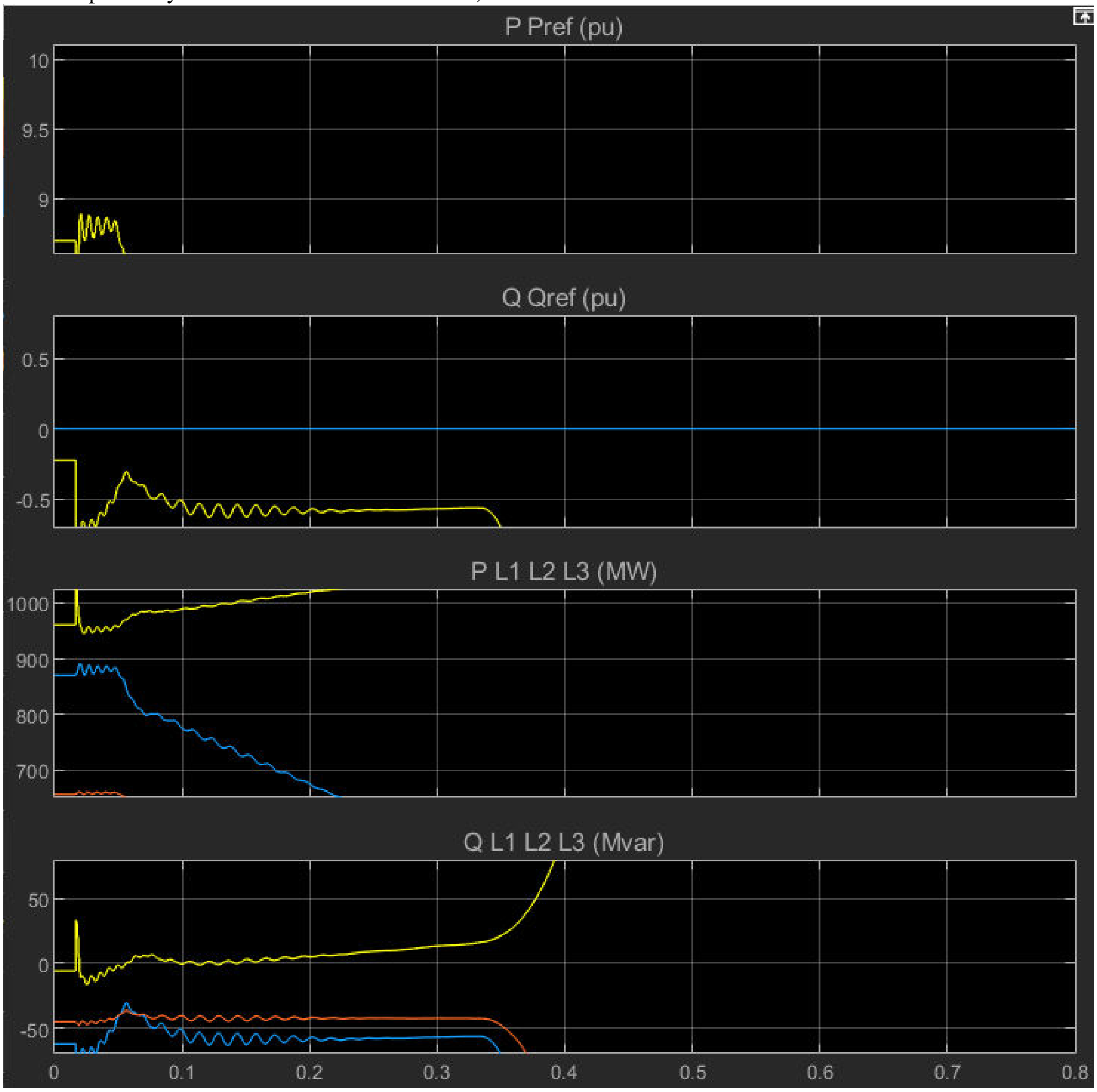

Figure 4: Output for UPFC

B. Var control in STATCOM mode

In the GUI block menu, change the operation mode to "STATCOM (Var Control)". Make sure that the STATCOM references values (1st line of parameters, [T1 T2 Q1 Q2]) are set to [0.3 0.5 +0.8 -0.8]. In this mode, the STATCOM is operated as a variable source of reactive power. Initially, Q is set to zero, then at T1=0.3 sec Q is increased to +0.8 pu (STATCOM absorbing reactive power) and at T2=0.5 sec, Q is reversed to -0.8 pu (STATCOM generating reactive power).

Run the simulation and observe on the STATCOM scope the dynamic response of the STATCOM. Zoom on the first trace around t=0.5 sec when Q is changed from +0.8 pu to -0.8 pu. When Q=+0.8 pu, the current flowing into the

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STATCOM (cyan trace) is lagging voltage (magenta trace), indicating that STATCOM is absorbing reactive power. When Qref is changed from +0.8 to -0.8, the current phase shift with respect to voltage changes from 90 degrees lagging to 90 degrees leading within one cycle. This control of reactive power is obtained by varying the magnitude of the secondary voltage Vs generated by the shunt converter while keeping it in phase with the bus B1 voltage Vp. This change of Vs magnitude is performed by controlling the dc bus voltage. When Q is changing from +0.8 pu to -0.8 pu, Vdc (trace 3) increases from 17.5 kV to 21 kV.

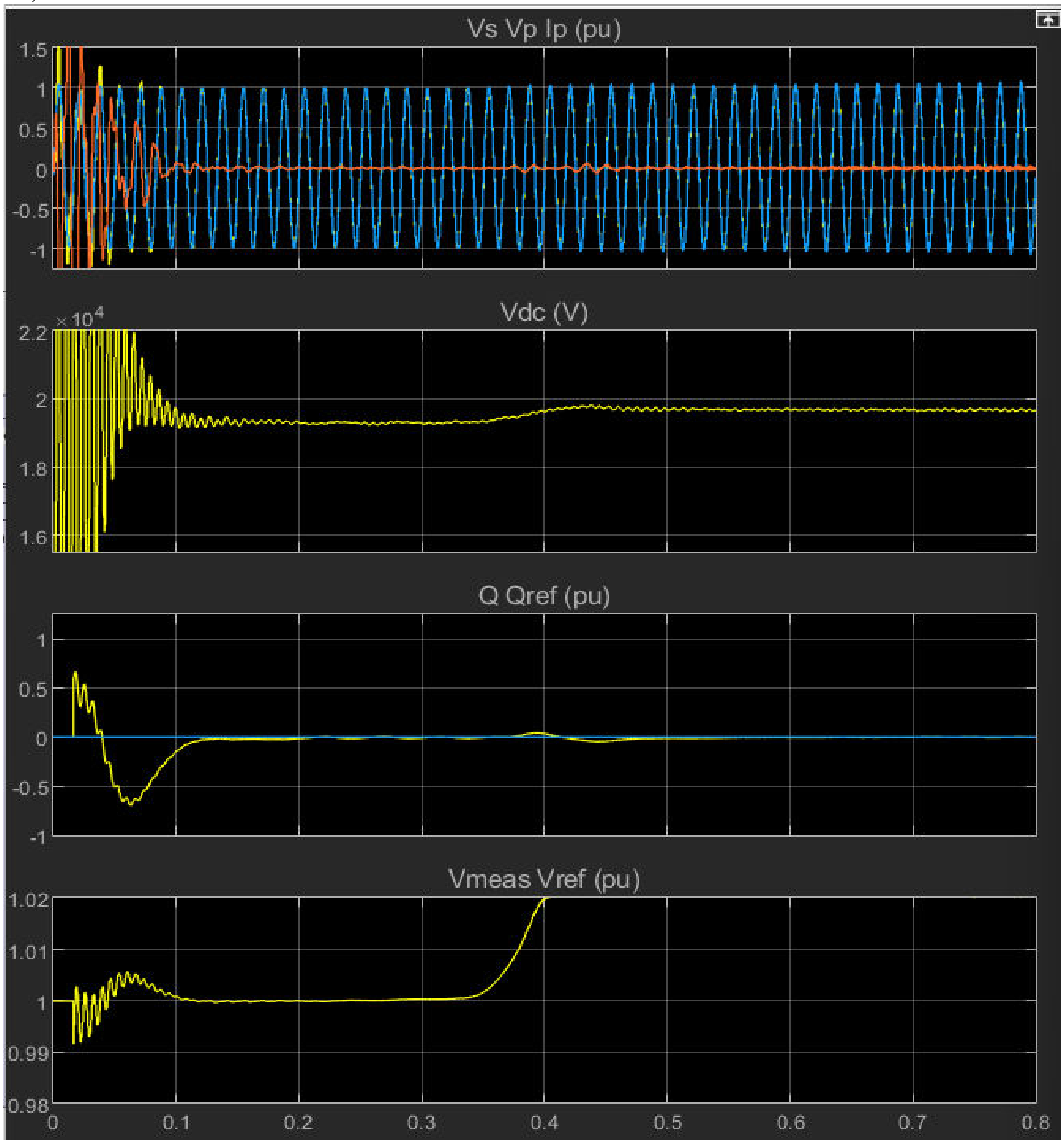

Figure 5: Output for STATCOM

IV. CONCLUSION

This research paper investigates the integration of a Unified Power Flow Controller (UPFC) with a Static Synchronous Compensator (STATCOM) to enhance load flow studies in modern power systems. A comprehensive power injection model was developed and simulated using MATLAB/Simulink, demonstrating the combined capabilities of UPFC and STATCOM in managing power flow, regulating voltage, and improving system stability. The simulation results highlighted the model's effectiveness in handling power flow, maintaining voltage levels, and dynamically responding to network changes, thereby showcasing its potential to address power system complexities. The UPFC-STATCOM integration also improved reactive power compensation and overall system performance. This study confirms the advantages of combining advanced FACTS devices for load flow analysis and sets a foundation for further research and

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practical application in real-world power networks. Future work could refine the model, test it in larger networks, and explore the economic implications of deploying UPFC-STATCOM systems.

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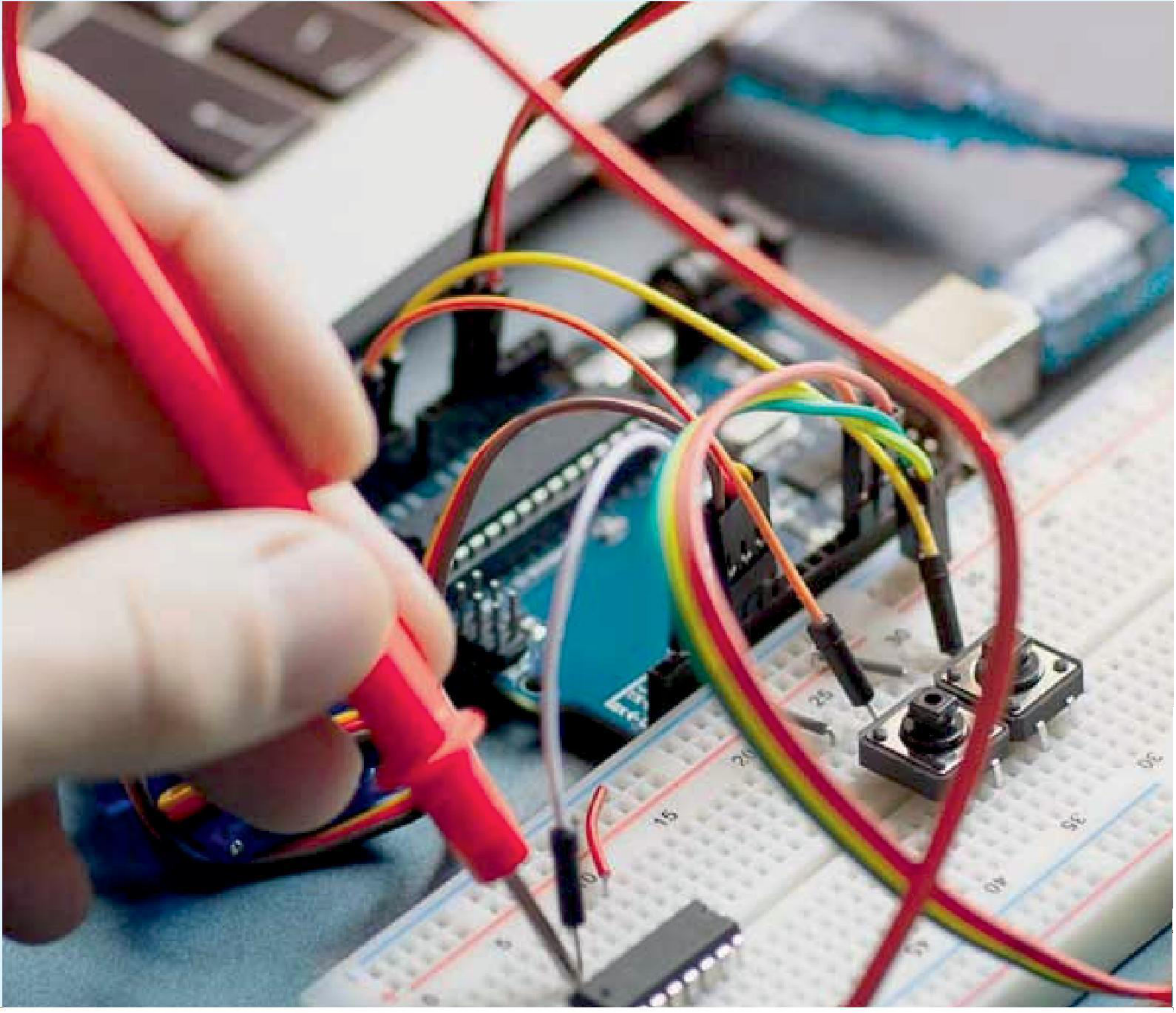

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