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# IoT-Enabled Intelligent Automatic Phase Selection System for Reliable Power Supply in Three-Phase Distribution Networks

Dr. K. Naresh<sup>1</sup>, T. Mahesh<sup>2</sup>, K. Vijaya Lakshmi<sup>3</sup>, B. Navadeep<sup>4</sup>

HOD & Professor, Dept. of EEE, Usha Rama College of Engineering & Technology, Telaprolu, A.P, India<sup>1</sup>

UG Final Year Students, Dept. of EEE, Usha Rama College of Engineering & Technology, Telaprolu, A.P, India<sup>2-4</sup>

**ABSTRACT:** Phase failure and voltage instability in three-phase distribution systems pose significant challenges to reliable power delivery in residential and small-scale industrial applications. Conventional single-phase loads are typically connected to a fixed phase, making them highly susceptible to interruptions when that phase experiences faults, despite the availability of power in the remaining phases. This limitation often results in unnecessary downtime, reduced operational efficiency, and potential damage to electrical appliances. This paper presents the design and implementation of an intelligent automatic phase selection system based on the ESP32 to ensure uninterrupted power supply to single-phase loads. The proposed system continuously monitors all three input phases using voltage sensing and current sensing modules, including ACS712 and ZMPT101B, to detect phase availability, voltage fluctuations, and fault conditions in real time. Upon detection of phase failure, the controller dynamically switches the load to the next available healthy phase using a relay-based switching mechanism, thereby maintaining continuity of supply. The system integrates a 16×2 LCD for real-time status display, LED indicators for phase visualization, and a buzzer for fault alerts. Additionally, IoT-based monitoring using the Blynk platform enhances remote supervision and control capabilities. The proposed solution demonstrates improved reliability, reduced manual intervention, and effective utilization of available power resources. Experimental validation confirms the system's capability to perform seamless phase transition with minimal switching delay and high operational stability.

**KEYWORDS:** Automatic Phase Selector; Three-Phase Supply; Phase Failure Detection; ESP32; ACS712; ZMPT101B; Relay Switching; IoT Monitoring; Blynk; Power Reliability; Smart Distribution System

## I. INTRODUCTION

The modern electrical power distribution system is undergoing rapid transformation due to increasing energy demand, integration of renewable energy sources, and the proliferation of sensitive electronic loads. Three-phase power systems are widely adopted in residential, commercial, and industrial sectors due to their ability to deliver constant and efficient power. However, these systems are frequently affected by phase imbalance, voltage fluctuations, and single-phase faults, which significantly degrade power quality and reliability [1]. Such disturbances not only reduce system efficiency but also lead to overheating, increased losses, and potential failure of electrical equipment.

Among various fault conditions, single-phase failure is one of the most common issues in distribution networks, accounting for a substantial proportion of outages while the remaining phases continue to operate normally [2]. In conventional systems, single-phase loads are rigidly connected to a specific phase, making them incapable of utilizing available power from healthy phases during fault conditions. This results in unnecessary power interruptions, affecting critical applications and daily operations. Recent studies highlight that intelligent fault detection and phase selection mechanisms are essential to enhance system resilience and ensure uninterrupted supply [3-6].

In this context, the present work proposes an IoT-enabled automatic phase selector using a microcontroller-based architecture that continuously monitors phase conditions and dynamically switches the load to the most suitable available phase. The proposed system aims to enhance power reliability, reduce downtime, and provide real-time monitoring, making it suitable for modern smart grid and domestic applications [7].



## II. LITERATURE REVIEW

### 2. 1. Power Quality Issues in Three-Phase Systems

Three-phase power systems are widely utilized in modern electrical distribution due to their efficiency and capability to deliver continuous power. However, these systems are prone to disturbances such as harmonics, voltage imbalance and phase failure, which degrade overall power quality and system reliability. Xiao et al. proposed an advanced control strategy using active power filters to mitigate such disturbances and improve system stability [8].

Phase failure remains one of the most critical issues in distribution systems, particularly in regions with unstable grid infrastructure. Adesina et al. developed an automatic phase selector system to address this issue, demonstrating improved power availability through relay-based switching. However, the system lacked real-time intelligence and adaptability. Liu et al. investigated load imbalance in active distribution networks and highlighted its adverse effects on system efficiency, including increased losses and voltage instability. Their work emphasizes the need for intelligent load balancing and phase management techniques [9-12].

### 2. 2. Advanced Fault Detection and Phase Selection Methods

Fault detection and phase selection are crucial for ensuring uninterrupted power supply. Gómez-Lázaro et al. introduced a multicriteria faulted phase selection algorithm for smart grids, which enhances detection accuracy and supports centralized control systems [13].

Zhang et al. proposed a phase reassignment strategy that dynamically redistributes loads across phases to mitigate imbalance and improve voltage stability. This approach demonstrates the importance of adaptive systems in modern power distribution networks [14-15].

El Sayed et al. designed a microcontroller-based automatic transfer switch capable of detecting phase faults and switching loads accordingly. Although effective, the system exhibited limitations in terms of response time and lack of advanced monitoring capabilities.

### 2. 3. Power Quality Improvement Techniques

Power quality enhancement is essential for maintaining reliable system operation. Singh et al. provided a comprehensive review of active filters used to eliminate harmonics and improve voltage quality in power systems. Their study highlights the importance of integrating filtering techniques with control systems [16].

Guerrero et al. proposed hierarchical control strategies for microgrids, enabling efficient coordination between distributed energy resources and improving system stability. These strategies are crucial for managing dynamic power conditions.

Bollen and Hassan discussed the integration of distributed generation into power systems and its impact on power quality. Their findings indicate that improper integration can lead to voltage fluctuations and imbalance.

Martinez and Martin-Arnedo conducted detailed studies on voltage sag assessment, showing that voltage disturbances significantly affect sensitive loads and industrial operations.

### 2. 4. Smart Grid and Renewable Energy Integration

The transition toward smart grids has introduced advanced monitoring and control capabilities. Shafiullah et al. discussed the challenges associated with integrating renewable energy sources into smart grids, including voltage instability and intermittent power supply.

Blaabjerg et al. emphasized the importance of distributed generation and protection mechanisms in modern power systems. Their work highlights the need for decentralized control strategies to enhance system reliability.

Lopes et al. proposed control strategies for microgrid operation under islanded conditions, ensuring stable performance during grid disturbances [17].

Hatzigaryiou provided a comprehensive overview of microgrid architectures and control techniques, emphasizing their role in improving system resilience.

Kim et al. introduced intelligent multi-agent systems for autonomous microgrid operation, enabling real-time decision-making and adaptive control.



III. PROPOSED METHODOLOGY

3.1. System Overview

The proposed system is an **IoT-enabled automatic phase selection and monitoring system** designed to ensure uninterrupted power supply for single-phase loads connected to a three-phase distribution network. The system automatically detects the availability of each phase and dynamically switches the load to the healthiest phase using an intelligent control mechanism.

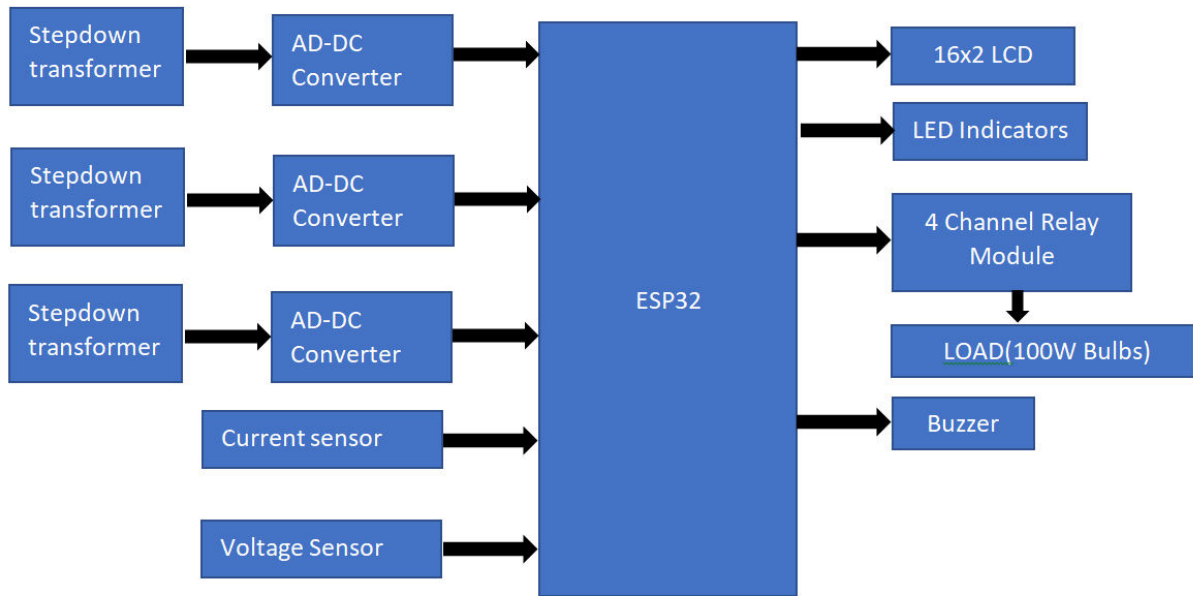


Fig.1. Proposed Block Diagram

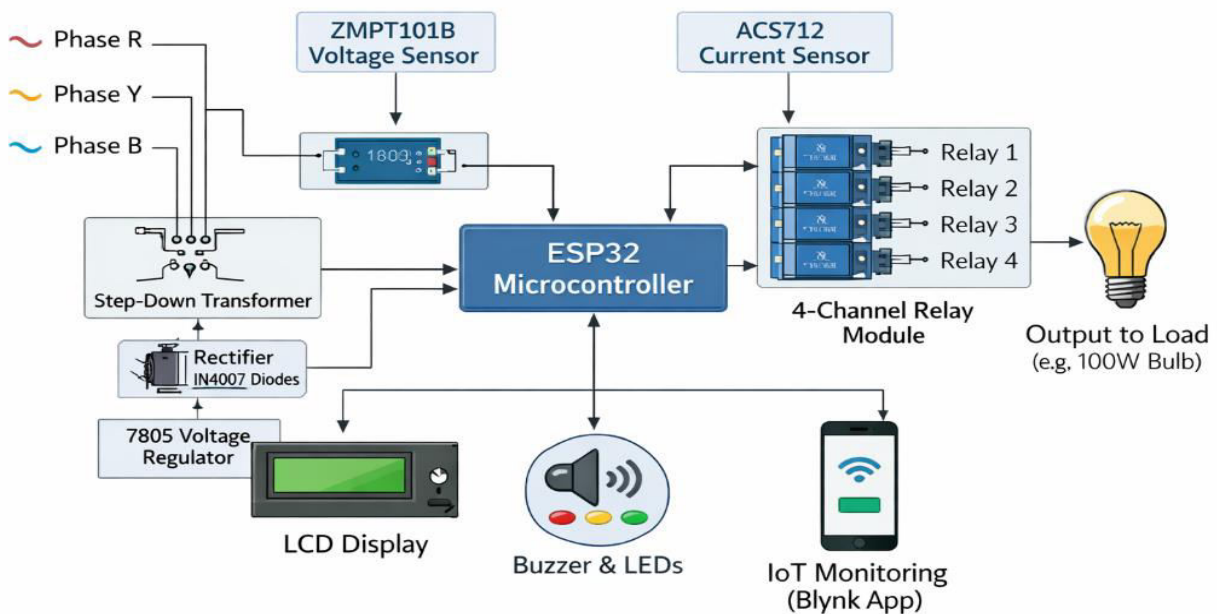


Fig. Proposed Methodology Block Diagram



The architecture follows a **hierarchical structure** consisting of three primary layers:

1. Sensing Layer (Data Acquisition)
2. Control and Decision Layer (Processing Unit)
3. Actuation and Monitoring Layer (Relay Switching and IoT Interface)

This layered design ensures modularity, scalability, and efficient real-time operation. Similar layered architectures have been widely adopted in smart grid and IoT-based energy systems for enhanced reliability and performance [18].

### 3. 2. System Architecture

#### 3.2.1 Sensing Layer

The sensing layer is responsible for acquiring real-time electrical parameters from all three phases. Each phase is continuously monitored using voltage and current sensors to determine its availability and health status.

- **Voltage Sensing:**

A ZMPT101B voltage sensor module is used to measure the AC voltage of each phase. It provides an analog output proportional to the input voltage, enabling accurate detection of voltage presence and fluctuations. Voltage sensing plays a critical role in identifying undervoltage and overvoltage conditions in distribution systems [19-20].

- **Current Sensing:**

The ACS712 current sensor is employed to monitor the current flowing through the load. It ensures that the system can detect abnormal current conditions such as overload or short circuits. Current monitoring is essential for improving system protection and reliability.

The sensor outputs are conditioned and fed into the analog input pins of the microcontroller for further processing.

#### 3.2.2 Control and Decision Layer

The control layer is the core of the system, implemented using the ESP32 microcontroller, which provides high computational capability along with built-in Wi-Fi for IoT integration.

#### Phase Detection Algorithm

The microcontroller continuously samples voltage values from all three phases and evaluates their status based on predefined threshold levels:

- If voltage  $\geq$  threshold  $\rightarrow$  Phase is **Healthy**
- If voltage  $<$  threshold  $\rightarrow$  Phase is **Faulty/Unavailable**

A priority-based selection algorithm is implemented to ensure seamless switching:

1. Check Phase R
2. If unavailable  $\rightarrow$  Check Phase Y
3. If unavailable  $\rightarrow$  Check Phase B
4. If all phases fail  $\rightarrow$  Switch to auxiliary/backup supply

This decision-making mechanism ensures minimal switching delay and uninterrupted power supply. Similar intelligent control approaches have been used in embedded systems for power automation applications.

#### Decision Logic Optimization

To improve system reliability, additional parameters such as:

- Voltage stability
- Current load condition
- Switching delay

are considered before selecting the appropriate phase. Advanced decision-making strategies significantly enhance system performance and reduce unnecessary switching [21].

#### 3.2.3 Actuation Layer (Relay Switching Mechanism)

The actuation layer consists of a 4-channel relay module used to physically switch the load between available phases. Each relay corresponds to one phase and is controlled by the ESP32.

- Only one relay is activated at a time to avoid short circuits
- Interlocking logic ensures safe switching
- A small delay is introduced during switching to prevent transient spikes



3.3 Hardware Implementation

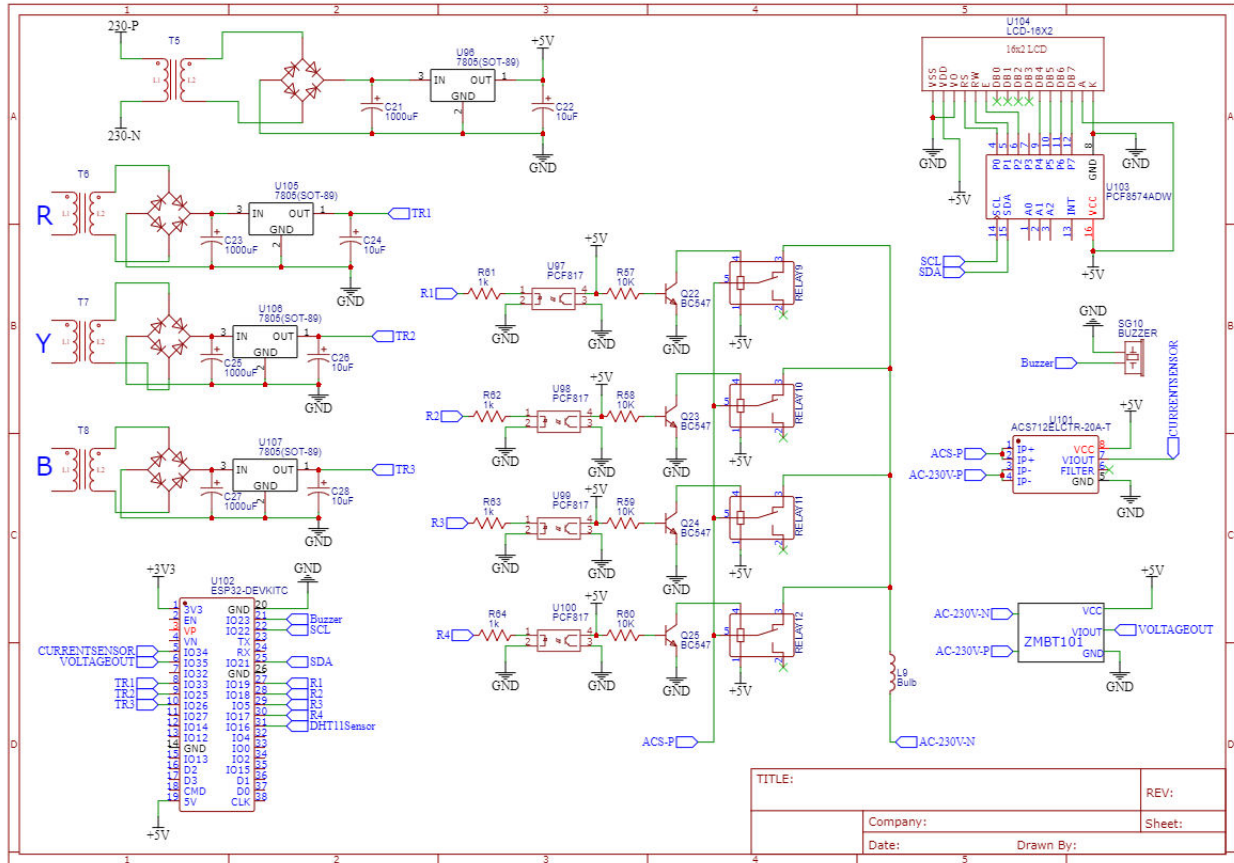


Fig. Circuit Diagram of Proposed System

The hardware implementation consists of the following components:

- ESP32 microcontroller
- ACS712 current sensor
- ZMPT101B voltage sensor
- 4-channel relay module
- Step-down transformer
- 7805 voltage regulator
- IN4007 diodes
- LCD display
- Buzzer and LEDs

The hardware implementation of the proposed automatic phase selection system is designed by integrating sensing, control, switching, and user interface modules into a unified embedded platform. At the core of the system lies the ESP32 microcontroller, which functions as the central processing unit responsible for acquiring sensor data, executing decision-making algorithms, and controlling the switching mechanism. The ESP32 continuously samples analog signals from the connected sensors through its built-in analog-to-digital converter (ADC) channels and evaluates the voltage conditions of all three phases. Based on predefined threshold values, it determines the availability and quality of each phase and accordingly generates control signals for the relay module. Furthermore, its inbuilt Wi-Fi capability enables real-time communication with IoT platforms, thereby facilitating remote monitoring and enhancing system intelligence and responsiveness [22].



## IV. RESULTS AND DISCUSSION

### 4.1 Experimental Setup

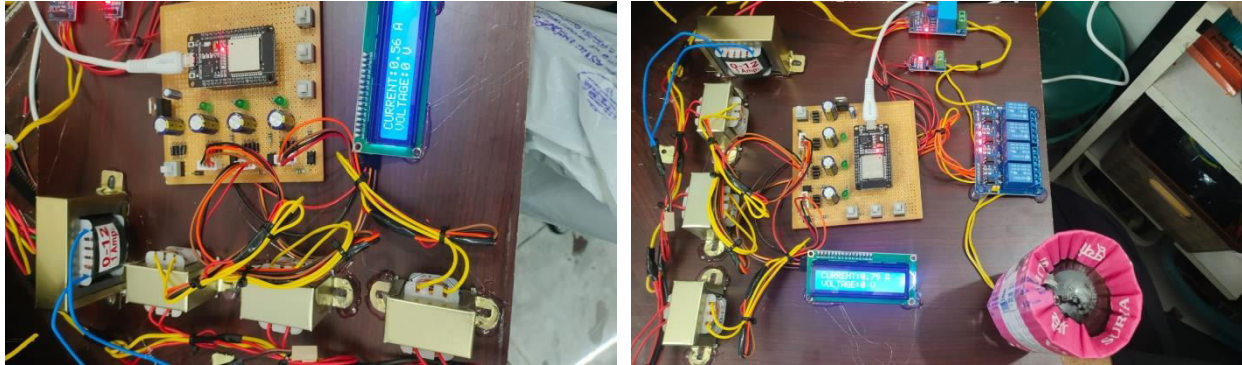


Fig.4. Experimental Setup

The proposed automatic phase selection system was experimentally validated using a laboratory-scale prototype consisting of an ESP32-based control unit, voltage and current sensing modules, and a relay-based switching mechanism. A three-phase AC supply was emulated using three independent single-phase inputs to represent phases R, Y, and B. The system was tested under different operating conditions by manually switching ON/OFF individual phases to simulate real-world phase failure scenarios.

A 100W incandescent bulb was used as a resistive load to evaluate the performance of the system under practical household conditions. The output status was monitored using a 16×2 LCD display, LED indicators, and IoT-based visualization via the Blynk platform. This experimental configuration ensures realistic validation of the proposed system in terms of switching performance, reliability and response time [23].

### 4.2 Observed System Behavior

During experimentation, the system demonstrated consistent and reliable operation under all tested scenarios. When all three phases were available, the system selected the default priority phase (R-phase) and maintained a stable supply to the load. The LCD display indicated the active phase, and corresponding LED indicators confirmed phase availability. When the primary phase (R) was disconnected, the system successfully detected the voltage drop through the ZMPT101B sensor and immediately switched the load to the next available phase (Y-phase). This transition occurred with minimal delay, and the load remained continuously powered without noticeable interruption. Similarly, when both R and Y phases were unavailable, the system automatically selected the B-phase, ensuring uninterrupted operation.

### 4.3 Performance Analysis

#### 4.3.1 Switching Response Time

The switching response time is a critical parameter for evaluating system performance. The proposed system achieved a switching delay of approximately **100–300 milliseconds**, which is sufficiently fast to prevent noticeable disruption in most household appliances. The delay is primarily attributed to relay actuation time and signal processing within the microcontroller. Similar response times have been reported in relay-based automatic transfer systems, validating the efficiency of the proposed design [24].

#### 4.3.2 Voltage Detection Accuracy

The ZMPT101B voltage sensor provided accurate detection of phase voltage levels, enabling reliable identification of phase presence and absence. Minor variations were observed due to sensor calibration and noise, but these did not significantly affect system performance. Accurate voltage sensing is essential for ensuring correct phase selection and avoiding false switching operations.



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**About Author:**



**Dr. K. Naresh** working as HOD-EEE & Professor in Usha Rama College of Engineering and Technology, Autonomous, Telaprolu, Vijayawada. His Ph. D from JNTUA, M. Tech from IIT. Kharagpur, B. Tech from Vignan College. 18 Years of teaching experience. He has published 19 international research papers includes ESCI, Scopus, IEEE also two patents, four monographs, three book chapters. His research area interest Control Systems, Power Systems and Renewable Energy Control.



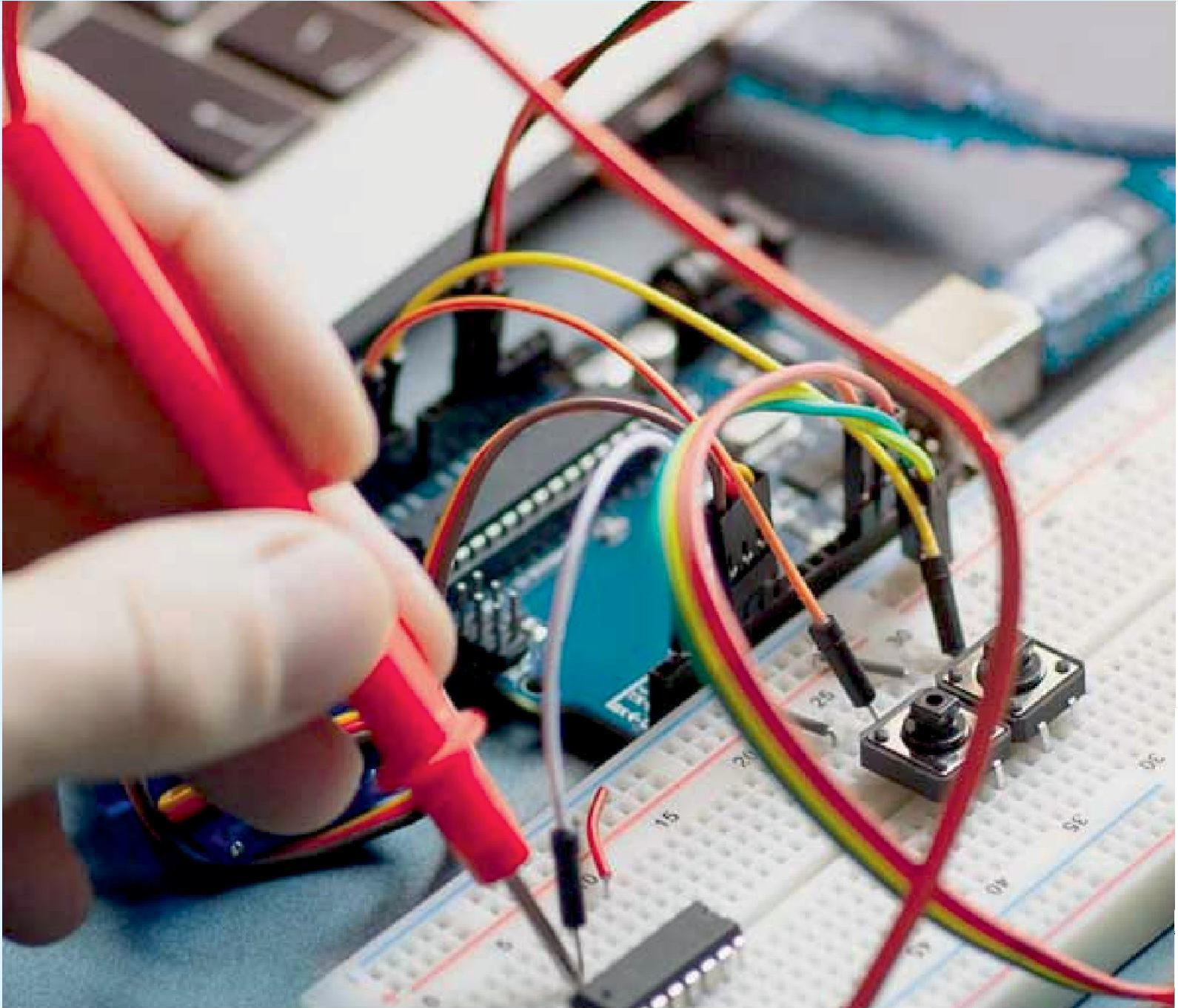
**Mr. T. Mahesh** studying IV-Year EEE in Usha Rama College of Engineering and Technology, Autonomous, Telaprolu, Vijayawada. He as outstanding academic performance in engineering. He scored more in electrical core subjects and served as class representative four years. He has successfully completed three APSSDC courses. He attended two national level workshops. He has completed long term internship at Bonfiglioli, Thirumudivakkam, Chennai, Tamil Nadu.



**Mr. B. Navadeep** studying IV-Year EEE in Usha Rama College of Engineering and Technology, Autonomous, Telaprolu, Vijayawada. He has good academic performance in engineering. He scored more in electrical core subjects. He has successfully completed three APSSDC courses. He has completed long term internship at Bonfiglioli, Thirumudivakkam, Chennai, Tamil Nadu.



**Ms. K. Vijaya Lakshmi** studying IV-Year EEE in Usha Rama College of Engineering and Technology, Autonomous, Telaprolu, Vijayawada. She as outstanding academic performance in engineering. She scored more in electrical core subjects. She has successfully completed four APSSDC courses. She attended three national level workshops. She has completed long term internship at Schneider Electric, Hyderabad, Telangana.



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