

ELECTRIFICATION OF ELECTRONIC AND POWER LAB.

BY

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CERTIFICATION

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DEDICATION

This project work is dedicated to Almighty God, the ALPHA AND OMEGA, and to my beloved parents, MR. AND MRS. ODEWAMIDE

III

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My profound gratitude and appreciation goes to God almighty, who has given me the grace, wisdom, knowledge, understanding and the ability to complete this program.

I appreciate the effort of my beloved parents MR. AND MRS. ODEWAMIDE who have supported me against all odds financially, spiritually, and morally towards the success of this program, I pray that you shall live long to eat the fruit you have labored.

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ABSTRACT

The electrification of Electronics and Power Laboratories plays a critical role in enhancing practical engineering education and research capabilities in tertiary institutions. This project focuses on the design, implementation, and commissioning of a reliable and safe electrical power system tailored to meet the operational demands of laboratory equipment used in electronics and power engineering studies. The project addresses challenges such as unstable power supply, inadequate wiring infrastructure, and safety concerns that hinder effective learning and experimentation. By integrating standard electrical components, including circuit breakers, distribution panels, protective devices, and power conditioning systems, the electrification process ensures consistent power delivery, equipment protection, and user safety. The project also incorporates energy efficiency measures and provision for future expansion to accommodate technological advancements. Ultimately, this initiative supports the development of hands-on technical skills, fosters innovation, and contributes to the overall improvement of engineering education quality.

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CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

The growing emphasis on practical and industry-relevant knowledge in electrical and electronics engineering has heightened the importance of well-equipped laboratories within educational institutions. These laboratories are no longer just ancillary facilities; they are critical to enabling students to bridge the gap between theoretical concepts and real-world applications. To support the increasing complexity of experiments and technological applications ranging from analog and digital electronics to high-voltage power systems and embedded systems laboratories must be powered by reliable, scalable, and safe electrical infrastructures. Electrification in this context encompasses the provisioning of well-designed power distribution systems, isolated AC/DC supply lines, surge and overload protection mechanisms, and renewable energy sources such as solar photovoltaics to promote operational sustainability.

As technological advancements redefine modern energy infrastructure, laboratory electrification is increasingly influenced by smart grid technologies, IoT-based energy monitoring, and automated safety controls. Smart energy systems enable real-time feedback on voltage, current, energy consumption, and fault detection, which is essential for ensuring equipment longevity and safe user interaction. For example, integrating IoT sensors with laboratory power systems allows for predictive maintenance, anomaly detection, and intelligent load management, thereby minimizing downtime and improving energy efficiency [1]. Moreover, the shift toward sustainability and clean energy integration has made it imperative for laboratories to adopt hybrid power solutions that include solar or wind generation systems alongside conventional grid supplies. These installations not only reduce operational costs but also serve as live educational tools for teaching renewable energy principles.

These modernized lab electrification initiatives also align with global sustainability fram

networks, particularly the United Nations Sustainable Development Goal 7 (SDG 7),

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which advocates for universal access to affordable, reliable, sustainable, and modern energy [2]. Engineering institutions implementing such laboratory upgrades are not only enhancing technical education but are also contributing to the broader global mission of reducing carbon emissions and promoting green technologies. By incorporating clean energy solutions into their infrastructure, institutions can reduce their carbon footprint and instill in students a mindset geared toward environmental responsibility and innovation in sustainable technologies [3].

1.2 Problem Statement

Electrical and electronics engineering education depends on well-equipped laboratories for effective hands-on learning. However, many labs, particularly in developing regions, suffer from unreliable power, outdated infrastructure, and poor safety standards. With the increasing demand for smart technologies and renewable integration, there is an urgent need for a modern, reliable, and safe electrification system that supports diverse power requirements and aligns with international standards.

1.3 Aim & Objectives

Aim: Electrification of Electronics and Power lab

The Objectives of this project are

- ✓ To install a modern and reliable power supply infrastructure in the electronics and power laboratory.
- ✓ To provide power outlets for both low-voltage electronics and high-power equipment.

pment.

- ✓ To integrate a solar energy backup system to reduce grid dependency.
- ✓ To ensure compliance with IEEE and IEC safety standards.
- ✓ To deploy an energy monitoring system for educational and management purposes.

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1.4 Scope of the Study

The project involves:

- ✓ Load analysis and capacity planning.
- ✓ Installation of main distribution boards and circuit protection systems.
- ✓ Provision of standard AC (230V/110V) and DC supply outlets.
- ✓ Renewable energy system (solar PV) installation.
- ✓ Electrical safety measures including grounding, surge protection, and emergency shutdown.
- ✓ Implementation of an Energy Monitoring System (EMS).

1.5 Significance of the Study

The electrification of the electronics and power laboratory is of paramount importance in fostering academic excellence, technical proficiency, and innovative research within institutions of higher learning. This study holds significant value for the following reasons:

- ✓ Improved Practical Instruction: Electrification enables the effective implementation of hands-on laboratory sessions, allowing students to apply theoretical concepts in real-world scenarios. This practical exposure is essential for understanding complex topics in electrical and electronics engineering, such as circuit design, power systems, and instrumentation.
- ✓ Facilitation of Research and Innovation: A fully electrified laboratory provides the necessary infrastructure to support advanced research activities in areas including renewable energy, power electronics, control systems, and smart grid technologies. This fosters innovation and contributes to the development of context-specific engineering solutions.

- ✓ Support for Sustainable Energy Education: The electrified lab environment facilitates experiments related to sustainable and renewable energy sources, such as solar and wind power systems. This supports global and national efforts toward clean energy adoption and environmental sustainability.
- ✓ Promotion of Laboratory Safety and Compliance: Modern electrification incorporates advanced safety measures, reducing the risk of electrical hazards. This ensures a safe environment for students and researchers to conduct experiments involving high-

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The electrification of power and electronics laboratories plays a critical role in enhancing the quality and relevance of engineering education in the 21st century. These laboratories serve as a bridge between theoretical knowledge and practical application, enabling students to gain hands-on experience with electrical systems, components, and technologies. As engineering curricula continue to evolve in response to rapid technological advancements, the demand for well-equipped, accessible, and modernized laboratory environments

nts has become more pressing than ever.

Traditionally, power and electronics labs relied heavily on physical equipment and in-person instruction, which, although effective, often imposed significant constraints on scalability, cost, and accessibility particularly in developing countries and underfunded institutions. In recent years, however, the integration of digital tools, remote access technologies, and simulation platforms has begun to transform the landscape of engineering education. These developments have given rise to what is now referred to as the "electrification" or modernization of educational laboratories, where digital infrastructure complements or even replaces traditional setups.

Modern laboratory environments now incorporate virtual laboratories, real-time simulations, Internet of Things (IoT) integration, and machine learning-based control systems to simulate and replicate real-world conditions. These advancements not only make learning more flexible and inclusive but also align educational outcomes with current industry standards. According to recent studies on ResearchGate and other scholarly platforms, such innovations are particularly beneficial for institutions facing physical, economic, or infrastructural limitations, allowing students to access and interact with sophisticated systems remotely.

This chapter provides a comprehensive review of the latest developments in the

electrification of power and electronics laboratories. It explores trends in virtual labs, remote learning tools, and the integration of smart technologies, drawing on contemporary literature and case studies. The aim is to underscore the importance of modernized lab environments in preparing students for careers in power engineering, electronics, renewable energy, and related fields, while also identifying existing challenges and potential solutions for future improvements.

2.2 Evolution of Power and Electronics Laboratories

Power and electronics laboratories have historically played a foundational role in engineering education, serving as critical platforms where theoretical concepts are translated into practical applications. These laboratories facilitate experiential learning by allowing students to design, construct, test, and analyze electrical circuits and systems, thereby deepening their understanding of classroom-taught theories. In traditional laboratory environments, students gain essential competencies in circuit assembly, measurement techniques, fault analysis, and system behavior under various load conditions skills indispensable for careers in electrical and electronic engineering.

However, the conventional model of laboratory-based instruction is increasingly challenged by a variety of logistical, economic, and infrastructural constraints. The initial investment required to establish a fully equipped power or electronics laboratory can be prohibitively high, especially for institutions in developing regions. Ongoing maintenance costs, equipment obsolescence, and the need for continuous updates to align with technological advancements further strain limited educational budgets [4], [5]. Additionally, physical laboratories often suffer from access restrictions caused by limited facility space, equipment availability, and the necessity of on-site presence barriers that disproportionately affect students in remote or underfunded regions.

In light of these limitations, the evolution of power and electronics laboratories has shifted toward more adaptive, scalable, and resource-efficient models. A prominent

example of such innovation is the introduction of low-cost educational lab kits developed by Banerjee et al. [6] in partnership with the IEEE Power Electronics Society. These modular kits are specifically designed to function in low-resource environments, offering portability, affordability, and ease of assembly. They allow students to engage directly with core concepts in power engineering such as voltage regulation, energy conversion, and cir

cuit dynamics outside the confines of conventional laboratory infrastructure.

The pedagogical impact of such low-cost kits is substantial. By fostering active, hands-on learning, these tools promote a deeper cognitive engagement with experimental tasks. As students are responsible for assembling circuits, conducting measurements, and interpreting results, they develop a stronger conceptual foundation and improved problem-solving skills. Empirical studies have demonstrated that this approach enhances retention rates and supports diverse learning styles, particularly among students with limited prior exposure to technical experimentation [7].

The evolution of laboratory instruction has also been catalyzed by the global transition to remote and hybrid learning models in response to the COVID-19 pandemic. With restrictions on physical access to laboratories, many educational institutions accelerated the deployment of portable lab kits, virtual labs, and simulation platforms as viable alternatives or supplements to traditional setups [8]. These solutions offer flexibility in time and space, allowing students to conduct experiments from home or in distributed learning environments. The integration of software-based simulation tools with physical kits further enriches the learning experience by enabling comparison between theoretical models and real-world behavior.

Collectively, these advancements mark a significant transformation in the delivery of engineering education. The shift from fixed-location, high-cost laboratory setups to portable, accessible, and digitally integrated alternatives represents a paradigm shift toward democratizing access to technical education. As engineering curricula continue

to evolve in response to global challenges and technological progress, the ongoing innovation in laboratory design will be central to shaping the next generation of skilled professionals.

2.3 Virtual Laboratories and Remote Learning

The role of virtual laboratories in transforming engineering education is becoming increasingly significant, particularly in disciplines like power and electronics, where students traditionally rely on hands-on experiments. These virtual labs provide flexible, interactive platforms that simulate real-world experiments and systems in a digital environment. The integration of cloud-based systems, real-time simulations, and emerging technologies like IoT, VR, and AR is making these virtual labs not only a supplement to traditional teaching but also a crucial tool in modern educational frameworks.

2.3.1 Platforms and Tools for Virtual Laboratories

Several platforms and tools have emerged to support the development of virtual laboratories, providing students with access to high-fidelity simulations and enabling them to conduct experiments remotely. Some key platforms include:

- **MATLAB/Simulink:** One of the most widely used platforms for virtual experimentation in engineering, particularly in power systems and electronics. Simulink allows students to model, simulate, and analyze complex systems, such as power grids or circuits, and test their designs in a virtual environment. The platform is highly interactive and integrates seamlessly with hardware, allowing for hybrid experiments that combine virtual simulation with physical hardware.
- **LabVIEW:** A graphical programming environment that supports the design of virtual labs, particularly in the context of control systems, data acquisition, and power electronics. It is frequently used in university labs for simulating and testing various control algorithms and for real-time system modeling. LabVIEW has been utilized for smart grid simulations and allows students to interact with 8 models of power systems and assess their behavior under different scenarios.
- **PSpice:** A simulation tool for designing and analyzing analog and digital circuits. It provides students with a platform to explore circuit behavior and perform simulations to evaluate system performance. PSpice is commonly used in virtual laboratories focusing on power electronics and circuit design.

- **Proteus:** Another simulation platform widely used in educational settings for virtual electronics labs. It offers tools for designing circuits, testing components, and visualizing system behavior. Students can test their designs virtually before creating physical prototypes.

These platforms, among others, have become integral components in the evolution of virtual labs, helping students understand and experiment with complex systems without the need for costly physical setups.

2.3.2 Case Studies of Virtual Laboratory Implementation

The successful implementation of virtual laboratories has been documented in several studies, demonstrating their potential in enhancing engineering education, especially in resource-constrained settings.

1. **Isaac et al. (Nigeria):** In a study conducted by Isaac et al. [9], the implementation of virtual laboratories in Nigerian universities was thoroughly explored. The researchers found that virtual labs helped bridge the gap in regions with insufficient physical laboratory resources, enabling students to continue their learning remotely or in a hybrid model. In institutions where traditional labs were underfunded, virtual labs became an invaluable tool, allowing students to perform experiments that were otherwise inaccessible. The study revealed that virtual labs were particularly beneficial in subjects like power electronics, where simulations provided a platform to design and test circuits in a safe, controlled environment.

2. **Ponce et al. (Smart Grid Education):** Ponce et al. [10] developed a real-time simulation environment for power electronics and smart grid education, using MATLAB/Simulink and LabVIEW. Their study focused on creating a dynamic learning experience, where students could engage in simulations that mirrored real-world systems.

ms, such as power grids and renewable energy setups. The use of these platforms enabled students to analyze and optimize system performance, develop control algorithms, and understand the intricacies of power flow, voltage regulation, and fault detection in smart grid systems. This initiative was particularly valuable for institutions with limited access to expensive physical equipment but which still needed to teach high-level concepts in power engineering.

3. **Cloud-based IoT-enabled Systems (Hamidi et al.):** Another innovative example is the integration of cloud computing and IoT in virtual labs, as demonstrated by Hamidi et al. [12]. The researchers implemented cloud-based systems that allowed for real-time monitoring and control of experiments via the internet. By integrating IoT devices, students could conduct experiments remotely, monitoring sensors, actuators, and data from connected devices in real-time. This approach offered unparalleled flexibility and scalability, allowing multiple students to access the same experiments simultaneously. This setup is especially beneficial for large universities or networks of schools that need to offer remote learning opportunities to students in different geographical locations.

2.3.3 Benefits and Challenges of Virtual Laboratories

Virtual laboratories offer several key benefits, particularly in terms of accessibility, flexibility, and cost-efficiency:

- **Accessibility and Equity:** Virtual labs provide students, particularly those in underserved or remote areas, with access to the same high-quality learning resources as those in well-funded institutions. By removing the need for physical infrastructure, virtual labs ensure that every student, regardless of location or financial situation, can participate in practical experimentation.
- **Cost-Effectiveness:** Traditional labs require significant investment in equipment, space, and maintenance. Virtual labs, in contrast, eliminate the need for expensive physical setups, making them a more sustainable solution for many educational i

institutions. The initial cost of setting up virtual lab platforms is typically lower than that of purchasing physical laboratory equipment.

- **Flexibility and Scalability:** With virtual labs, experiments can be conducted at any time, and students can repeat experiments as many times as needed. Furthermore, virtual labs can be scaled to accommodate large numbers of students without requiring additional physical space or equipment.

However, there are some challenges to be addressed:

- **Technical Barriers:** Not all students have access to the necessary hardware or internet connectivity to fully participate in virtual lab activities. While cloud-based systems can alleviate some of these issues, bandwidth limitations and lack of access to powerful computers may still pose a challenge in some regions.
- **Lack of Hands-on Experience:** While virtual labs replicate real-world experiments, they cannot fully substitute for physical, hands-on experience. Some aspects of learning, such as understanding the physical behavior of materials or troubleshooting real-world issues, may not be fully captured in virtual environments.

2.3.4 Future Directions for Virtual Laboratories

The future of virtual laboratories in engineering education looks promising, especially as technologies such as Virtual Reality (VR) and Augmented Reality (AR) continue to evolve. VR offers an immersive environment where students can interact with three-dimensional models of circuits, power systems, or machinery, providing a more hands-

on feel in a virtual setting. AR, on the other hand, can augment physical experiments with real-time data visualizations, guiding students through procedures or offering real-time feedback on their actions.

Furthermore, as 5G and edge computing technologies continue to advance, the potential for remote laboratories becomes even greater. Students could conduct experiments on d

devices that are physically located in different regions, controlled via the internet, while real-time data is streamed to their devices.

2.4 Integration of Advanced Technologies

The integration of advanced technologies into power and electronics laboratories is reshaping the educational landscape and the functionality of engineering infrastructure. By incorporating innovations such as the Internet of Things (IoT) and machine learning (ML), laboratories can offer dynamic, adaptive, and data-driven learning environments that mimic real-world industrial settings. These technologies also support the evolution of smart grid systems and intelligent energy management strategies, which are increasingly important in modern power systems.

2.4.1 Role of IoT in Smart Laboratory and Grid Systems

The Internet of Things (IoT) refers to a networked system of interconnected physical devices ranging from sensors to actuators that communicate and exchange data through the internet or local networks. In the context of power and electronics laboratories, IoT facilitates the automation, monitoring, and remote control of various experimental setups, thereby enhancing safety, efficiency, and interactivity.

Saleem et al. [10] examined the deployment of IoT in smart grid environments, demonstrating that IoT-enabled systems significantly improve real-time decision-making and energy distribution. In educational settings, IoT can be used to collect and analyze experimental data, monitor laboratory conditions (e.g., temperature, voltage levels, power consumption), and remotely manage test benches and instruments. This capability is particularly beneficial for resource-constrained institutions where staff may

be limited and manual monitoring is inefficient or impractical.

Moreover, IoT integration supports remote experimentation, allowing students to interact with physical lab equipment via cloud-based platforms. This is especially valuable in blended or distance learning environments, where physical access to laboratories is restricted.

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2.4.2 Machine Learning in Power Electronics Optimization

Machine Learning (ML), a subset of artificial intelligence (AI), involves algorithms that learn from data to make predictions or decisions without explicit programming. In the field of power electronics, ML offers robust solutions for optimizing system performance, predictive maintenance, and fault diagnosis.

Bahrami and Khashroum [14] conducted an extensive review of machine learning applications in power electronics, identifying several key use cases such as:

- **Control Optimization:** ML algorithms can tune control parameters for converters and inverters more efficiently than traditional methods, especially in non-linear and time-varying systems.
- **Fault Detection and Classification:** By training models on historical and real-time data, ML systems can detect anomalies in circuits, power modules, and battery systems with high accuracy.
- **Energy Efficiency:** ML models can forecast load profiles and optimize energy consumption strategies in smart grids and laboratory environments.

In academic laboratories, integrating ML tools allows students to simulate and implement intelligent control systems. They gain hands-on experience with technologies that are increasingly being adopted across industries, from renewable energy systems to electric vehicles.

2.4.3 Educational Impact and Industry Alignment

The convergence of IoT and machine learning in laboratory design has profound

implications for engineering education. These technologies foster experiential learning by enabling real-time interaction with data-rich environments, thereby reinforcing theoretical knowledge through practical application. Students develop competencies in data acquisition, programming, systems integration, and AI-driven analytics skills that are in high demand in modern industries.

Furthermore, smart laboratories equipped with IoT and ML components can simulate complex scenarios such as grid faults, energy storage behavior, or dynamic load changes. These simulations expose students to the operational intricacies of intelligent grid systems and power electronics, bridging the gap between academic training and industrial practice.

From an institutional perspective, the adoption of these technologies aligns curricula with the needs of Industry 4.0, which emphasizes automation, data exchange, and smart systems. Universities that integrate IoT and ML into their teaching infrastructure position their graduates for success in evolving fields such as renewable energy systems, power quality management, and smart infrastructure development.

2.5 Case Studies of Modernized Laboratory Implementations

2.5.1 High Voltage and Power Electronics Laboratory Ohio State University

The High Voltage and Power Electronics Laboratory (HVPEL) at Ohio State University serves as a prominent example. According to Ferdowsi and Case [15], the lab immerses learners in end-to-end system design, renewable energy, and electric vehicle systems.

2.5.2 Applied Power Electronics Laboratory IIT Bombay

The Applied Power Electronics Laboratory at the Indian Institute of Technology (IIT) Bombay is another exemplary model. As reported by Agarwal and Singh [16], the lab integrates dSPACE and OPAL-RT platforms for hardware-in-the-loop simulations.