Quest Journals
Journal of Electronics and Communication Engineering Research
Volume 12 ~ Issue 1 (Jan.-Feb. 2026) pp: 28-33
ISSN(Online): 2321-5941
www.questjournals.org

Research Paper

A Practical Review of Safety Practices and Protection Devices in Electrical Engineering Workshops: Lessons from Common Experiments and Real-World Applications

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Abstract
Electrical engineering workshops are a crucial part of undergraduate training. They let students move from theory to real practice by working directly with circuits, motors, transformers, power electronics, and basic wiring. In these labs, learners build important skills: putting things together, taking measurements, finding and fixing faults, and understanding how systems behave. Experiments usually happen in low-voltage setups (under 1 kV) using breadboards, power supplies, oscilloscopes, multimeters, function generators, and small machines. The labs build deep knowledge and confidence, but they also bring serious dangers that require strict safety rules. Risks include electric shock from accidental contact, arc flash during short circuits or bad connections, overcurrent problems causing overheating or fires, and mechanical injuries from unguarded moving parts. These dangers are much higher when students are still learning to spot risks, using equipment for the first time, or working fast in busy lab groups.
Keywords: *electrical workshop safety, laboratory hazards, protection devices, IEC standards, TCVN regulations, academic laboratory safety*

I. Introduction

Practical,hands-on workshops play a pivotal role in undergraduate electrical engineering education, offering students the indispensable experience needed to bridge theoretical knowledge with real-world applications.Activities such as circuit building, motor testing, transformer operation, power electronics prototyping, three-phase system analysis, and basic installations enable learners to cultivate critical skills,including assembly, measurement, troubleshooting, and system analysis. These exercises are typicallycarriedout in low-voltage settings (below 1 kV) withequipment such as breadboards, power supplies, oscilloscopes, multimeters, function generators, and small machines. While these labs enhancetechnical proficiency and self-assurance, they simultaneously expose students and instructors toinherent electrical hazards,necessitating rigorous adherenceto safety protocols.Key risks include electric shock from unintended contact, arc flashes during short circuits or faulty connections, overcurrent incidents leading to overheating or fires, and mechanical injuries caused byexposed rotating components.Such hazards are exacerbatedbyfactors likestudents' inexperiencewith the equipment, limitedawarenessof risks, large lab groupsizes,andtimepressures. This review targets apressing issue: the persistence of preventable accidents in educational electrical workshops despite theavailabilityofrobust safety standards and protective devices.While industrial workplaces benefit from stringentregulations and comprehensive incident reporting systems, university laboratories often lag behind in implementingcomparablesafetypractices.Contributingfactors include disparitiesin student preparedness, overcrowdedclasses, inadequateinstructor-to-student ratios, aging labinfrastructure—particularly in underfunded institutions—and experimental setups that divergefromcommercial safety standards. Statistical trends shed light on the gravity of the problem.From 2011 to 2024, over 2,000 occupational fatalities causedby electrical incidents wererecorded in the U.S., translating to an average rate of approximately 0.11 per 100,000 workers annually.Whileconstruction and maintenance present higher fatalityrates, academic environments frequentlygo unreported. An analysis of 176 laboratory incidents in China between 1984 and 2024 revealedthat over 78% involvedfires or explosionstied to electrical faults suchas overloaded circuits, insulation failure, or improper grounding practices. Similar trends surface worldwide; for example, studies from Taiwanese universities underscoredeficiencies in institutional safety measures and student training within electrical and electronic engineering programs.IntheUnited States,somereports suggest academiclab accident rates could be 10–50 times greater than those in industrialsettings due to users' lackof experience and the ad hoc nature of experimental conditions. Research on laboratory electrical safety consistently underscores the importance offostering a proactive mindset and cultivating an ingrained culture of safety. Academic institutions bear a uniqueresponsibility toshieldstudentsfromharmwhile nurturing an enduringsense of risk awareness critical fortheir professional lives. The complexity of modern electrical equipment—characterizedby high-frequency switching components andprecision measurement devices—furtherintensifies this responsibility.A survey conducted across electrical engineering departments in Taiwan highlighted systemicissuessuch as infrequent training regimens, inadequate institutional dedicationto safety practices,andweakenforcement ofsafety protocols—concerns echoed in many partsof Asia. The University of Illinois Division of Research Safety offers actionablerecommendations for minimizing invisibleyet potentiallyfatal risks. These include routine inspections of equipment, mandated use of personal protective equipment (PPE), and strictprohibitionson live-part contact.A2021ResearchGate studyon lab equipment safety reiteratesthat misuse of devices or overlooked environmental factors can leadto health hazards, accidental discharges, or fires, necessitating unrelentingvigilance. Admiredinstitutions like Massachusetts Institute of Technology (MIT)provideexemplary modelsforenforcing stringentsafety measures. MIT’s electrical safety guidelines require protective shielding forexposed live conductors, mandatory specialized training for high-voltage applications, and strict enforcementpoliciesthatinclude disciplinary actions such as potential expulsion for noncompliance.The OccupationalSafetyand Health Administration (OSHA) further reinforces electricity's classification as a critical workplace hazard demanding multi-layered protective strategies—principles reflected in Howard University’s LaboratorySafetyManual. These examples highlight best practices that university laboratories should prioritize to ensure greater alignment with the rigor observed in industrial safety standards.

In Vietnam, where engineering enrollment has grown rapidly and hands-on training is a core requirement, similar hazards exist but are compounded by local realities. Many university workshops operate with legacy equipment, variable maintenance budgets, and increasing class sizes, raising the likelihood of procedural errors or device failures (Tadee et al., 2025). National standards, such as TCVN 7447:2010 (adopting IEC 60364 for low-voltage electrical installations), TCVN equivalents for protective devices, and MOET (Ministry of Education and Training) safety directives, provide a regulatory framework, yet implementation in educational settings varies (Vietnam National Standards, 2010). Phenikaa University’s electrical lab protocols, for example, prohibit jewelry, mandate anti-static footwear, and require pre-experiment checks to minimize shock risks — practices that reflect broader efforts to align with international norms while addressing local constraints (Phenikaa University, n.d.).

This review aims to synthesize existing literature, international and Vietnamese standards (IEC 60364 series, IEC 61010 for laboratory equipment safety, NFPA 70E for arc flash protection, and relevant TCVN documents), and practical insights gained from daily workshop teaching (NFPA, 2024; Araneo et al., 2019.

By consolidating these elements, the paper seeks to contribute practical, evidence-informed guidance that strengthens safety culture in electrical engineering workshops, reduces preventable incidents, protects students and staff, and better prepares future engineers to embed risk management in their professional practice.

II. Common electrical hazards in workshops

Electrical workshops in undergraduate programs put students in front of various hazards that can usually be handled with good care, but if ignored they can cause serious injury, break equipment, or start fires. The dangers mostly come from direct work with live circuits, energized parts, and setups that don’t always follow standard industrial rules. The most common and immediate hazard is electric shock — either from touching live wires directly or indirectly through bad insulation, exposed terminals, or missing grounding. In normal lab experiments like building circuits on breadboards, starting motors, testing transformers, or connecting power supplies, students can easily touch live spots while using multimeters or oscilloscopes. Even low-voltage setups (24–400 V) can be dangerous: currents as low as 10–20 mA can lock muscles so you can’t let go, and 50–100 mA across the chest might cause ventricular fibrillation. How bad it gets depends on the path (hand-to-hand or hand-to-foot), how long contact lasts, skin resistance (much lower when wet or sweaty), and frequency — AC at 50/60 Hz is especially risky because of higher let-go thresholds. Lab conditions make it worse: humid air, conductive floors, or students wearing metal rings/jewelry all increase conductivity and danger.

Arc flash and arc blast are another big hazard, specially in experiments with high-current sources, capacitors, or three-phase setups. An arc flash happens when current jumps through air by mistake, reaching temperatures over 19,000 °C and sending out intense light, heat, pressure waves, and molten metal. In student labs, it’s often caused by accidental shorts while connecting wires to live busbars, dropping tools across terminals, or forgetting to de-energize before changing something. Even low-voltage experiments can have damaging arcs from stored energy in capacitors or inductors. The energy released can cause bad burns, blindness from UV/IR light, hearing damage from the blast, or internal injuries from flying pieces. NFPA 70E defines arc flash boundaries and PPE requirements, but lots of educational workshops don’t have formal arc flash risk assessments or labeled zones, leaving students and teachers open to danger during high-power work like starting induction motors or synchronizing generators.

Overcurrent and short-circuit faults are some of the most frequent causes of lab accidents and broken equipment. Overcurrent comes from overloading circuits (too many things plugged into one outlet or power strip), wrong component ratings (underrated resistors or wires), or mistakes in wiring on breadboards. Short circuits usually happen from crossed wires, solder bridges, reversed polarity, or damaged insulation after repeated student use. These can create huge heat, melt wires, ignite insulation, or make upstream fuses/breakers trip suddenly — sometimes with force. In three-phase tests, unbalanced loads or phase reversal can overheat motors or make them spin backward. Fire risk jumps when flammable stuff (paper, plastic cases, cleaning solvents) is near fault points. Overheating cables or connectors from bad connections or loose terminals is another quiet but dangerous problem, often noticed too late in busy labs.

Mechanical hazards linked to electrical systems shouldn't be ignored either. Rotating machines — DC motors, induction motors, synchronous machines — can cause entanglement, pinch injuries, or flying debris if guards are missing or removed during demos. Electromagnetic forces in high-current coils or transformers can make unexpected movement or vibration. Also, electromagnetic interference (EMI) and ergonomic problems (bad lighting, awkward positions during long wiring sessions) indirectly lead to mistakes that cause electrical faults.

In the Vietnamese context, these hazards get worse because of real conditions: many university workshops still use old equipment with worn insulation or outdated protection, class sizes often go over 30–40 students per session (which cuts supervision), and tropical humidity raises leakage currents and corrosion. Common student experiments — like building rectifier circuits, testing transformers under load, or wiring distribution panels — usually involve live debugging, which increases exposure. Anecdotal reports from Vietnamese engineering departments mention repeated problems like RCDs tripping from small leaks, fuses blowing from polarity errors, and occasional minor shocks when probing oscilloscopes without proper isolation.

Recognizing and sorting these hazards is the first step to controlling them. The next sections look at specific protection devices and systems meant to stop faults, limit energy release, and prevent contact — drawing from international standards and real workshop experience to help create safer learning spaces.

III. Key protection devices and systems

To address the electrical hazards discussed earlier, electrical engineering workshops must implement a multi-tiered safety strategy. This approach integrates passive design elements, active protection devices, procedural safeguards, and personal safety measures. Thefollowing section explores the main protection systems and devices utilized in low-voltage educational environments, emphasizing their operational principles, criteriafor selection, practical use in student experiments, potentialdrawbacks, and compliance with both international and Vietnamese standards. The focus remains on pragmaticand cost-efficient options suited for university labs, where equipment is shared among numerous users, and experimentalsetupsare frequentlyadjusted. Grounding and earthing systems constitute the foundational defense against indirect contact shocks and the accumulation of static electricity. In configurations such as TT, TN-S, or TN-C-S systems (inaccordancewith IEC 60364 / TCVN 7447:2010), a low-impedance earth path safelychannels fault currents to the ground.This action triggers protective devices and prevents exposed conductive components from becoming energized. Workshop safetyis further enhanced through equipotential bonding,which connects all metallic workshop surfaces—machine frames, equipment enclosures, and workbenches—to a unified earth electrode,typicallya copper rod or plate embedded in soil.Thisapproach reduces touch voltage differences to safeguardusers. Nonetheless, students frequently make errors suchasneglecting bonding wires whilesetting up breadboards or using worn extension cords without proper grounding pins. Effective grounding greatlymitigates shock hazards since fault currents areredirected to the earth rather than through individuals. Maintenance involves periodic earth resistance checks—targetvaluesbeing less than 5 Ω for general labs andbelow 1 Ω for delicate equipment—using clamp meters or fall-of-potential testing. In Vietnam's humid climate, corrosion of earth electrodes canbeproblematic; visual inspections and resistance measurementsmust therefore be conducted every sixto twelve months. Devices providing overcurrent protection preventharm causedby overloads or short circuits, safeguarding wiringsystems from overheating, insulation failures, and fire risks. Workshop panels predominantly feature Miniature Circuit Breakers (MCBs) and Molded Case Circuit Breakers (MCCBs) due to their ability tobe reset and theirprecision in tripping behavior (e.g., B, C, D type curves). For instance, Type C MCBs with magnetic trip thresholdsof fiveto ten times the nominal current work well for experiments involving motor startup currents, such asDC motor speed control or induction motor tests. While fuses remain common in older labs dueto lower costs,they lack reset functionality and are more challenging to coordinate effectively. Proper selection requires matching a device's rated current withthe circuit load (e.g., a 16 A MCB for circuitsdrawing around 10 A), ensuring discrimination betweenprotectiondevices (withupstream breakers set to trip more slowly), and adhering to TCVN 6434 (IEC 60898 standards for MCBs). However,issues persist in practice, such as students overloadingpower strips during group tasks.This often causes nuisance trips or unchecked overheating,underscoring the importance ofassigning dedicated outlets toindividualworkspaces and implementing load-monitoring systems. Residual current devices (RCDs/RCCBs/RCBOs) offersuperior personal protection against electric shockscausedby leakage currents from insulation failures or accidental contact. Functioning based on phase-to-neutral current imbalance detection, thesedevices trip whenleakage exceeds 30 mA within 300 milliseconds—or even faster at higher sensitivities (e.g.,10 mA in wet conditions). RCBOs combine RCD functionalitywith overcurrent protection,makingthem ideal for controlling individual bench circuits. Vietnamese workshops follow TCVN 6950 (IEC 61008) standards for RCCBs, requiring a 30 mA sensitivity for final circuits. Testing routines involve monthly push-button inspections and annual trip-time validationsviaspecialized testers. Commonlyprotected lab equipment includes oscilloscope probes, power supplies, and breadboard components thatexpose students to live circuits during hands-on tasks. Without RCDs, minor leakagescaused by factorslike wet hands or faulty probes can go unnoticed, possiblyresulting in electric shocks that might escalate in severity. The wide deployment of these devices has substantiallylowered accidental risk levels in educational settings. Surge protection devices (SPDs), on the other hand, defend sensitive electronics suchas oscilloscopes, function generators, and computers against transient overvoltages caused by lightning strikes, switching surges, or nearby electrical faults. SPDs are categorized into three types: Type 1 SPDshandle direct lightning exposure; Type 2 safeguardagainst indirect surges; and Type 3 protectend-use appliancesat outlets.GivenVietnam's tropical conditions with frequentthunderstorms, installing Type 2 SPDs at distribution panels and Type 3 SPDs at bench-level outlets isstronglyrecommended,as outlined by TCVN standards and IEC 61643 guidelines. In tropical Vietnam, where lightning is frequent, Type 2 SPDs installed at distribution boards and Type 3 at bench outlets are recommended per TCVN standards and IEC 61643. Labs with long cable runs or external power feeds benefit most, preventing damage to costly instruments.

Personal protective equipment (PPE) and Insulating Tools provide the last line of defense. Insulated gloves (rated 1000 V), safety mats (dielectric strength >5 kV/mm), face shields, and arc-rated clothing are essential for live work. IEC 61010-1 (laboratory equipment safety) and NFPA 70E guide PPE selection based on hazard analysis. In low-voltage workshops, Category 0 or 2 arc-rated clothing suffices for most tasks, but students often neglect PPE due to discomfort—emphasizing mandatory use and training.

Lockout/Tagout (LOTO) Procedures ensure energy isolation during maintenance or machine experiments (e.g., motor disassembly). Padlocks and tags applied to breakers prevent accidental re-energization. OSHA and Vietnamese MOET guidelines mandate LOTO for any work on de-energized equipment, with training and audits required.

These devices, when properly selected, installed, and maintained, create multiple barriers against hazards. However, effectiveness depends on regular testing (e.g., annual RCD/MCB checks), student training, and integration into lab protocols. The next section examines practical lessons from real incidents to illustrate how these systems perform—or fail—in everyday workshop scenarios.

IV. Standards, regulations, and best practices

Standards, rules, and best practices form the foundationof electrical safety in teaching workshops. They guide system design,installation, operation, maintenance, and inspection to safeguardstudents, instructors, and equipment in low-voltage environments. Globally, IEC 60364 serves as the primary standardfor low-voltage installationsup to 1,000 V AC or 1,500 V DC. The latest edition (IEC 60364-1:2025) outlines principles for shock protection (Part 4-41), thermal effects (Part 4-42), overcurrent (Part 4-43), and equipment selection/installation (Part 5 series), emphasizing risk assessment, earthing systems, and verification. Many national codes,like Vietnam'sTCVN7447series, closely mirror IEC 60364 while addressing local needs. For lab equipment specifically, IEC 61010-1 ensures protectionagainst electrical,mechanical, thermal, and radiationhazards with requirementsforinsulation,protectivebarriers,userinstructions, and safetylabels. In workplacesafety,NFPA 70E (2024 edition) goes beyond installation rules, focusing on practices like arc flash riskassessments, boundaries (limited/restricted/prohibited), PPE categories (0–4), energized work permits, and lockout/tagout(LOTO).ThoughU.S.-centric, itsinfluenceextends globally and is particularly relevant for high-powerlabactivities.NFPA 70E alignswithOSHA regulationstoreduceshock, arc flash, and other risks. InVietnam, electrical safety standards alignwithIEC 60364 through the TCVN 7447 series. Key elements include TT/TN earthing systems, 30 mA RCD protection for final circuits, equipotentialbonding, and routine inspections. Complementary standards like TCVN6950cover RCCBs, while guidelines fromVietnam'sMinistryofEducation and Training mandate safety training, emergencyplans, and certified equipment.SchoolslikePhenikaaUniversity adoptpracticalmeasures toaddress challengeslikehumid climates, outdated equipment, and largeclasssizes. Effective safetypractices incorporate these standards into routine activities. Pre-lab safety briefings and signed agreements ensure rule awareness.Daily equipmentchecks detectissuesearly, whilelabeledwarnings and dedicatedbenchcircuits helppreventhazards.EnforcingLOTO procedures for de-energized work and providingPPE(insulated gloves, safety glasses, arc-rated clothing)are essential. Hands-on training with de-energized mock-ups or simulations fosters confidence. Incident reporting and annual retrainingrefine protocols overtime. However, Vietnameseworkshops face challengessuch as limitedbudgets, high educator workloads, andinconsistentadherence to standards in older facilities.Low-cost strategies like prioritizing RCDs, using student-led safety checklists, and promoting peermonitoring canaddress these issues.Withpropertraining, regular audits, and clearpolicies,workshopscanachieve safer environments while preparing students for professional practice.

V. Challenges and recommendations for electrical engineering workshops

Improving safety in electrical engineering workshops is challenging, especially in developing countries like Vietnam. Budget constraints often hinder schools from upgrading equipment,leaving many with outdated tools, worn insulation, insufficient RCD protection, and a higher riskof faults. Overcrowdedclassesof30–50 students make supervision difficult,increasing the likelihoodof errors. Students often lack prior knowledge of electrical risks, leading to common mistakes such aspoor grounding, socket overloading,andbypassing safety interlocks. Tropical humidity accelerates corrosion and insulation damage,while irregular maintenance exacerbates these issues. Compliance with TCVN and IEC standards is inconsistent due to weak enforcement, limited certified tools, and a tendencyto prioritizespeedoversafety.Additional challenges include high student-to-teacher ratios, lackof safety staff, inadequate training materials, and resource scarcitythat often prioritizes academic results over safety investments. Toaddress these challenges practically and affordably: integrate safety modules intocourses with hands-on RCD/MCB testing and hazard identification;mandate certification before lab access;implement student-led safety checklists and peer monitoring;prioritizecost-efficient upgrades suchas installing 30 mA RCDs,replacingdamaged cords, adding surge protectors,andconductingbiannual earth resistance and RCD trip-time tests.Display clear safety signs, set arc flash boundaries, andequip benches with emergency stop buttons. Enforce strict lockout/tagout procedureswithproper training;utilize simulation software to minimize live work;build anincident-reporting culture for continuous improvement; and seek partnerships with MOET or industryfor training support and donated tools. Incrementaladoption of these measurescansignificantly enhance safety while maintaining functionality.

VI. Conclusion

In conclusion, this review highlights why safety is critical in electrical engineering labs by addressing hazards (electricshocks, arc flashes, overcurrents, fires) and protectivemeasures (grounding, RCDs, MCBs, PPE, LOTO) aligned with standards like IEC 60364:2025and NFPA 70E:2024.Basedonglobaldata and Vietnam's educational conditions, it emphasizes that while hands-on learning inherently involves risks, most accidents arepreventable through proactivemeasures like layered protections, quality training, and preventive maintenance. Althoughchallenges like outdatedfacilities and limited budgetspersist, adoptingcost-effective strategies suchas mandatory training, incremental upgrades, and improved reporting ensuressafer learningenvironments.Prioritizing safety not onlyprotectsindividuals but alsoinstillsprofessionalstandards in future engineers,promoting a culture of risk awareness in an increasingly complex electrical field. With thoughtful implementation, workshops can become benchmarks for safe and effective practical education.

*Acknowledgments: I sincerely thank Thai Nguyen University of Technology (TNUT) for their invaluable support in the publication of this research article.

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