CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter outlines the systematic approach adopted for the electrification of the Electronics and Power Laboratories. The methodology includes site assessment, selection and installation of equipment, wiring and safety planning, calibration, and testing procedures. Emphasis is placed on integrating a range of analog, digital, renewable energy, communication, and measurement systems to provide a functional and future-ready educational environment.

3.2 Project Design Framework

The electrification of the labs was structured into the following major phases:

i. Needs Assessment and Planning
ii. Power Design and Load Analysis
iii. Equipment Categorization and Zoning
iv. Installation of Electrical Infrastructure
v. Equipment Integration and Configuration
vi. Testing, Calibration, and Safety Checks
vii. Training and Demonstration

3.3 Needs Assessment and Planning

A comprehensive needs assessment was carried out to determine the electrical load requirement of each piece of equipment and define zones for practical sessions. Equipment was grouped into functional domains:

- Measurement and Instrumentation
- Energy Systems (Renewable and Conventional)
- Analog and Digital Electronics
- Control and Communication Systems

Each group was assigned a designated lab section to avoid power interference and improve workflow.

3.4 Power Design and Load Analysis

The power design and load analysis are critical components in determining the electrical infrastructure required to support the safe and reliable operation of laboratory equipmen

t. The total power consumption was calculated based on the rated power specifications of all equipment expected to be operated concurrently or intermittently within the laborat ory. This evaluation ensures that all electrical installations, including wiring, protective de vices, and power sources, are appropriately sized to handle the electrical load without ris k of overload, voltage drop, or system failure.

3.4.1 Equipment Inventory and Power Ratings

The primary equipment considered in the load analysis included the following:

Variable Transformer and Voltmeter

- Typically rated between 0.5 kVA to 2 kVA, depending on the model.
- Used for regulated voltage output in AC testing applications.

AC Motor Assembly Trainer

- Comprises single-phase and three-phase motor configurations.
- Power consumption ranges between 1 HP (746 W) and 3 HP (2.24 kW).

Wind and Solar Energy Training Systems

- Includes power electronic converters and small-scale generators.
- Power usage may vary between 300 W to 1.5 kW during simulation and testing.

Audio & Digital Hardware Training Boards

- Operate on low-voltage DC (5V or 12V), with current consumption typically below 2A.
- Total power demand estimated around 60 W per board.

Wattmeter, Analog Meter, and Digital Multimeter

- Individually consume negligible power (<10 W), but collectively accounted for in s tandby mode.

GSM Trainer and Communication Modules (FM Receiver/Transmitter)

- These modules require stable DC input (typically 12V at 1–2A), amounting to 24 W per module.

3.4.2 Load Classification

The devices were categorized as either **resistive**, **inductive**, or **mixed loads**:

- **Resistive loads**: Measurement equipment and trainers (e.g., wattmeters, digital bo ards)

- **Inductive loads**: AC motors, transformers, and rotating machines
- **Mixed loads**: Trainers incorporating power electronics and control modules

3.4.3 Maximum Demand Estimation

To estimate the Maximum Demand (MD), both diversity factor and load factor were applied. Although not all equipment runs simultaneously, the power design was sized to accommodate worst-case conditions.

Formula used:

$$Total\ laod\ \ (kW) = \sum Power\ Rated\ X\ Demand\ Factor$$

Based on the inventory, the total connected load was approximated at 6.5 kW, and the maximum demand was projected at 5.2 kW after applying a demand factor of 0.8.

3.4.4 Power Design Considerations

Using the calculated maximum demand:

- **Circuit Breaker Rating**: Selected to be 10–32A depending on the sub-circuit, based on expected current draw using:

$I = \frac{P}{V\cos\varnothing}$ Where, cos ∅ (power factor) is assumed to be 0.85 for inductive loads.

- **Cable Sizing**: Conductors were sized based on load current, length of run, and permissible voltage drop (max 5%). For a 5.2 kW load at 230V:

$$I = \frac{5200}{230\ x\ 0.85} = 26.6A$$

A 4 mm² copper conductor was selected, allowing for safety margin.

- **Socket and Outlet Distribution**: Sockets rated at 13A and 15A were distributed across workstations with individual MCBs for isolation and fault protection.

- **Backup Sizing:** The analysis also guided the sizing of UPS or inverter systems, ensuring support for at least 70% of the total load during power interruptions.

3.5 Equipment Categorization and Zoning

Based on their functions and voltage requirements, the equipment was zoned as follows:

- **Zone A – Renewable Energy Section:**
    - Wind Energy Training System
    - Solar Energy Training Panel
    - Variable Transformer
    - Wattmeter
- **Zone B – Electrical Machines and Power Systems:**
    - AC Motor Assembling Trainer
    - Speed/Slip Indicator
    - RLC Load Vector Analyzer
- **Zone C – Analog and Digital Electronics:**
    - Operational Amplifier Modules
    - Local Capacitor Units
    - Audio Amplifier
    - Frequency Meter
    - Sampling & Time Division Multiplex System
    - Audio & Digital Hardware Training Boards
- **Zone D – Instrumentation and Control:**
    - Variable Voltmeter
    - Analog and Multifunction Digital Meters
    - Digital Multimeter
    - Control Unit
- **Zone E – Communication Systems:**
    - GSM Trainer
    - FM Radio Receiver
    - FM Transmitter

3.6 Electrical Installation

The electrical installation was a critical component of the project, aimed at ensuring saf e, reliable, and efficient power distribution to all laboratory equipment and systems. The i nstallation process encompassed several sub-components, including cabling and wiring, provision of power outlets, the main distribution board (MDB), and a comprehensive gro unding system.

3.6.1 Cabling and Wiring

High-conductivity copper conductors were selected for all internal wiring due to their exc ellent electrical performance and durability. The conductor gauges were carefully chosen based on the total load current calculations, adhering to relevant standards such as the I EEE and IET Wiring Regulations (BS 7671). This ensured that voltage drops were within acceptable limits and that cables could safely carry the expected current without overhe ating.

To maintain neatness and prevent mechanical damage, **polyvinyl chloride (PVC) trunkin g** was employed for cable routing along walls and workstations. This also facilitated eas y maintenance and future upgrades. All wiring connections were terminated using insula ted cable lugs and securely fastened within junction boxes where necessary.

3.6.2 Power Outlets

Each workstation within the laboratory was fitted with industrial-grade **alternating curre nt (AC) power sockets**, rated to handle higher current demands typical of electrical and e lectronic testing equipment. These outlets were configured with **individual circuit protect ion** using miniature circuit breakers (MCBs), providing localized overcurrent protection to prevent faults from affecting the entire system.

Additionally, socket installations adhered to ergonomic positioning standards to ensure user safety and accessibility, minimizing the risk of tripping hazards or cable strain durin g operation.

3.6.3 Main Distribution Board (MDB)

A centrally located **Main Distribution Board (MDB)** was installed to serve as the primary node for electrical distribution across the laboratory. The MDB was fitted with the followi ng safety and control devices:

- **Miniature Circuit Breakers (MCBs):** These were allocated to each sub-circuit to pr ovide overcurrent protection and allow for isolation during maintenance or fault c onditions.
- **Residual Current Devices (RCDs):** RCDs were incorporated to detect and interrupt

leakage currents, thereby providing enhanced protection against electric shocks.

- **Energy Meter:** A digital energy meter was integrated into the MDB for real-time m onitoring of power consumption, enabling energy auditing and efficient power ma nagement within the lab.

The MDB was installed in a ventilated enclosure, conforming to IP-rated standards to ens ure protection against dust and accidental contact.

3.6.4 Grounding (Earthing)

To ensure user safety and system stability, a robust **grounding (earthing) system** was i mplemented. **Copper earth rods** were driven into the soil at strategically selected locatio ns around the lab perimeter. These rods were connected to the electrical system's ground ing conductors using corrosion-resistant clamps and earth wires of appropriate cross-se ctional area.

The earthing system was designed to maintain a low resistance path to ground, in compl iance with IEC 60364 standards. This setup protects personnel and equipment by providi ng a safe discharge path for fault currents and dissipating static charges, thereby minim izing the risk of electric shock, fire, or equipment damage.

3.7 Integration of Training Equipment

The integration of training equipment was a crucial phase of the laboratory setup, aimed at creating a functional, flexible, and interactive learning environment for practical instru ction in electrical, electronic, and communication systems. The process involved careful electrical isolation, circuit protection, labeling for identification, and system interoperabili ty to ensure safe and efficient use by students and instructors.

Each training system was connected to **individually isolated circuits**, protected by miniat ure circuit breakers (MCBs) and clearly labeled control switches. This configuration allow ed for independent operation and troubleshooting without affecting other equipment or c ircuits within the laboratory. Integration tasks spanned various electrical, electronic, and r enewable energy modules as outlined below:

3.7.1 Instrumentation Panels

The laboratory instrumentation was anchored by a **variable voltmeter** and a **multifuncti on digital meter panel**, which were wired to allow precise measurement of AC and DC vol tage levels. These meters facilitated both analog and digital monitoring of circuit param eters, enabling students to observe real-time electrical behavior under varying conditions.

3.7.2 Renewable Energy Modules

Solar and wind energy systems were connected to the training console to simulate realworld renewable generation scenarios. This included the integration of photovoltaic panels and a mini wind turbine, coupled with charge controllers and inverters. Output parameters such as voltage, current, and power were measured and displayed to allow **comparative analysis of solar versus wind generation efficiencies** under different environmental conditions.

3.7.3 Electrical Measurement and Load Testing

Instrumentation including **wattmeters, analog ammeters and voltmeters, and frequency meters** were configured into dedicated test benches. These instruments allowed for dynamic load testing, efficiency analysis, and circuit behavior observation under varying loads and configurations. Students could investigate power factor, total power consumption, and harmonic behavior in resistive, inductive, and capacitive circuits.

3.7.4 Analog Electronics Circuits

Operational amplifier configurations (e.g., inverting, non-inverting, integrator, and differentiator circuits) and **audio amplifier circuits** were constructed on both **breadboards** for experimental learning and **printed circuit boards (PCBs)** for permanent setups. These circuits were used to teach signal amplification, filtering, and waveform shaping. Testing included waveform analysis using function generators and oscilloscopes.

3.7.5 Electrical Machines Trainer

The **AC motor trainer** was assembled and tested using **slip-speed indicators** to examine rotor behavior under varying load conditions. This trainer enabled detailed exploration of motor characteristics such as torque-slip relationship, synchronous speed, and rotor efficiency. Measurements were compared with theoretical models to reinforce understanding of rotating magnetic fields and three-phase induction principles.

3.7.6 Communication Systems Modules

A **GSM trainer** and **FM transmitter/receiver units** were integrated to support hands-on training in wireless communication. These modules demonstrated basic concepts such as signal modulation/demodulation, transmission range, antenna effects, and interference mitigation. The GSM trainer also facilitated the exploration of mobile communication protocols, SIM interfacing, and message transmission.

3.7.7 Signal Processing Systems

Sampling and Time Division Multiplexing (TDM) systems were connected to digital oscilloscopes to enable visualization of time-domain signals. Students could examine how analog signals are converted into discrete samples and how multiple signals are transmitted over a single channel using TDM techniques. These setups were instrumental in illustrating principles of analog-to-digital conversion, bandwidth allocation, and noise immuni ty.

3.8 Testing and Calibration

- All devices were tested for continuity and correct voltage supply before first operation.
- Measuring instruments (voltmeter, wattmeter, DMM, etc.) were calibrated using reference standards.
- Simulations were performed before live power tests to ensure safety and correctness.

3.9 Safety Considerations

- Warning labels, danger signs, and user guidelines were placed near all high-voltage stations.
- Emergency cutoff switches were installed.
- Fire extinguishers and circuit insulation tools were made available.
- Only authorized users with prior training were allowed to operate high-voltage equipment.