### Core Research Platforms & Systems

This section covers the primary energy generation and storage systems that form the foundation of the lab's experimental capabilities.

**For Solar Energy:**

| SL | Platform/System | Key Specifications & Features | Primary Research Applications |
| --- | --- | --- | --- |
| 1 | **Modular Solar PV Research Platform** | 15 kW hybrid solar array (avg. efficiency >22%) Includes **bifacial** and **Mono-PERC** and **perovskite** panels on adjustable mounting racks,a Class AAA solar simulator,grid-tied & hybrid inverters,multiple MPPT/PWM charge controllers,MLPEs,IV curve tracers,pyranometers,IoT-enabled data loggers | R&D of soiling, humidity, and high-temperature impacts on PV performance,  Degradation studies  Hybrid system testing  Development of advanced inverter control algorithms for grid stability.  Real-time outdoor/indoor comparative studies of different PV technologies in the Pabna climate. |
| 2 | **Solar Thermal Demonstration** | Evacuated tube and flat-plate collectors, heat exchangers, thermal storage tanks, temperature/pressure sensors | Solar thermal efficiency, integration with building HVAC, hybrid PV-thermal research |

**For Wind Energy:**

| SL | Platform/System | Key Specifications & Features | Primary Research Applications |
| --- | --- | --- | --- |
| 1 | **Configurable Wind Energy Test Bench** | Compact 7.5 kW horizontal-axis wind turbine coupled with a digitally controlled variable-speed fan array to simulate diverse wind conditions. Includes adjustable blade pitch and yaw control mechanisms, 3D-printed modular blades,  dedicated anemometer array,torque/speed sensors, Wind tunnel for aerodynamics,SCADA integration | Aerodynamic testing of custom 3D-printed blade profiles.  Validation of power curves and turbine control strategies.  Investigation of turbine performance in turbulent, low-wind-speed environments,blade material studies, grid integration |
| 2 | **Small Wind Turbine Kit** | Portable 1 kW turbines, DIY blade design station, power electronics bench | Student projects, rural electrification prototypes, standalone system design |

**For Bio-energy:**

| SL | Platform/System | Key Specifications & Features | Primary Research Applications |
| --- | --- | --- | --- |
| 1 | **Lab-Scale Bioenergy Conversion Unit** 🌱 | Lab-scale fluidized bed gasifier, two-stage anaerobic digester, biogas purification (scrubbers, membranes), CHP engine, gas chromatograph for biogas studies and a **downdraft biomass gasifier** for producing syngas from local agricultural residues (e.g., rice husks, jute stalks),Gas composition analyzer | Optimization of biogas yield from co-digestion of organic wastes,Characterization of syngas quality for use in small-scale power generation.,Developing sustainable waste-to-energy solutions for rural communities, waste-to-energy policy studies |
| 2 | **Algae Bioreactor** | Photo-bioreactor array, CO₂ injection, lipid extraction setup | Biofuel research, carbon capture, circular economy integration |

**For Energy Storage System**

| SL | Platform/System | Key Specifications & Features | Primary Research Applications |
| --- | --- | --- | --- |
| 1 | **Hybrid Energy Storage Testbed** 🔋 | A multi-chemistry energy storage system (5-10 kWh initial capacity) featuring **Lithium-Ion (LFP),** **Vented Lead-Acid (VLA),vanadium redox flow** battery banks. Integrated with a programmable Battery Management System (BMS) and a dedicated **Battery Health Diagnostics System** for impedance spectroscopy and cycle analysis, thermal chambers with thermal monitoring | Performance and degradation analysis of different battery technologies.  Development of smart charging/discharging algorithms to maximize battery lifespan.  Testing energy storage integration, safety protocols, second-life applications, microgrid storage testing |
| 2 | **Supercapacitor Bank** | 10 kW modular setup, rapid charge/discharge testing, integration with renewables | Grid stabilization, hybrid storage systems, EV fast-charging research |

### Advanced Diagnostics & Measurement Instruments

These instruments are essential for high-fidelity data collection, system analysis, and diagnostics across all research platforms.

| # | Instrument | Core Capabilities | Purpose in the Lab |
| --- | --- | --- | --- |
| 1 | **Power Quality & Grid Analyzer** | Simultaneous multi-phase measurement of voltage, current, frequency, harmonics (up to the 50th), transients, and power factor. Compliant with IEC 61000-4-30 Class A standards. | Diagnosing power quality issues in grid-tied and off-grid systems.  Validating the grid compliance of new inverter designs.  Conducting energy audits and load profile analysis. |
| 2 | **Centralized Data Acquisition (DAQ) System** | High-speed, multi-channel NI-cDAQ platform with a suite of modules for various sensors (thermocouples, RTDs, strain gauges, voltage/current transducers, pyranometers). | Acts as the central nervous system of the lab for real-time, synchronized data logging from all experiments.  Enables automated test sequences and hardware-in-the-loop (HIL) simulations. |
| 3 | **Rotating Machine Insulation Analyzer** | Performs automated tests including winding resistance, turns ratio (TTR), tan-delta/power factor, and excitation current on motors and generators. | Assessing the health and predicting failures in generators used in biomass or micro-hydro systems.  Quality control for electric motors used in renewable energy applications. |
| 4 | **Thermal & Acoustic Imaging System** | Combines a high-resolution **infrared thermography camera** for non-contact temperature mapping and an **acoustic imaging camera** for pinpointing pressurized leaks and electrical partial discharge. | Detecting hotspots in PV panels and electrical connections.  Visualizing energy loss in thermal systems.  Advanced safety inspection and fault localization (e.g., corona discharge). |

### Computational & Simulation Infrastructure

This infrastructure provides the digital backbone for modeling, simulation, data analysis, and developing the control logic for the physical hardware.

| # | Category | Software/Hardware & Key Features | Role in Research & Development |
| --- | --- | --- | --- |
| 1 | **High-Performance Computing & Workstations** | * **HPC Cluster:** 4-node cluster with multi-core CPUs (32+ cores), 128GB+ RAM per node, and NVIDIA GPU acceleration. * **Workstations:** 5 units with high-frequency CPUs (e.g., Intel i9/AMD Ryzen 9), 64GB RAM, and professional GPUs. | * Executing complex Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA) simulations. * Training machine learning models for energy forecasting and fault detection. * High-speed data processing and visualization. |
| 2 | **System Modeling & Simulation Software** | * **MATLAB/Simulink:** Full suite with toolboxes for Simscape Electrical, Control Systems, and Deep Learning. * **ANSYS Fluent / COMSOL Multiphysics:** For advanced thermo-fluid and coupled physics simulations. | * Modeling entire energy systems and developing control strategies. * Simulating wind turbine aerodynamics and heat transfer in solar thermal systems. * Creating digital twins of laboratory hardware for pre-deployment testing. |
| 3 | **Techno-Economic & Planning Software** | * **HOMER Pro:** For microgrid design and optimization. * **RETScreen Expert:** For clean energy project feasibility analysis. * **LEAP:** For long-range energy alternatives and policy planning. | * Assessing the economic viability of hybrid renewable systems for rural electrification in Bangladesh. * Conducting feasibility studies for pilot projects. * Developing data-driven energy policy recommendations. |
| 4 | **Data Science & Control Software** | * **Python/R:** With full scientific libraries (Pandas, Scikit-learn, TensorFlow). * **LabVIEW Professional:** For graphical system design and hardware integration. * **PV\*SOL Premium:** For detailed photovoltaic system design and yield forecasting. | * Developing predictive models for energy demand and generation. * Creating intuitive control dashboards and automating data acquisition. * Designing and validating the performance of specific PV installations. |

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| Sl. No. | Equipment Name | Features | Research/Academic Application |
| --- | --- | --- | --- |
| 1 | **Solar PV Research Platform** | Includes a 10 kW monocrystalline solar panel array (>20% efficiency), smart grid-compatible solar inverters, and an indoor Class AAA solar simulator for controlled irradiance testing. | Investigation of photovoltaic efficiency, degradation analysis, and development of hybrid solar systems. |
| 2 | **Wind Energy Experimental Setup** | Compact 5 kW wind turbine with adjustable blade pitch, coupled with a subsonic wind tunnel for aerodynamic performance studies. | Optimization of wind turbine designs and site-specific wind resource assessment, especially for coastal and elevated regions. |
| 3 | **Bioenergy Conversion System** | Integrated bench-scale biomass gasifier and anaerobic digester with real-time gas yield monitoring. | Research on conversion of agricultural waste into biofuels; sustainable rural electrification models. |
| 4 | **Battery Storage & Analysis Platform** | Lithium-ion and flow battery modules (up to 50 kWh), integrated with a programmable BMS for charge-discharge cycle analysis and thermal monitoring. | Evaluation of energy storage reliability, aging characteristics, and safety protocols. |
| 5 | **Advanced Power Quality Analyzer** | Precision instrument capable of capturing harmonics, voltage fluctuations, and power transients (e.g., Fluke 435 Series II or equivalent). | Analysis of grid compatibility, transient detection, energy audit, and harmonic filtering studies. |
| 6 | **Thermal Imaging and Heat Flow Diagnostics** | Includes IR thermal cameras and surface heat flux sensors to detect insulation failure or excessive energy losses. | Energy auditing in buildings and industrial systems; passive design validation. |
| 7 | **High-Performance Computing Cluster** | 4-node compute cluster with 32-core CPUs per node, 128 GB RAM, and GPU acceleration for simulation-heavy applications. | Complex simulations of energy systems, fluid dynamics for turbine optimization, and AI model training for predictive maintenance. |
| 8 | **Real-Time DAQ Systems** | National Instruments (NI) DAQ modules with configurable I/O for temperature, current, voltage, and pressure sensing. | Monitoring and control in experimental energy setups; data acquisition for research validation. |
| 9 | **Scientific Workstations** | Five high-performance computing terminals (Intel i9 CPUs, 64 GB RAM, 1 TB SSD, high-end GPUs). | For modeling, data analytics, control system simulation, and software development. |