IARE
INSTITUTE OF
AERONAUTICAL ENGINEERING

HIGH IMPACT PRACTICES [HIPS]

CORNERSTONE PROJECTS:
POWER ELECTRONICS
INFORMATION PACKET
2025-2026

INSTITUTE OF AERONAUTICAL ENGINEERING
25 YEARS 2000 2025

I appreciate your interest in the Cornerstone Project (CoP), Department of EEE at the Institute of Aeronautical Engineering!

A cornerstone project (CoP) is typically introduced during the early or middle stages of an academic program at the Institute of Aeronautical Engineering. It focuses on helping students build foundational skills and understand how to apply basic concepts to real-world scenarios. These projects are usually smaller in scope, moderately complex, and designed to strengthen practical understanding of core subjects.

The Cornerstone Projects provide a platform for students to bridge the gap between classroom concepts and industry-relevant skills. By working on hands-on challenges such as Smart Sensor Calibration using Machine Learning students apply core EEE concepts like signal processing, sensor technology, embedded systems, and control theory in practical scenarios. These projects foster critical thinking, innovation, and interdisciplinary collaboration, enabling students to see the real-world impact of their theoretical knowledge. This not only enhances their academic understanding but also prepares them for future roles in research, development, and industry.

Cornerstone Project (CoP) teams are:

- Collaborative Project – This is an excellent opportunity for students who are committed to working towards social developments and emerging needs.
- Project Activity – The project coordinator listed current working areas for offering cornerstone projects with a team size of at least two students. The coordinator allotted mentors based on the work area and facilitated exclusive project laboratories for selected cornerstone project (CoP)students. This cornerstone project (CoP)bridges the gap between academic learning and real-world social applications. It helps enhance the professional development
- Short-term - Each undergraduate student may participate in a project for an assigned period.

The primary goal of Cornerstone Projects in the Department of Electrical and Electronics Engineering (EEE) is to integrate foundational engineering knowledge with practical, real-world problem-solving to foster innovation, critical thinking, and hands-on technical skills.

- Apply theoretical concepts from circuits, electronics, control systems, embedded systems, and signal processing.
- Encourage team-based design thinking and interdisciplinary collaboration.
- Promote awareness of sustainable and socially relevant solutions aligned with global challenges (such as the UN Sustainable Development Goals).
- Prepare students for industry, entrepreneurship, and advanced research through experiential learning.
- Strengthen skills in circuit design, embedded systems, signal processing, IoT, power systems, and control engineering.
- Encourage students to design original solutions to engineering problems using creative approaches and emerging technologies.
- Cultivate the ability to work effectively in interdisciplinary teams, reflecting real-world engineering environments.
- Provide opportunities to work with tools and platforms like MATLAB, Arduino, Raspberry Pi, LabVIEW, and simulation software.
- Align project outcomes with social, environmental, or community needs—often by mapping them to the **UN Sustainable Development Goals (SDGs)**.
- Inspire students to explore deeper concepts, conduct experiments, and pursue independent or faculty-guided research.
- Develop adaptability and curiosity that prepare students for emerging technologies and continuous learning.

The research theme of this AI based projects also focuses on the challenges presented by the Sustainable Development Goals (SDGs).

IARE Sustainability Development Goals (SDGs) highlighted with Blue Colour Font	
SDG #1	End poverty in all its forms everywhere
SDG #2	End hunger, achieve food security and improved nutrition and promote sustainable agriculture
SDG #3	Ensure healthy lives and promote well-being for all at all ages
SDG #4	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
SDG #5	Achieve gender equality and empower all women and girls
SDG #6	Ensure availability and sustainable management of water and sanitation for all
SDG #7	Ensure access to affordable, reliable, sustainable and modern energy for all
SDG #8	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
SDG #9	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
SDG #10	Reduce inequality within and among countries
SDG #11	Make cities and human settlements inclusive, safe, resilient and sustainable
SDG #12	Ensure sustainable consumption and production patterns
SDG #13	Take urgent action to combat climate change and its impacts
SDG #14	Conserve and sustainably use the oceans, seas and marine resources for sustainable development
SDG #15	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
SDG #16	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
SDG #17	Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

The following research domains are recommended for HIPs-Power Electronics Projects, and selected students should find the research gap and frame the problem statements from any one of the themes below.

1. VR Laboratory for Virtual Testing of Power Electronics Circuit **(SDG#4, SDG #9, SDG #12, SDG#13)**
2. Energy Harvesting Techniques for Low-Power IoT Devices **(SDG#7, SDG #9, SDG#11, SDG #12, SDG#13)**
3. Optimizing Power Electronics with Machine Learning Algorithms and Data Science **(SDG#7, SDG #9, SDG #12, SDG#13)**
4. Resource-efficient Machine Learning for Power Electronic Systems **(SDG#7, SDG #9, SDG #12, SDG#13)**
5. Machine learning and optimization techniques for electrical drives**(SDG#7, SDG #9, SDG #12, SDG#13)**
6. Automate design of filters, converters, and magnetics for target specs**(SDG#7, SDG #9, SDG #12, SDG#13)**
7. Optimize battery charging/discharging and motor drive efficiency using AI**(SDG#7, SDG #9, SDG #12, SDG#13)**
8. Monitor and analyse grid-level or local power flow data to improve efficiency. **(SDG#7, SDG #9, SDG#11, SDG #12, SDG#13)**
9. Forecast solar or wind power generation to optimize inverter and grid-tied converter performance. **(SDG#7, SDG #9, SDG#11, SDG #12, SDG#13)**
10. Create AI-powered digital replicas of power electronics systems for testing and optimization **(SDG#4, SDG #7, SDG#9, SDG #12, SDG#13)**

In order to participate in Power Electronics Projects, you must formally apply and be accepted by the project coordinator. To proceed, please mail to the project coordinator, Dr. Damodhar Reddy, Professor and Head, Dept. of EEE, Email Id: dr.damodharreddy@iare.ac.in. This will bring up all available open positions tagged as Power Electronics projects. When submitting a project document and an updated résumé, include a statement regarding why you are interested in working with the team to which you are applying. Please note that participation by the power electrics project team requires registration for the accompanying research statement from any of the specified domains. More information will be provided to all selected Power Electronics project applicants who have been offered a position. If you have any questions about a particular team, please contact the team's faculty mentor(s). We encourage you to contemplate this fascinating new opportunity. We look forward to receiving your application submission.

VR Laboratory for Virtual Testing of Power Electronics Circuit

GOAL

To develop a Virtual Reality (VR)-based laboratory environment that allows students, researchers, and engineers to simulate, interact with, and test power electronics circuits in a virtual 3D space, offering a safe, immersive, and cost-effective alternative to physical laboratories.

Enhance Practical Learning: Provide hands-on experience in circuit design, testing, and analysis without the risks of high-voltage hardware.

Safe Testing Environment: Simulate hazardous scenarios (e.g., short circuits, overloads) in a controlled virtual setting to teach fault diagnosis and safety protocols.

Cost Efficiency: Eliminate the need for expensive physical components and lab infrastructure.

Real-Time Interaction: Enable users to build, modify, and test circuits in real time using VR controllers and gestures.

Remote Access and Collaboration: Support distance learning and teamwork through online access to the virtual lab.

Scalable Circuit Simulations: Support a wide range of power electronics circuits, such as inverters, converters, and motor controllers.

Integrate with Educational Tools: Include measurement tools like virtual oscilloscopes, multimeters, and real-time waveforms for analysis.

Power electronics is a hardware-intensive field that often involves high power levels and safety concerns. A VR-based lab environment allows learners and engineers.

METHODS & TECHNOLOGIES

Virtual Modelling of Power Circuits: Digitally recreate power electronic components (like converters, inverters, rectifiers) using 3D modelling tools. Implement realistic circuit behaviour using mathematical models and electrical simulation engines.

Interactive Simulation Techniques: Allow users to build, connect, and modify circuits dynamically within the VR environment. Enable real-time feedback and behaviour changes based on user inputs and simulated conditions.

Immersive Learning Design: Apply pedagogical frameworks such as constructivist learning and experiential learning to guide lab activities. Include tasks like guided experiments, fault detection exercises, and open-ended problem-solving scenarios.

Remote Access and Multi-User Interaction: Deploy the lab in cloud/online platforms to support remote learning, team projects, and instructor-guided sessions. Incorporate collaborative features such as shared workspaces and voice/text communication.

VR Development Platforms: Unity 3D or Unreal Engine: For building the virtual environment and managing user interaction.

Electrical Simulation Engines: Integration with tools like MATLAB/Simulink, PSpice, LTspice (via APIs or simulation plugins). Custom real-time solvers developed within the VR platform using Python/C++

3D Modelling & Asset Design: Tools like Blender, AutoCAD, or Fusion 360 for creating realistic components and lab setups.

Virtual Measurement Instruments: Simulated oscilloscopes, multimeters, waveform analysers, and signal generators embedded in the environment.

Cloud and Networking Tools: For deploying multi-user environments and storing user progress and experiments. Use of Firebase, Photon Engine, or WebRTC for real-time collaboration.

MAJORS & AREAS OF INTEREST

Simulation-Based Learning: Emphasizes the use of digital simulations over physical components to understand circuit behaviour. Reduces dependency on costly hardware while ensuring conceptual clarity.

Safe, Risk-Free Experimentation: Prefers virtual platforms to conduct experiments involving high voltage or fault conditions, which are otherwise dangerous in real labs.

Immersive and Experiential Education: Supports learning-by-doing in a 3D environment, enhancing student engagement and retention. Refers to experiential learning theory and constructivist teaching models.

Remote and Inclusive Access: Prefers accessible platforms that can be used by students from home or remote campuses. Encourages inclusivity for institutions lacking full lab infrastructure.

Modern Power Electronics Education: Refers to real-world applications in smart grids, electric vehicles, and industrial automation. Prefers updated pedagogy matching the needs of modern Power Electronics education.

Digital Twin and Industry 4.0 Integration: Aligns with the concepts of **digital twins**, where a real system is mirrored in a virtual simulation for testing and monitoring. Prepares students for technologies central to Industry 4.0.

Interdisciplinary Collaboration: Refers to joint input from **EEE, Computer Science, Mechatronics**, and **Educational Technology** for design, simulation, and UX.

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PARTNERS & SPONSORS

None

Energy Harvesting Techniques for Low-Power IoT Devices

GOAL

The main goal is to develop and optimize energy harvesting methods that enable low power Internet of Things (IoT) devices to self-sustain their operation by capturing ambient energy from the environment. This reduces or eliminates the need for frequent battery replacements, thereby enhancing device longevity, reliability, and eco-friendliness.

Identify Suitable Energy Sources: Explore ambient energy forms such as solar, thermal, vibrational, radio frequency (RF), or mechanical energy that can be harvested efficiently.

Design Efficient Energy Harvesters: Develop circuits and materials that maximize the conversion of ambient energy into usable electrical power.

Optimize Power Management: Implement smart power conditioning and storage to ensure stable operation despite intermittent or low energy input.

Integrate with Low-Power IoT Systems: Tailor energy harvesting solutions compatible with the power consumption profiles of various IoT sensors and communication modules.

Enhance Device Autonomy: Enable IoT devices to operate unattended for extended periods in remote or inaccessible locations.

Promote Sustainability: Reduce environmental impact by minimizing battery waste and reliance on external power sources.

As IoT devices proliferate in smart homes, healthcare, agriculture, and industry, energy harvesting offers a promising way to support **scalable, maintenance-free deployments** critical for the sustainability of IoT ecosystems.

METHODS & TECHNOLOGIES

Solar Energy Harvesting Using photovoltaic (PV) cells to convert sunlight into electrical energy. Suitable for outdoor and some indoor applications where light is available.

Thermoelectric Energy Harvesting Exploiting temperature differences using thermoelectric generators (TEGs) to produce electricity, often from body heat, industrial equipment, or environmental heat gradients.

Vibrational and Mechanical Energy Harvesting Utilizing piezoelectric materials, electromagnetic generators, or electrostatic converters to capture mechanical vibrations, movements, or pressure changes.

Radio Frequency (RF) Energy Harvesting Capturing ambient electromagnetic waves from sources like Wi-Fi, cellular signals, or dedicated RF transmitters, and converting them into electrical power.

Magnetic Induction and Electromagnetic Harvesting Using coils and magnets to convert changing magnetic fields into electrical energy, often from nearby machinery or power lines.

Power Conditioning Circuits Regulate, stabilize, and convert harvested energy into usable voltages, including DC-DC converters and maximum power point tracking (MPPT) systems.

Energy Storage Components Integrate supercapacitors, rechargeable batteries, or thin-film batteries to store harvested energy for continuous device operation.

Ultra-Low Power Electronics Design IoT sensors and microcontrollers that operate at minimal power, often in sleep modes with intermittent wake-ups to conserve energy.

Energy-Aware Communication Protocols Use low-power wireless communication standards like BLE (Bluetooth Low Energy), Zigbee, LoRaWAN, or NB-IoT to reduce transmission power requirements.

MAJORS & AREAS OF INTEREST

Electrical and Electronics Engineering (EEE) Focus on circuit design, power electronics, sensor interfacing, and embedded systems critical for designing efficient energy harvesters and IoT devices. Study of Power Electronics, microcontrollers, and signal processing for energy management**.**

Computer Engineering Emphasis on embedded systems programming, firmware development, and low-power computing architectures. Design and optimization of IoT communication protocols and edge computing techniques.

Renewable Energy Engineering Specialization in sustainable energy sources and technologies such as solar, thermoelectric, and vibration energy harvesting. Research in integrating renewable sources with low-power devices.

Materials Science and Engineering Development and characterization of advanced materials used in energy harvesters such as piezoelectric, thermoelectric, and photovoltaic materials. Focus on flexible, lightweight, and high-efficiency materials**.**

Telecommunications Engineering Study of wireless communication technologies like BLE, Zigbee, LoRaWAN, and NB-IoT tailored for low-power IoT networks. Exploration of RF energy harvesting and ambient RF signal utilization.

Computer Science and Artificial Intelligence Algorithms for power management, energy-aware computing, and predictive maintenance in IoT. AI-enabled optimization of energy harvesting and device operation.

Mechanical Engineering Design and analysis of mechanical structures and MEMS devices for vibrational energy harvesting. Integration of mechanical systems with electronics for efficient energy conversion**.**

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PARTNERS & SPONSORS

None

Optimizing Power Electronics with Machine Learning Algorithms and Data Science

GOAL

The goal of integrating machine learning (ML) in power electronics is to improve efficiency, reliability, and intelligence through data-driven methods. Performance Optimization is achieved by using ML to fine-tune control parameters, enhancing conversion efficiency in systems like DC-DC converters and inverters. Fault Detection and Prognostics enable early fault identification and predict the Remaining Useful Life (RUL) of components using operational data.

Load and Demand Forecasting uses time-series models for accurate load prediction, aiding in better energy management. Thermal and Stress Analysis applies ML to estimate thermal behavior and reduce component stress. Energy Efficiency Enhancement identifies energy loss patterns and suggests design or operational improvements.

Smart Control Systems leverage adaptive ML strategies for nonlinear or time-varying systems. Anomaly Detection uses unsupervised learning to spot real-time abnormalities. Data-Driven Modelling replaces or augments physical models for faster simulations. Design Automation employs optimization algorithms for component selection and tuning. Finally, Integration with IoT and Edge Devices enables lightweight ML models to run on embedded hardware for real-time diagnostics and control.

METHODS & TECHNOLOGIES

Data Collection and Preprocessing: Acquire operational and environmental data from simulations or real-time sensors. Clean, normalize, and extract features relevant to power electronics performance.

Machine Learning Model Development: Develop and train supervised, unsupervised, or reinforcement learning models for prediction, classification, and control. Select models based on system behaviour and data characteristics.

Control and Optimization Techniques: Integrate ML with traditional control strategies like PID or MPC for adaptive and efficient control. Use heuristic algorithms (GA, PSO) to optimize component selection and system parameters.

Data Science and Analysis: Apply statistical and data visualization tools to uncover trends and relationships in power electronics data. Use time-series analysis and forecasting for predictive applications.

Simulation and Validation: Simulate system behaviour under various conditions using MATLAB/Simulink or PSIM. Validate model performance through cross-validation or real-world experimental setups.

Deployment and Edge Integration: Deploy trained ML models on embedded or edge devices for real-time diagnostics and control. Integrate with IoT platforms to enable remote monitoring and adaptive feedback loops.

MAJORS & AREAS OF INTEREST

The intersection of power electronics with machine learning and data science spans across multiple engineering and scientific disciplines, making it an interdisciplinary field with growing academic and industrial interest. Electrical and Electronics Engineering is the core major where this topic is most deeply rooted, particularly in areas focusing on power conversion, control systems, renewable energy systems, and electric drives.

Control Systems Engineering is another key area, as intelligent algorithms are often applied to replace or enhance conventional controllers (e.g., PID, PI) used in converters and inverters. Students and professionals in Mechatronics Engineering also engage in this field, especially in applications like electric vehicles and robotics, where embedded ML models are used for motor control and energy management.

On the computational side, Computer Science and Artificial Intelligence play a vital role in developing the machine learning models, algorithms, and data analytics platforms that support smart power electronics systems. Specializations in Data Science, Machine Learning Engineering, and Embedded Systems are particularly relevant for building real-time models that can run on low-power microcontrollers or FPGA-based platforms.

Mechanical Engineering and Thermal Engineering are indirectly related but important, as they contribute to modelling thermal behaviour, cooling systems, and electromechanical integration—areas where data-driven predictive maintenance is applied.

Emerging areas of interest include Smart Grids, Electric Vehicles (EVs), Battery Management Systems (BMS), Industrial Automation, and Renewable Energy Systems. These domains rely heavily on intelligent power electronics and benefit from machine learning for forecasting, diagnostics, optimization, and decision-making.

Research in Cyber-Physical Systems, Internet of Things (IoT), and Edge AI also overlaps with this field, especially as power electronic devices become more connected and autonomous. Overall, this topic is highly relevant for students and researchers across engineering, computer science, and energy technology domains who are interested in applying AI to real-world power and energy challenges.

Resource-efficient Machine Learning for Power Electronic Systems

GOAL

The goal is to **develop lightweight ML models** specifically tailored for real-time applications on embedded devices used in power electronics. These models must have low memory and computational requirements, making them suitable for microcontrollers, DSPs, or FPGAs. A key focus is to **reduce power consumption of ML workloads** by optimizing both model architectures and inference strategies during training and deployment phases.

For **on-device fault detection and diagnostics**, efficient anomaly detection algorithms are implemented locally, ensuring fast and reliable system responses without reliance on cloud computing. Techniques like **model compression and pruning**—including quantization, pruning, and knowledge distillation—are applied to significantly shrink model size while maintaining accuracy.

Real-time adaptive control strategies are enabled using low-latency ML algorithms that adjust to changing loads or fault conditions in power converters and inverters. To further enhance efficiency, **data-efficient learning** approaches such as transfer learning, few-shot learning, and online learning are used to minimize data and training requirements.

Through **Edge AI integration**, ML models are deployed on decentralized platforms for smarter, localized decision-making in systems like smart grids and renewable energy setups. **Hardware-aware ML optimization** ensures models are designed in alignment with the constraints of embedded hardware like ARM Cortex-M or STM32.

Despite their lightweight nature, these ML systems are designed to **maintain high accuracy and reliability** in real-world environments. Finally, to ensure optimal performance, various ML methods are **benchmarked and compared** in terms of latency, energy use, memory footprint, and predictive effectiveness.

METHODS & TECHNOLOGIES

Model Compression and Optimization: Use **quantization**, **pruning**, and **knowledge distillation** to reduce model size and computation. Apply **weight sharing** and **low-rank factorization** to simplify neural networks.

Lightweight ML Algorithms: Implement compact models like **Decision Trees**, **Random Forests, SVM with linear kernels**, or **TinyML-optimized neural networks**. Use **Mobile Net**, **Squeeze Net**, or **TinyML frameworks** for deep learning tasks.

Transfer and Online Learning: Use **transfer learning** from pre-trained models to reduce training time and data requirements. Apply **online or incremental learning** for real-time adaptation with limited resources.

Edge Computing Deployment: Develop models deployable on microcontrollers. Use **Edge AI toolkits** like TensorFlow Lite, PyTorch Mobile, or Edge Impulse.

Real-Time Signal Processing: Combine ML with fast DSP techniques for filtering and feature extraction. Use FFT, wavelet transforms, or sliding windows to extract features efficiently.

Hardware-Aware Model Design: Use **Neural Architecture Search (NAS)** or manual tuning to design models that fit the resource limits of specific platforms

Co-Design with Control Algorithms: Integrate ML with classical control for hybrid control strategies in converters or inverters.

MAJORS & AREAS OF INTEREST

The study and application of resource-efficient machine learning in power electronic systems intersect multiple academic disciplines and engineering fields. Primarily, Electrical and Electronics Engineering serves as the foundation, focusing on power converter design, control systems, and embedded hardware development. Within this major, special attention is given to Power Electronics, Control Engineering, and Embedded Systems, as these areas combine hardware constraints with algorithmic control to optimize system performance.

The field also deeply involves Computer Science and Artificial Intelligence, particularly in machine learning algorithm design, model compression techniques, and efficient software frameworks tailored for embedded platforms.

Data Science contributes through data acquisition, signal processing, and analytics, enabling the extraction of meaningful insights from sensor data critical for predictive maintenance and fault diagnosis. Mechanical and Thermal Engineering play supporting roles by addressing thermal management and reliability challenges in power devices, where predictive models must account for physical stress and degradation.

Emerging interdisciplinary areas like Cyber-Physical Systems, Internet of Things (IoT), and Edge AI further broaden the scope by integrating communication networks and decentralized intelligence into power electronics. Research and development in Renewable Energy Systems, Electric Vehicles (EVs), and Smart Grids increasingly leverage resource-efficient ML methods to create scalable, autonomous, and energy-conscious power electronic solutions.

Machine learning and optimization techniques for electrical drives

GOALS

The goal is to enable the **intelligent control of electric drives** by integrating machine learning (ML) techniques into traditional control systems. ML-based controllers—such as neural networks or reinforcement learning—can be developed to replace or enhance conventional PID or vector control methods, offering more adaptive and data-driven performance. A critical aspect of this approach is **parameter estimation and identification**, where supervised or unsupervised ML models are used to estimate key drive parameters like rotor resistance or inductance in real time, enabling more responsive and accurate control.

Efficiency optimization is achieved by applying optimization algorithms that minimize losses and enhance the torque-per-ampere ratio, especially under varying load conditions. In parallel, **predictive maintenance** strategies leverage ML to detect early signs of faults in motors, sensors, or drive electronics, thereby reducing downtime and improving system reliability.

ML also supports **sensorless operation** by accurately estimating rotor speed, position, or torque, reducing the need for physical sensors and lowering system complexity and cost. For better dynamic performance, ML techniques enhance **speed and torque control**, improving response and stability under disturbances or nonlinear load conditions.

Further, **energy consumption forecasting** uses time-series ML models to anticipate energy use trends in motor systems, supporting more efficient energy planning. **Real-time monitoring and diagnostics** are enabled through lightweight ML models that run directly on embedded controllers, providing continuous anomaly detection and health monitoring.

In addition, **data-driven drive modelling** replaces complex physical models with ML-based surrogates, allowing faster simulation and real-time implementation. Finally, **benchmarking and validation** ensure ML-driven approaches are rigorously compared with traditional methods in terms of control accuracy, energy efficiency, responsiveness, and hardware resource usage.

METHODS & TECHNOLOGIES

Machine Learning for Control: Implement **supervised learning** (e.g., regression models, neural networks) for speed and torque control.

Use **reinforcement learning (RL)** or **deep RL** (e.g., DDPG, PPO) for adaptive and optimal control under variable conditions.

Parameter Estimation and System Identification: Apply ML algorithms (e.g., Random Forest, SVR, MLP) to estimate motor parameters (resistance, inductance, inertia).

Use **system identification techniques** combined with ML to model motor dynamics from input-output data.

Fault Detection and Predictive Maintenance: Use classification algorithms (e.g., SVM, k-NN, CNN) to detect faults like bearing wear, rotor bar defects, or insulation failure.

Deploy **time-series anomaly detection** or **autoencoders** for unsupervised fault diagnosis.

Sensorless Estimation: Use ML models (e.g., LSTM, RNN, Kalman filters + neural networks) to estimate rotor position and speed without physical sensors.

Optimization Techniques: Use **Genetic Algorithms (GA)**, **Particle Swarm Optimization (PSO)**, **Differential Evolution (DE)**, or **Bayesian Optimization** to:

- Tune controller parameters (e.g., PI gains)
- Optimize energy efficiency
- Maximize torque-per-amp or reduce flux weakening losses

Simulation and Co-Modelling: Simulate motor drive systems in **MATLAB/Simulink**, **PLECS**, or **PSIM**. Use ML models as co-simulation agents for fast, data-driven predictions.

Real-Time Data Processing: Use feature extraction techniques (FFT, wavelets, statistical metrics) to preprocess drive signal data for ML models.

Hardware-in-the-Loop (HIL) Testing: Validate ML-based control and diagnostics using real-time HIL platforms to test in safe, controlled environments.

MAJORS & AREAS OF INTEREST

The study and application of machine learning and optimization in electrical drives sit at the crossroads of several key academic disciplines and engineering domains. At the core is Electrical and Electronics Engineering, which provides foundational knowledge in power electronics, motor control, and embedded systems design. Within this major, specialties such as Control Systems Engineering and Power Systems focus on developing algorithms and hardware for efficient and reliable drive operation. Computer Science and Artificial Intelligence contribute by supplying expertise in machine learning algorithms, data analytics, and software frameworks necessary for building intelligent control systems.

Mechanical Engineering also plays a role, especially in understanding the physical dynamics, thermal management, and mechanical stresses on motors and drives, which are crucial for accurate modelling and predictive maintenance. Areas like Mechatronics and Robotics Engineering leverage these techniques for precision motion control and automation applications. Additionally, Data Science is vital for processing and interpreting the large volumes of sensor data generated by electrical drives, enabling advanced diagnostics and optimization.

Emerging interdisciplinary fields such as Cyber-Physical Systems, Internet of Things (IoT), and Embedded AI increasingly integrate with electrical drives, allowing for smarter, connected, and autonomous systems. Applications in Electric Vehicles (EVs), Renewable Energy Integration, and Industrial Automation are prominent areas where these technologies are actively researched and developed. This multidisciplinary interest fosters innovation toward smarter, more efficient, and adaptive electrical drive systems.

Automate design of filters, converters, and magnetics for target specs

GOAL

The goal is to **automate the design of passive filters, power converters, and magnetic components** to streamline development, reduce manual effort, and improve design accuracy. This involves automatically generating optimized LC/LCL filter configurations based on target parameters such as harmonic attenuation, total harmonic distortion (THD), cutoff frequency, and impedance. Similarly, **power converter design** can be automated by selecting the appropriate topology—buck, boost, flyback, etc.—and dimensioning key components like MOSFETs, diodes, inductors, and capacitors to meet specific voltage, current, power, and efficiency requirements.

Magnetic component design is also automated by intelligently selecting core shapes, materials, winding configurations, and wire gauges that comply with electrical and thermal constraints. Through **constraint-based component selection**, the system can choose components from libraries that meet electrical ratings, thermal limits, cost constraints, and size requirements. These tasks are driven by **multi-objective optimization** algorithms that balance trade-offs such as efficiency versus size, cost versus performance, and ripple versus bandwidth.

By automating these processes, the system can **significantly reduce design time and eliminate manual errors**, streamlining repetitive calculations and accelerating prototyping. Integration with **simulation and CAD tools** allows automated validation of designs using platforms like SPICE or Simulink, followed by export of schematics for physical layout. The system also supports **custom design via user input**, where users define constraints such as input/output voltage, power rating, or ripple limits and receive complete design outputs.

METHODS & TECHNOLOGIES

Rule-Based Design Automation: Encode design heuristics and industry standards as rules for initial sizing of filters, converters, and magnetics.

Analytical Calculations: Use established formulas to compute component values (e.g., inductance, capacitance, switching frequency) from user input specs.

Multi-Objective Optimization: Apply metaheuristic algorithms such as Genetic Algorithms (GA), Particle Swarm Optimization (PSO), or Differential Evolution (DE) to optimize for efficiency, cost, size, and performance.

Machine Learning Prediction Models: Train regression or classification models on historical design data to predict optimal design parameters quickly.

Surrogate Modelling and AI-Driven Simulation: Replace costly simulations with surrogate models (e.g., neural networks, Gaussian processes) to speed up design iterations.

Constraint Handling and Feasibility Checks: Implement constraint solvers to ensure all designs meet electrical, thermal, mechanical, and manufacturability limits.

Component Library Integration: Use databases of real-world components to select parts that meet ratings and availability constraints.

Simulation and Validation Loop: Integrate circuit and magnetic simulations (SPICE, FEA) to validate automated designs and refine parameters iteratively.

Automated Report Generation: Generate design reports with specifications, component lists, simulation results, and compliance checks.

User Interface for Custom Inputs: Develop front-end interfaces to capture design goals and constraints and provide interactive feedback.

MAJORS & AREAS OF INTEREST

The automation of designing filters, converters, and magnetic components spans multiple interrelated fields of study and engineering disciplines. At its core lies Electrical Engineering, particularly the subfields of Power Electronics, Electromagnetics, and Control Systems Engineering, which provide foundational knowledge on converter topologies, filter design, magnetic component behaviour, and system-level control. These areas focus on understanding the physical principles and circuit design techniques essential for efficient energy conversion and electromagnetic compatibility.

Complementing this is Computer Science, especially in areas such as Machine Learning, Artificial Intelligence, and Optimization Algorithms, which are crucial for developing intelligent design automation tools capable of handling complex, multi-objective problems. Knowledge in Software Engineering supports the creation of integrated simulation and design platforms.

Mechanical Engineering and Materials Science contribute insights into thermal management, mechanical stresses, and material properties critical for magnetic core design and durability. Thermal analysis ensures designs can withstand operational conditions, while material science advances improve magnetic performance and efficiency.

Additional relevant fields include Applied Mathematics and Operations Research, which offer advanced optimization techniques and mathematical modelling frameworks vital for formulating and solving design problems involving numerous trade-offs.

Emerging interdisciplinary areas such as Mechatronics, Embedded Systems, and Cyber-Physical Systems also play an increasing role by integrating sensor feedback, control algorithms, and adaptive design principles for smarter, more resilient power electronics.

Optimize battery charging/discharging and motor drive efficiency using AI

GOAL

The goal is to **optimize energy systems—particularly in electric vehicles and industrial drives—using AI-driven control and monitoring techniques**. One key area is the **optimization of battery charging profiles**, where adaptive AI algorithms minimize charging time, heat buildup, and long-term battery degradation. Similarly, **battery discharging efficiency** is improved through intelligent discharge control, which maximizes usable capacity and extends battery life under varying load conditions.

To further enhance system performance, **AI models optimize motor drive efficiency** by dynamically adjusting control parameters to deliver maximum torque with minimal energy loss. **Predictive health monitoring** plays a vital role in maintaining system reliability, with machine learning models estimating battery **State of Health (SoH)** and **State of Charge (SoC)** for proactive maintenance and smarter energy use.

Real-time energy management becomes possible by integrating AI for coordinated control between the battery and motor, balancing power delivery, regenerative braking, and energy storage. To **reduce thermal stress**, AI techniques are employed to monitor and manage temperature during both charging/discharging cycles and motor operation, thus preserving component lifespan.

Under variable environmental and operating conditions, **adaptive AI controllers** ensure robust performance by adjusting to changes in temperature, load, and system aging. AI-driven **optimization and reinforcement learning** methods minimize energy consumption and losses by continually fine-tuning system behaviour for peak efficiency.

For real-world deployment, these AI solutions are designed for **seamless integration with embedded systems**, enabling real-time operation within the constraints of EV or industrial drive platforms. Finally, all AI-driven methods are rigorously **benchmarked against conventional techniques**, ensuring quantifiable improvements in efficiency, reliability, and performance.

METHODS & TECHNOLOGIES

Machine Learning Models for Prediction: Use supervised learning (e.g., regression, neural networks, gradient boosting) to predict battery State of Charge (SoC), State of Health (SoH), and remaining useful life. Train models on historical battery and motor data for accurate real-time estimation.

Reinforcement Learning (RL) for Control Optimization: Implement RL algorithms (e.g., Deep Q-Networks, PPO, DDPG) to learn optimal charging/discharging profiles and motor drive control policies that maximize efficiency and lifespan. Enable adaptive and continuous learning under varying conditions.

Optimization Algorithms: Apply multi-objective optimization (genetic algorithms, particle swarm optimization) to balance trade-offs between charging speed, battery health, and energy efficiency. Use model predictive control (MPC) combined with AI for predictive and adaptive control strategies.

Thermal Modelling and Management: Integrate thermal models with AI to predict temperature rise and implement cooling control strategies.

Sensor Data Fusion and Feature Extraction: Use signal processing and feature engineering on voltage, current, temperature, and vibration sensors for input to AI models.

Edge AI Deployment: Develop lightweight AI models optimized for embedded deployment in Battery Management Systems (BMS) and motor controllers.

Simulation and Digital Twin Development: Create digital twins of battery and motor systems to simulate and validate AI control strategies before real-world deployment.

Data Augmentation and Transfer Learning: Use synthetic data generation and transfer learning to overcome limited real-world datasets and improve model robustness.

Fault Detection and Predictive Maintenance: Employ anomaly detection and classification algorithms to identify early signs of battery degradation or motor faults.

Continuous Learning and Online Adaptation: Implement online learning algorithms for real-time updating of AI models based on new data and operating conditions.

MAJORS & AREAS OF INTEREST

This interdisciplinary field combines expertise from Electrical Engineering, Computer Science, and Mechanical Engineering, among others. Electrical Engineering provides foundational knowledge in power electronics, electric machines, battery technology, and control systems, all essential for understanding the physical and operational aspects of battery management and motor drives.

Computer Science and Artificial Intelligence contribute critical skills in machine learning, reinforcement learning, data analytics, and algorithm development that drive intelligent optimization and predictive modelling in these systems.

Mechanical Engineering is important for insights into thermal management, materials science, and system integration, ensuring the physical reliability and efficiency of batteries and motors under varying operating conditions.

Supporting fields like Applied Mathematics and Operations Research offer advanced tools for optimization theory, statistical modelling, and system simulation needed to solve complex, multi-objective problems in battery and motor control.

Emerging areas such as Mechatronics, Embedded Systems, and Internet of Things (IoT) provide expertise in integrating sensors, real-time data processing, and smart control necessary for adaptive, AI-driven energy management.

Applications driving research and development in these areas include Electric Vehicles, Renewable Energy Systems, Smart Grids, and Industrial Automation, where enhanced battery and motor efficiency translate directly into improved sustainability and performance.

Monitor and analyse grid-level or local power flow data to improve efficiency

GOAL

The goal is to enable **real-time power flow monitoring** and intelligent energy management across electrical grids or localized networks. This involves the continuous collection and visualization of key parameters such as voltage, current, power factor, and energy consumption, providing operators with up-to-date insights into system behaviour. To ensure the integrity of this data, **data quality and validation** techniques are applied, including noise filtering and sensor data verification, enhancing measurement reliability.

Load profiling and pattern recognition leverage statistical and machine learning methods to identify consumption trends, peak demand periods, and opportunities for demand-side management. Concurrently, the system facilitates **loss identification and reduction** by detecting and quantifying inefficiencies in transmission, distribution, or faulty equipment.

Through **anomaly and fault detection**, AI models identify irregularities like outages, voltage fluctuations, and potential energy theft, enabling quicker response and mitigation. **Predictive analytics** further enhance operations by forecasting short- and long-term power demand, helping to optimize power generation and distribution planning.

METHODS & TECHNOLOGIES

Data Acquisition and Integration: Deploy smart meters, PMUs (Phasor Measurement Units), and IoT sensors to collect voltage, current, power, frequency, and phase data in real time. Use SCADA systems or IoT platforms to integrate heterogeneous data sources.

Data Preprocessing and Validation: Clean and filter raw data to remove noise and correct missing or corrupted entries. Use statistical checks and sensor fusion techniques to ensure data quality.

Load Profiling and Clustering: Apply clustering algorithms (k-means, DBSCAN) and time-series analysis to segment load types and identify consumption patterns.

Anomaly and Fault Detection: Use machine learning models such as Isolation Forest, One-Class SVM, or Autoencoders to detect abnormal power flow conditions and faults.

Power Loss Analysis: Model the grid to compute and localize losses using state estimation and energy balance methods.

Demand Forecasting: Implement time-series forecasting models (ARIMA, LSTM, Prophet) to predict load and generation.

Optimization of Power Flow: Use Optimal Power Flow (OPF) algorithms combined with real-time data to suggest operational adjustments.

Employ reinforcement learning for adaptive control of voltage regulators, capacitors, and switches.

Visualization and Reporting: Develop dashboards for real-time monitoring and historical trend analysis. Generate automated reports with recommendations for grid operators.

Cybersecurity and Data Privacy: Incorporate encryption, authentication, and anomaly detection for secure data transmission and storage.

Scalable Data Architecture: Use distributed databases and cloud computing to handle big data from wide-area measurements.

MAJORS & AREAS OF INTEREST

Electrical Engineering is the core discipline, focusing on power systems, power electronics, grid stability, and energy management systems. It provides the foundation for understanding electrical grid operation, power flow dynamics, and grid infrastructure.

Computer Science plays a vital role in developing the data processing, machine learning, and cybersecurity techniques necessary for analyzing vast power flow datasets and ensuring secure grid operations.

Data Science and Analytics specialize in extracting actionable insights from large-scale grid data, applying statistical methods, machine learning, and visualization tools for fault detection, load forecasting, and efficiency improvements.

Control Systems Engineering focuses on designing and implementing automated control and optimization strategies for grid stability, demand response, and integration of distributed energy resources.

Mechanical Engineering and Thermal Sciences contribute to understanding the physical infrastructure, including thermal management of equipment and reliability analysis.

Cybersecurity has become increasingly important to protect grid data, communication networks, and control systems from threats and vulnerabilities.

Systems Engineering and Operations Research provide methodologies for complex system integration, optimization, and decision-making under uncertainty in grid operations.

Forecast solar or wind power generation to optimize inverter and grid-tied converter performance

GOALS

The goal is to **develop accurate renewable power forecasts** to enhance the reliability and efficiency of solar and wind energy integration into the grid. This involves creating short- and medium-term models that predict solar irradiance and wind power output using historical performance data combined with weather forecasts. To improve model precision, **weather and environmental data**—such as temperature, cloud cover, and wind direction—are incorporated into the forecasting process.

With access to accurate generation predictions, systems can **optimize inverter control parameters** in real time, dynamically adjusting voltage, frequency, and reactive power support to match expected output. These forecasts also support **enhanced performance of grid-tied converters** by optimizing switching strategies and improving power factor correction based on anticipated generation profiles.

Forecast data plays a crucial role in **improving energy management and dispatch**, enabling smarter decisions for energy distribution, storage utilization, and demand response planning. It also helps **mitigate grid instabilities** by anticipating generation fluctuations and allowing for proactive voltage and frequency regulation.

To ensure resilience and adaptability, **adaptive and robust forecasting models** are developed using machine learning and statistical techniques that respond to seasonal variations and changing weather patterns. These models are further refined through **real-time forecast updating**, leveraging live data from sensors and weather stations to maintain accuracy.

Model performance is continually validated by **comparing forecast outputs with actual generation data**, enabling iterative improvements. Finally, for real-time operational effectiveness, these forecasting systems are **integrated directly with inverter and grid-tied converter control systems**, ensuring seamless coordination for optimal power flow and grid stability.

METHODS & TECHNOLOGIES

Data Collection and Preprocessing: Gather historical power output, meteorological data (irradiance, wind speed/direction, temperature, humidity). Clean, normalize, and align multi-source datasets for model input.

Statistical and Machine Learning Forecasting Models: Use time-series models such as ARIMA, SARIMA for baseline forecasting. Employ machine learning techniques like Random Forests, Gradient Boosting Machines (XG Boost, Light GBM). Use deep learning models such as LSTM, GRU, Temporal Convolutional Networks (TCN) for capturing temporal dependencies.

Physics-Informed Modelling: Combine empirical data with physical models of solar irradiance or wind turbine power curves for improved accuracy.

Feature Engineering: Extract relevant features including lagged variables, moving averages, and weather pattern indicators.

Use principal component analysis (PCA) or autoencoders for dimensionality reduction.

Ensemble Methods: Combine multiple models (statistical + ML + physics-based) to improve robustness and accuracy.

Real-Time Updating and Online Learning: Implement models that update forecasts dynamically with new sensor and weather data.

Optimization Algorithms for Control: Use model predictive control (MPC) or reinforcement learning (RL) to optimize inverter and converter parameters based on forecasted power.

Simulation and Validation: Simulate inverter/grid converter behaviour under forecasted scenarios using tools like MATLAB/Simulink or PLECS.Validate forecast accuracy with real-world generation data.

Integration with Control Systems: Develop APIs or middleware for seamless data exchange between forecasting modules and inverter/converter controllers.

Visualization and Reporting: Create dashboards to display forecast accuracy, power predictions, and system performance indicators.

MAJORS & AREAS OF INTEREST

The interdisciplinary nature of forecasting renewable power generation and optimizing inverter-converter performance draws heavily from both traditional and emerging academic domains. At its foundation lies Electrical Engineering, where students and researchers gain core knowledge in power systems, grid dynamics, and power electronic converters essential for managing energy flow between renewable sources and utility infrastructure.

Renewable Energy Engineering further deepens this focus by emphasizing system integration, yield optimization, and environmental impact, particularly in the context of solar PV systems, wind turbines, and hybrid microgrids. Equally crucial is the role of Computer Science and Artificial Intelligence, which offer the tools to develop and deploy advanced forecasting models using machine learning, neural networks, and data-driven control algorithms for predictive and autonomous system behaviour.

As energy systems become smarter and more decentralized, Control Systems Engineering plays a pivotal role in real-time decision-making and stability assurance using techniques like Model Predictive Control (MPC) and fuzzy logic-based control. Data Science and Applied Mathematics support the statistical underpinnings of these predictions, enabling engineers to interpret large volumes of weather, sensor, and historical data to reduce uncertainty and enhance response precision.

In the hardware domain, Embedded Systems Engineering and IoT contribute to real-time monitoring and control through microcontrollers, edge devices, and sensor networks. Additionally, Energy Policy, Smart Grid Planning, and Sustainability Studies are increasingly relevant, as the success of these technologies depends on their regulatory alignment, market fit, and contribution to decarbonization goals. Together, these fields form a robust, interdisciplinary knowledge base essential for building intelligent, high-performance, and grid-compliant renewable energy systems.

Create AI-powered digital replicas of power electronics systems for testing and optimization

GOAL

The goal is to **develop accurate digital twins** of power electronic systems by creating high-fidelity AI models that replicate their electrical, thermal, and dynamic behavior. These digital twins serve as virtual counterparts of physical devices, enabling a comprehensive understanding of system performance under various conditions. By **integrating real-time data** from sensors and operational logs, the digital twin remains synchronized with the physical system, ensuring that it accurately reflects current operating conditions.

A key advantage of digital twins is their ability to **enable virtual testing and fault simulation**, allowing engineers to explore different operating scenarios, identify failure modes, and evaluate system robustness without risking physical hardware. This virtual environment also supports **system parameter optimization**, using AI algorithms to enhance efficiency, reliability, and thermal performance.

Digital twins significantly **reduce physical prototyping costs and development time** by enabling early design validation and iterative improvements through simulation. They also play a critical role in **facilitating predictive maintenance**, forecasting component degradation, and allowing for proactive scheduling of service and replacements.

For control system development, digital twins provide a safe and flexible platform to **support design iteration and algorithm testing**, enabling engineers to refine strategies before real-world deployment. These models are designed for **scalability**, allowing seamless expansion from individual components such as converters or filters to entire power electronic subsystems.

To ensure ease of use, **user-friendly interfaces** are developed for intuitive visualization, control, and analysis, empowering engineers to interact effectively with the digital models. Lastly, the digital twin's accuracy is **continuously validated** and refined through real-time feedback from the physical system, ensuring its reliability as a tool for diagnostics, optimization, and innovation.

METHODS & TECHNOLOGIES

System Identification and Modelling: Use system identification techniques to derive mathematical models from measured input-output data. Combine physics-based models with data-driven AI models for hybrid modelling.

Machine Learning and Deep Learning: Train neural networks (e.g., feedforward, recurrent, convolutional) to capture nonlinear dynamic behaviour. Use reinforcement learning to model control system behaviour and adaptation.

Data Assimilation and Synchronization: Implement real-time data streaming and assimilation methods to synchronize digital twin states with the physical system

Simulation and Virtual Testing: Simulate electrical, thermal, and mechanical interactions under various scenarios, including faults and abnormal conditions.

Optimization Algorithms: Use gradient-based methods, genetic algorithms, or Bayesian optimization to fine-tune system parameters virtually.

Predictive Analytics for Maintenance: Apply predictive maintenance algorithms to forecast failures based on digital twin outputs and real-time data.

Model Updating and Calibration: Continuously update the digital twin with live data using online learning and adaptive filtering (e.g., Kalman filters).

Visualization and User Interaction: Develop dashboards and interactive 3D visualizations for monitoring and scenario analysis.

Cloud and Edge Computing Integration: Use cloud platforms for heavy computation and edge devices for real-time low-latency control.

API Development for Integration: Provide APIs to connect digital twins with control systems, databases, and external applications.

MAJORS & AREAS OF INTEREST

The development of AI-driven digital twins for power electronics sits at the intersection of multiple high-impact academic and industrial disciplines. At the core lies Electrical and Electronics Engineering, where expertise in power converters, semiconductor devices, and control theory enables accurate modelling of physical systems.

This is complemented by Artificial Intelligence and Machine Learning, which empower digital twins with adaptive behaviour, predictive insight, and intelligent optimization capabilities.
Fields such as Control Systems Engineering and Embedded Systems play a pivotal role in real-time monitoring and response, ensuring that digital replicas accurately reflect and respond to dynamic system conditions.

Computer Science and Data Science contribute robust computational frameworks and analytics tools necessary for managing large-scale data streams, building simulation environments, and training predictive models.

Meanwhile, Mechanical and Thermal Engineering provides essential insights into non-electrical aspects like heat dissipation and mechanical stress—critical for creating holistic, multi-physics digital twins.
In addition, emerging disciplines like Cyber-Physical Systems, Digital Twin Engineering, and Smart Grid Technology offer specialized knowledge in designing interconnected systems where physical and digital entities operate in unison.

These fields are especially crucial as power electronics becomes more deeply embedded in intelligent infrastructure, such as renewable energy systems, electric vehicles, and autonomous microgrids. Professionals trained across these areas are well-positioned to lead innovation in AI-powered system design, fault prediction, automated testing, and lifecycle optimization—ultimately transforming how power electronics are developed, maintained, and scaled in the modern energy landscape.