IDEA-iPEBB

Innovative Design Automation Framework for integrated Power Electronics Building Block (iPEBB)

ELECOMP Capstone Design Project 2024-2025

Sponsoring Company:

University of Rhode Island Power Electronics Laboratory (URI PEL)

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Company Overview:

The University of Rhode Island Power Electronics Laboratory (URI-PEL) is conducting cutting-edge research in the field of power electronics. Our vision is to develop highly reliable and intelligent power conversion systems (PCSs) and to accelerate the design process for power electronics in various applications. Based on our strong research foundation in power electronics, we have advanced various multidisciplinary research projects.

Our work has been published in distinguished journals and conference papers and is supported by various federal and state agencies, including the Office of Naval Research (ONR), the United States Geological Survey (USGS), etc.

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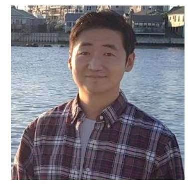

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Project Motivation:

The design process is crucial in defining the performance of PCSs. Traditionally, the industry has relied on human experts. These methods are often labor-intensive, time-consuming, and may not yield optimal results. In addition, each application and model present distinct design targets and constraints, necessitating recurring PCS design efforts. These can range from merely adjusting design parameters within an existing circuit topology to address modified goals to more comprehensive changes like reworking the system architecture or adopting entirely new topologies. All these endeavors aim to enhance various performance aspects, particularly the conversion efficiency and power density of PCSs.

There is a growing trend towards machine learning (ML)-based design methods, which show great potential in identifying optimal design parameters with greater precision and efficiency. Despite this, computer-aided design still faces challenges due to the lack of standardization in power electronics. The vast number of possible topologies, the variety of components that can perform the same function, and the nature of the entire design process makes it difficult to consider all parameters and variables required for a complete design.

Therefore, this capstone design project will focus on developing an innovative design automation framework inspired by modular-type power conversion systems, specifically integrated power electronics building blocks (iPEBB), to accelerate PCS design process and manufacturing. It will also incorporate an ML-based design tool and heterogeneous computing, building on the strong fundamentals of power electronics. This work is part of an ONR project and applies the same concept to different applications, i.e., unmanned aerial vehicles (UAVs).

Anticipated Best Outcome:

The anticipated best outcome of this project, as presented in Figure 1, is a fully functional prototype of two power conversion systems (PCS #1 and #2) for two different drone applications, 6-stack (S) hexacopter and 4-S quadcopter) along with a power electronics design automation (PEDA) tool, implemented on heterogeneous computing using Amazon Web Services (AWS), OCT-FPGA, or others. First, based on the design outcomes from the PEDA tool and human effort, a single iPEBB will be designed, implemented, and evaluated to meet the electrical requirements, including a comparison of the two design outcomes. Subsequently, multiple iPEBBs will be configured and evaluated, and finally demonstrated by assembling them into two drones.

The final outcome will be presented not only at the URI Capstone Design Summit but also at the student project demonstrations during the 2025 IEEE Energy Conversion Congress and Exposition (ECCE), one of the most distinguished conferences in the field of power electronics. For reference, here is the information for the 2024 IEEE ECCE student demos: https://www.ieee-ecce.org/2024/student-project-demonstrations/.

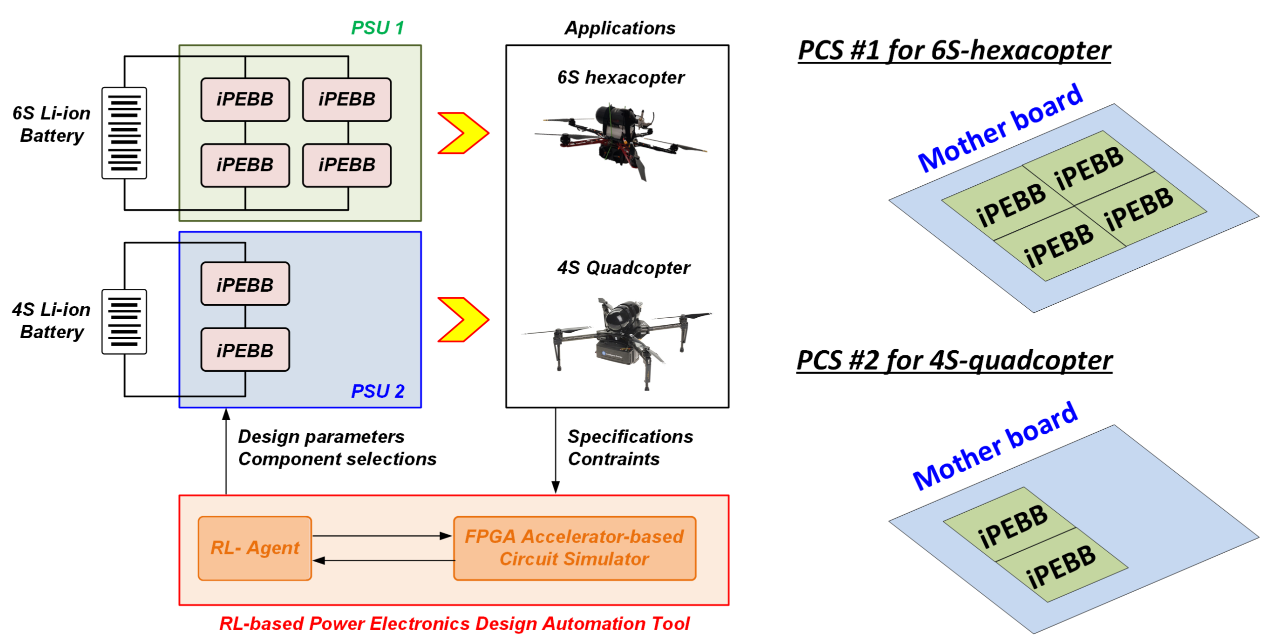

Figure 1. Overview of Capstone Design Project

Project Details:

The objective of this project is to develop power conversion systems (PCSs) for unmanned aerial vehicles (UAVs) using multiple modular-type converters, specifically iPEBBs, to accelerate PCS design and manufacturing. These converters will be optimally designed using a power electronics-focused design automation tool. To achieve the project's final goal, we will proceed in three steps: 1) study existing design methodologies for iPEBBs, 2) implement the PEDA tool on Amazon Web Services or equivalent platforms, and 3) build and evaluate the PCSs for two types of UAVs with different specifications using iPEBBs.

[Overall system concept]

An UAV, commonly known as a drone, is an aircraft without a human pilot, crew, or passengers on board. Initially developed for military missions, UAVs have expanded into many non-military applications as their prices have dropped. These applications include aerial photography, environmental monitoring, infrastructure inspections, and entertainment. Compared to other electric mobility, UAVs require relatively small power ratings, making them suitable for undergraduate-level projects. Moreover, their structure is similar to other electric transport, such as aircraft, ships, and electric vehicles. Currently, the URI PEL has one drone with partially configurable parts and aims to develop two systems. The components for drones are listed below:

Drone	
Frame	DJI F550 + Extended arms
Receiver	Futaba R7008SB
Flight Controller	Pixhawk4, Pixhawk 4 PMU
GPS	Pixhawk, Neo-M8N GP
ESC, Motor, Propellers	DJI E800 Propulsion (6S)

The hardware system of the UAV has a straightforward structure, as shown in Fig. 2. The energy source is a battery, from which the PCS delivers energy to the motors via electronic speed control (ESC). Additionally, it supports various electronic devices, including flight controllers, GPS, and receivers. The required specifications for PCSs are as follows:

1) Input voltage: 4S: 12.8-16.8 V, 6S: 19.2-25.2 V.
2) Output voltage: 4S: 14.8 V, 6S: 22.2 V.
3) Output power: TBD.
4) Other functions, projections: TBD.

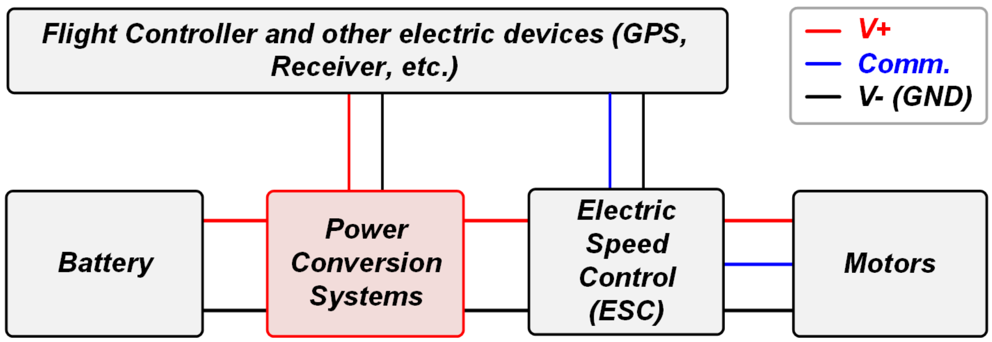

Figure 2. Block diagram of the hardware circuit for PCS in drone applications.

For the PEDA tool, the overall architecture of the RL-based design method is presented in Fig. 3. This framework uniquely integrates various computing platforms, such as FPGA and CPU. The domain-specific design of the FPGA primarily enhances the speed of circuit simulation, addressing the current bottleneck in state-of-the-art ML-based design tools. Equally crucial is the innovative software/hardware integration, which facilitates swift interaction between the fast FPGA-based circuit simulator and the easy-to-program RL agent on a general-purpose computing platform (CPU). Fundamentally, this heterogeneous computing platform allows different computing modalities (both domain-specific and general-purpose) to leverage their unique strengths and work cohesively to ensure rapid ML-driven PCS design and optimization. The proposed framework is expected to be deployed as a service on cloud-hosted heterogeneous computing platforms, enabling power electronics engineers globally to benefit from swift, high-quality training and design. They can achieve this by simply supplying the design targets and constraints for the ML algorithm tailored to their specific application requirements.

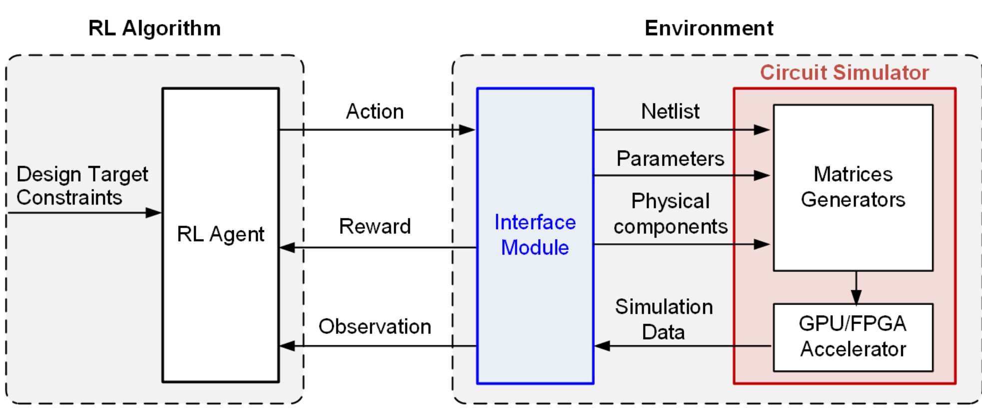

Figure 3. The architecture of the RL-based PEDA Tool.

In Phase I (Fall Semester), we aim to accomplish a preliminary study, build and evaluate a single PCS for hardware, and complete the PEDA tool on the local FPGA board.

[Hardware/Electrical Tasks:]

1. Select the topology of the iPEBBs.
2. Design a single iPEBB using traditional ways, including component selections.
3. Implement and evaluate a single iPEBB board.
4. Build drones.

[Firmware/Software/Computer Tasks:]

1. Study the preliminary open-source microelectronics and power electronics resources: (https://github.com/ksettaluri6/AutoCkt, https://github.com/URI-nextlab/ML-Powelec)
2. Implement the framework on a local FPGA board (Acquire PYNQ Z2 Board or equivalent).
3. Extract the design parameters from the local FPGA board.

In Phase II (Spring Semester), our goals are to implement two PCSs consisting of multiple iPEBBs, develop the PEDA tool on a web-accessible platform, and apply the outcomes to drones.

[Hardware/Electrical Tasks:]

1. Implement a single iPEBB using the results from the PEAD tool and compare it with previous designs.
2. Develop configuration methods of multiple iPEBB.
3. Implement and evaluate multiple iPEBB boards as a single PCS (PCS #1 and #2).
4. Apply the completed boards to two different drones.

[Firmware/Software/Computer Tasks:]

1. Implement the design framework to AWS or equivalent to be public access.
2. Extract the design parameters from the RL-based PEDA tool.
3. Optimize the PEDA framework to enhance accuracy and speed.

Composition of Team:

2 electrical engineers, and 2-3 computer engineers.

Skills Required:

Electrical Engineering Skills Required:

- Analog and power electronics circuit design (ELE 212, ELE446)
- Proficiency in MatLab, Simulink, and circuit simulation (PowerSIM, LTSpice)
- Knowledge of using lab equipment, including oscilloscope, power supplies, e-load, etc.
- PCB layout experience.
- Soldering skills and experience working with various electronics circuit.

Computer Engineering Skills Required:

- Experience with microcontroller or FPGA.
- Familiarity with computer architecture.
- Experience with Machine Learning and embedded systems.
- Knowledge of multicore/multiprocessor architectures.
- Ability to test, debug and validate code.