EE5610 : Digital Controller for Energy Conversion

INDIAN INSTITUTE
OF TECHNOLOGY
PALAKKAD

Final Report

Course Project

Modeling and Designing a Battery Power Flow Control

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Abstract

This report describes the design and implementation of a battery power flow control model. The system consists of a **battery**, a **DC voltage source**, a **bidirectional DC/DC converter**, and a **common load**. It operates in two modes—**charge** and **discharge**—depending on the availability of the voltage source. Key control strategies, including the use of **PI controllers**, are outlined to ensure proper functionality in both modes.

Battery Power Flow

A Battery Power Flow Control model[1] incorporates various key components, including a **battery**, a **bidirectional DC/DC converter**, a **DC voltage source**, and a **common load**. The combination of these components creates a flexible power management system that can either charge or discharge the battery based on the current requirements and availability of the voltage source. This dynamic functionality is achieved through well-defined control strategies and the ability to switch between charge and discharge modes.

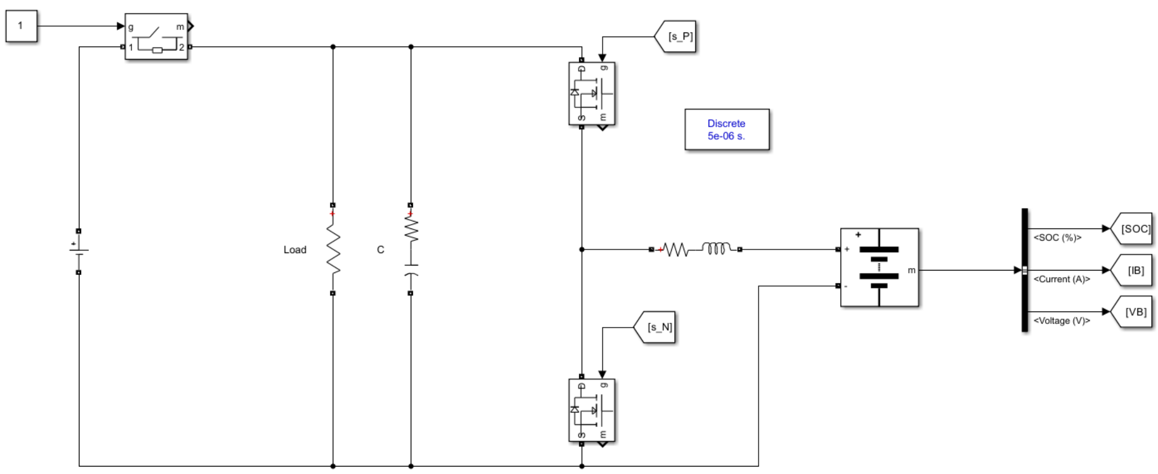


Figure 1: Battery Flow Model

The system dynamically switches between two modes:

- **Charge Mode:** When the voltage source is enabled, it charges the battery and supplies the load.
- **Discharge Mode:** When the voltage source is disabled, the battery supplies power to the load.

Charge Mode

The charge mode is a critical part of the system, as it manages the process of charging the battery in an optimal way to maximize battery life and ensure efficiency. Charging is typically performed in two stages:

- **Constant Current Mode:** The battery is charged with a fixed current. The **maximum allowable current** for this project is **22A**, based on battery properties.

- **Constant Voltage Mode:** The battery voltage is held constant while the charging current decreases as the battery nears full capacity.

Constant Current Mode

In the constant current mode, the battery is charged at a fixed current of **22A**, which is the maximum allowable current for this system based on the battery's specifications. This mode is employed when the battery voltage is significantly lower than the reference voltage, allowing the current to remain constant until the battery voltage reaches the desired level.

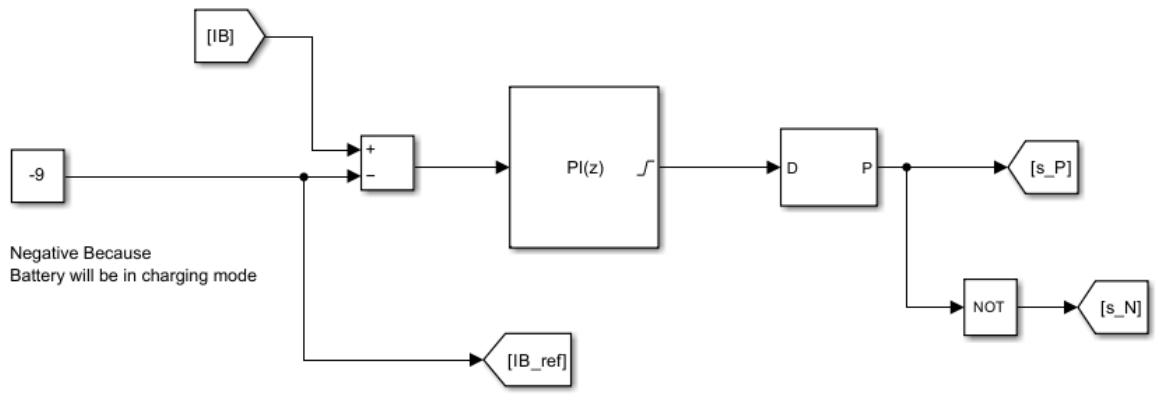


Figure 2: Current Control with P = 0.005 and I = 10

The performance of the current control system is shown above, where the PI controller is tuned to ensure stable operation. The results demonstrate that the system maintains a consistent current during the charging process.

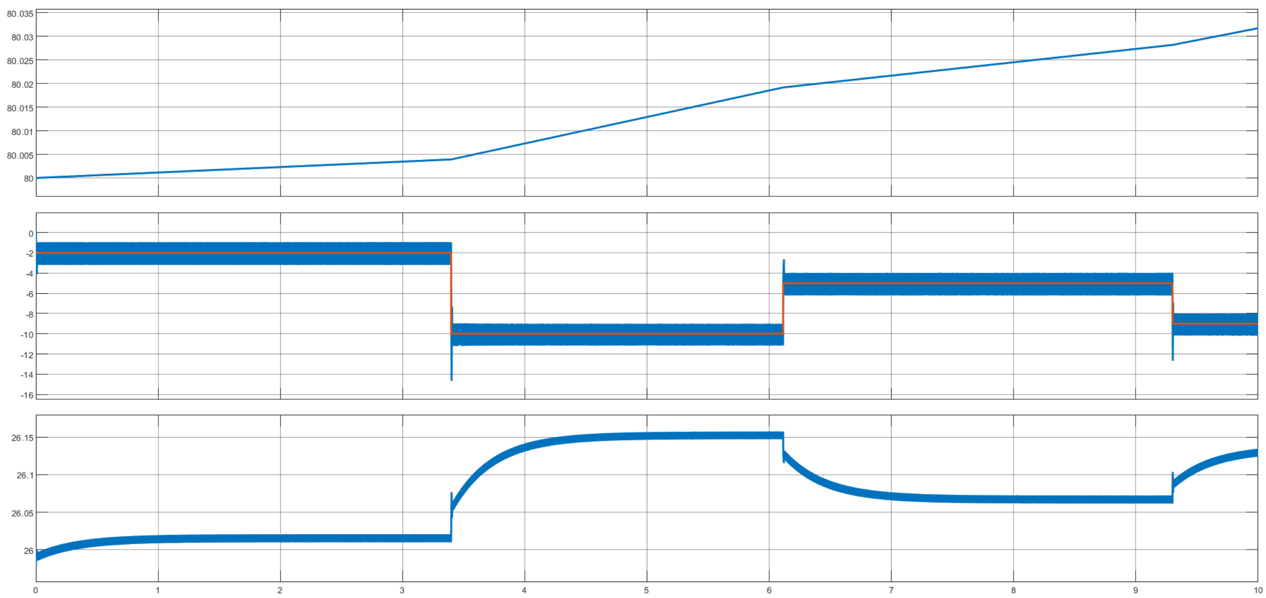
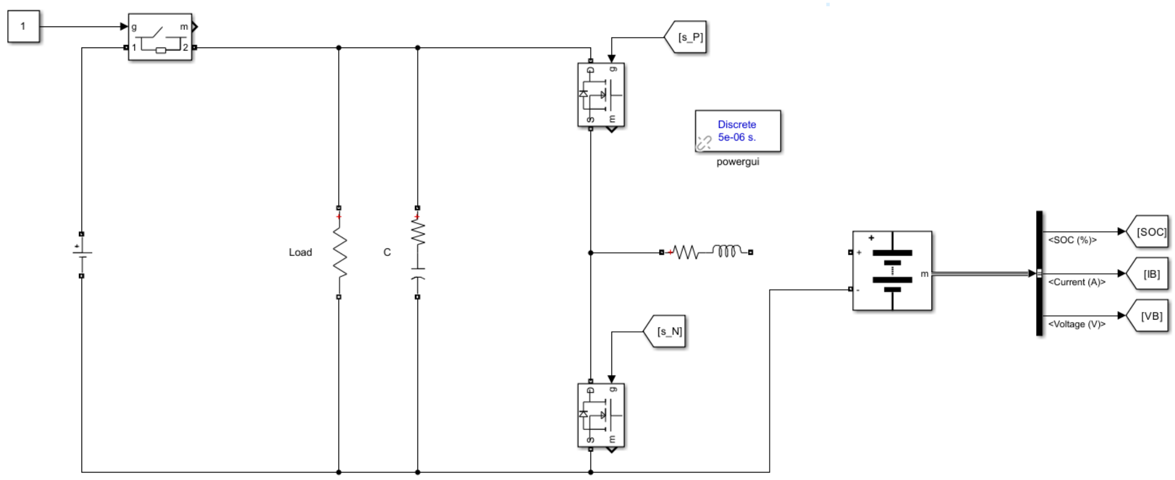


Figure 3: Current Control Verification using varying Reference Current

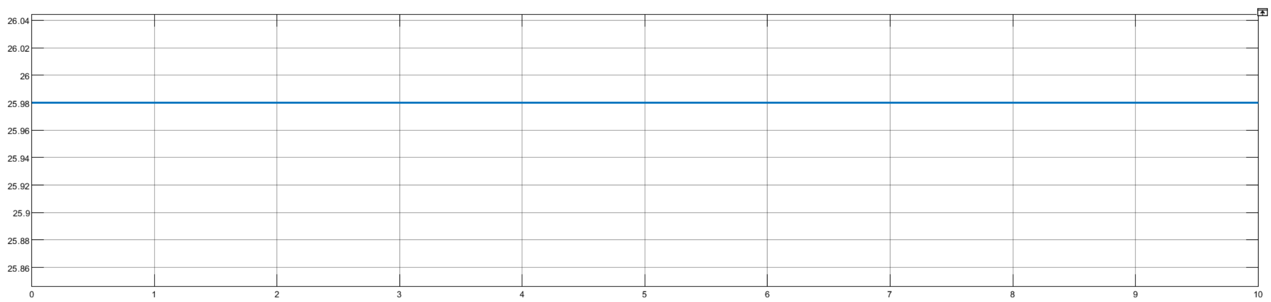
As seen in the graph above, the system adjusts the reference current dynamically to maintain the desired charging current. Battery manufacturers typically transition from constant current charging to constant voltage charging when the battery reaches approximately **80% state of charge (SOC)**.

Some battery manufacturers transition from constant current to constant voltage charging at approximately **80% state of charge (SOC)**.

- During an open circuit test, the **open-circuit voltage** at **80% SOC** was measured to be **25.98V**.



- The measured **open-circuit voltage** at 80% SOC was confirmed to be **25.98V**.



- This voltage value serves as a critical parameter for the charging algorithm, which ensures safe charging until the battery reaches **80% SOC**.
- The charging algorithm is designed to stop at this voltage, with a potential refinement to the algorithm needed for charging the battery to **100% SOC**.

Constant Voltage Mode

When the battery voltage reaches the desired value, the system transitions to constant voltage mode. In this mode, a **PI controller** is used to regulate the charging current in response to changes in the battery voltage. The key goal is to ensure that the battery is charged efficiently and safely by gradually decreasing the current as the battery voltage increases. To regulate the battery current during charging, a **PI controller** is employed.

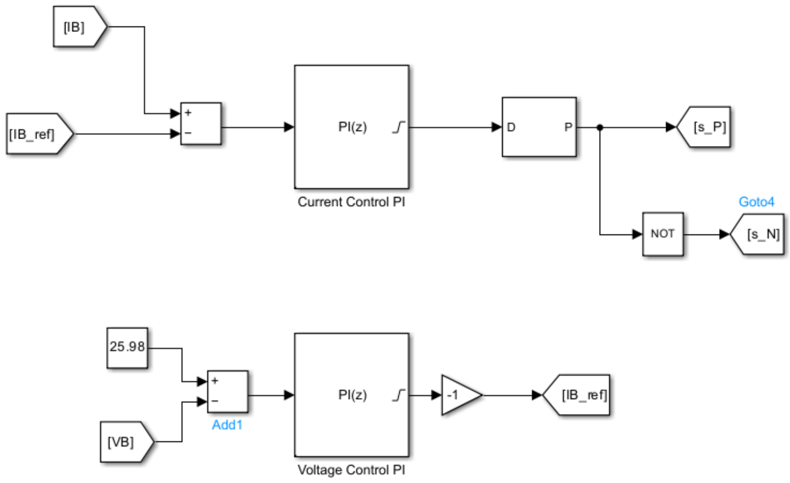


Figure 4: Voltage Controller for Charging with P = 40 and I = 2000

The key parameters for the controller are:

- **Upper Limit:** The maximum current of **22A**.
- **Reference Voltage:** The open-circuit voltage of **25.98V**.

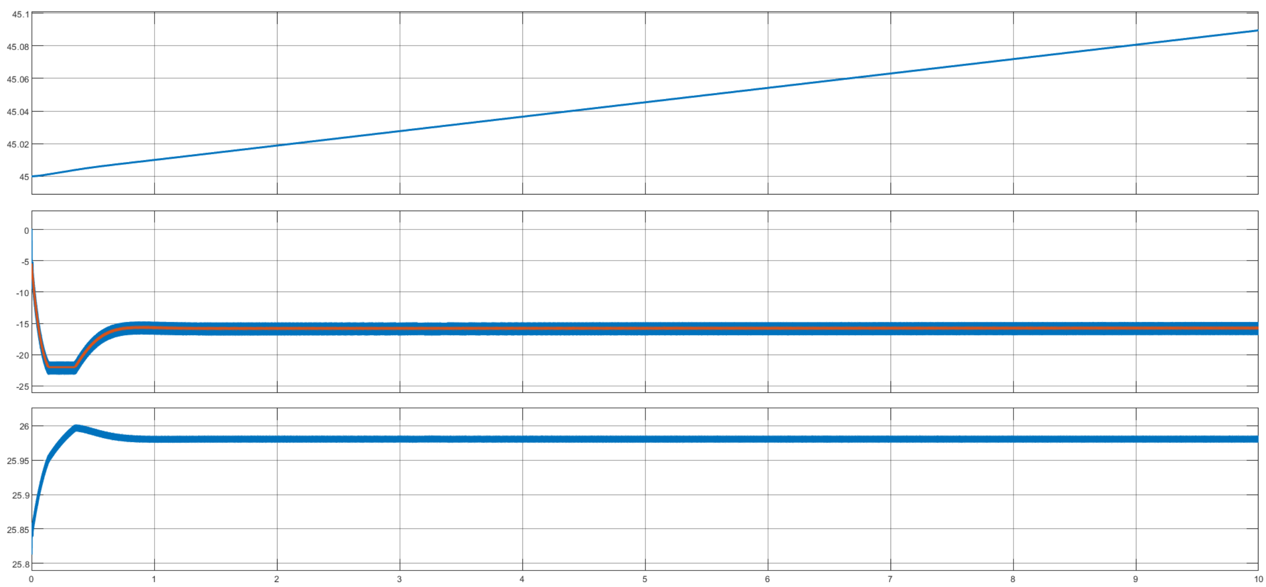


Figure 5: Voltage Control Result for Charging

Initially, the **reference current** is at its **maximum level** because the battery voltage is lower than **25.98V**. As the battery voltage increases, the **PI controller** reduces the reference current to prevent overcharging. During testing, the battery charged successfully at **25.98V** and **16A**.

While the battery charges, the voltage gradually increases. Consequently, the **charge current decreases**, ensuring safe and efficient charging. The **charge mode** was completed successfully with this strategy.

Discharge Mode

In discharge mode, the system operates in a different configuration, where the **battery** supplies power to the **load**. The primary objective of discharge mode is to provide a stable and constant voltage of **48V** to the load, ensuring that the load receives uninterrupted power even when the external voltage source is unavailable. The battery's discharge cycle is carefully managed to prevent excessive voltage drop or damage to the battery, and the system ensures efficient energy delivery.

Similar to the charging process, a **PI controller** is used to regulate the discharge current. This helps in maintaining a constant voltage at the load while preventing any sudden fluctuations that could affect the load's performance. The **Proportional-Integral (PI) controller** continuously adjusts the output current, ensuring that the battery operates within its limits and the load receives a steady supply of power.

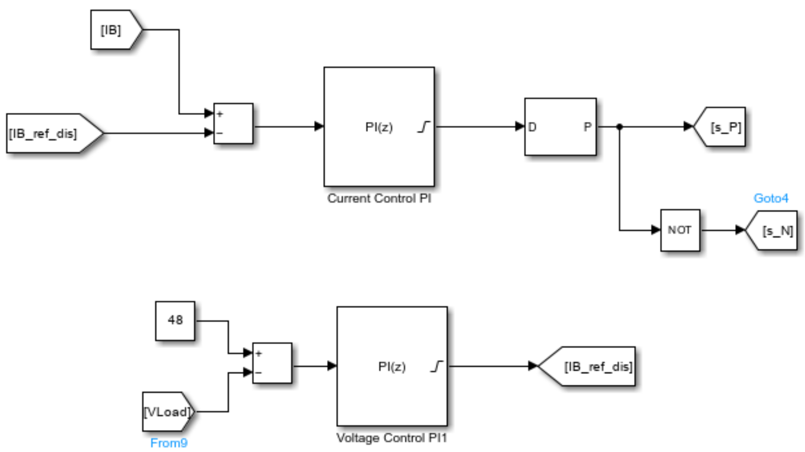


Figure 6: Voltage Controller for Discharging with P = 0.25 and I = 50

During the discharge mode, the following observations are noted:

- The battery is actively discharging, with the **State of Charge (SOC)** gradually decreasing over time.
- The battery current remains **positive**, indicating that the battery is supplying power to the load.
- The **load voltage** is maintained at approximately **48V**, ensuring that the load receives a stable and reliable supply of power.
- The **discharge current** is dynamically controlled by the PI controller to avoid over-discharge or excessive current that could damage the battery.

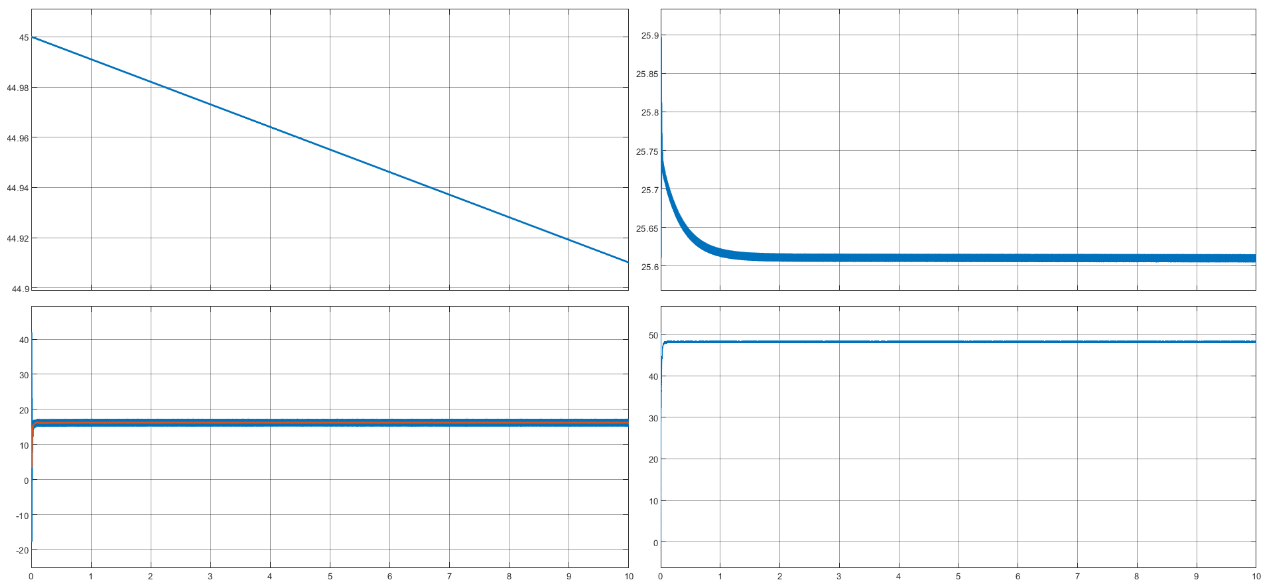


Figure 7: Voltage Control Result for Discharging

As shown in the graph above, the system successfully operates in **discharge mode**, maintaining a stable **48V** output to the load while the battery continues to discharge. The **PI controller** ensures that the battery discharges efficiently and within the safe operating range, thus optimizing performance and extending battery life.

Mode Switching

To achieve seamless operation between the charging and discharging modes, a **switching mechanism** was implemented. This mechanism allows the system to transition between the two modes based on the status of the **voltage source**. The system switches modes automatically, depending on the availability of the voltage source and the power requirements of the load.

The mode selection operates as follows:

- **Charge Mode:** When the external voltage source is **enabled**, the system switches to charge mode. In this mode, the battery is charged, and the load is powered by the external voltage source. This ensures that the battery stores energy while the load continues to receive power.
- **Discharge Mode:** When the voltage source is **disabled** or unavailable, the system switches to discharge mode. In this mode, the battery supplies power directly to the load, ensuring uninterrupted power delivery to the load even in the absence of an external voltage source.

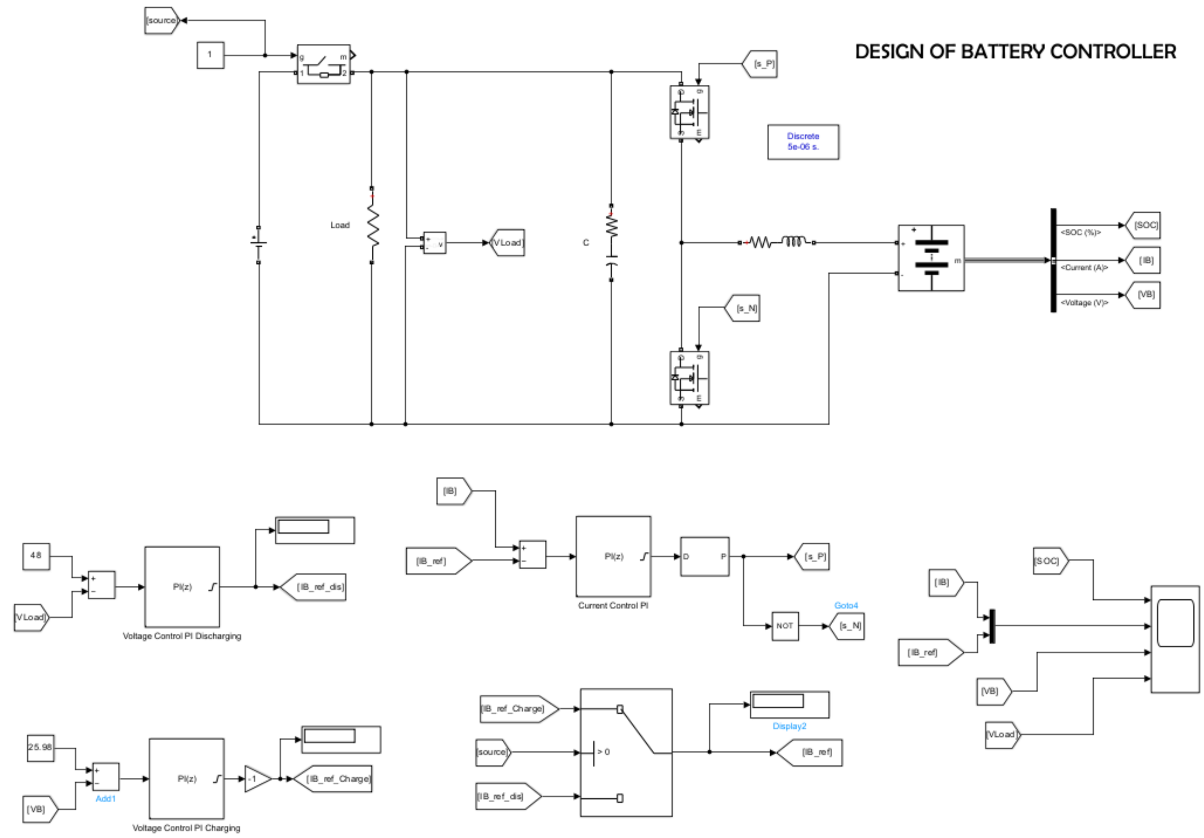


Figure 8: Final System with Switching Mechanism

The implementation of the switching mechanism ensures that the transition between charge and discharge modes occurs without causing any disruptions to the power supply. By monitoring the status of the voltage source, the system can automatically switch modes in real time, thus providing a dynamic and responsive power management solution.

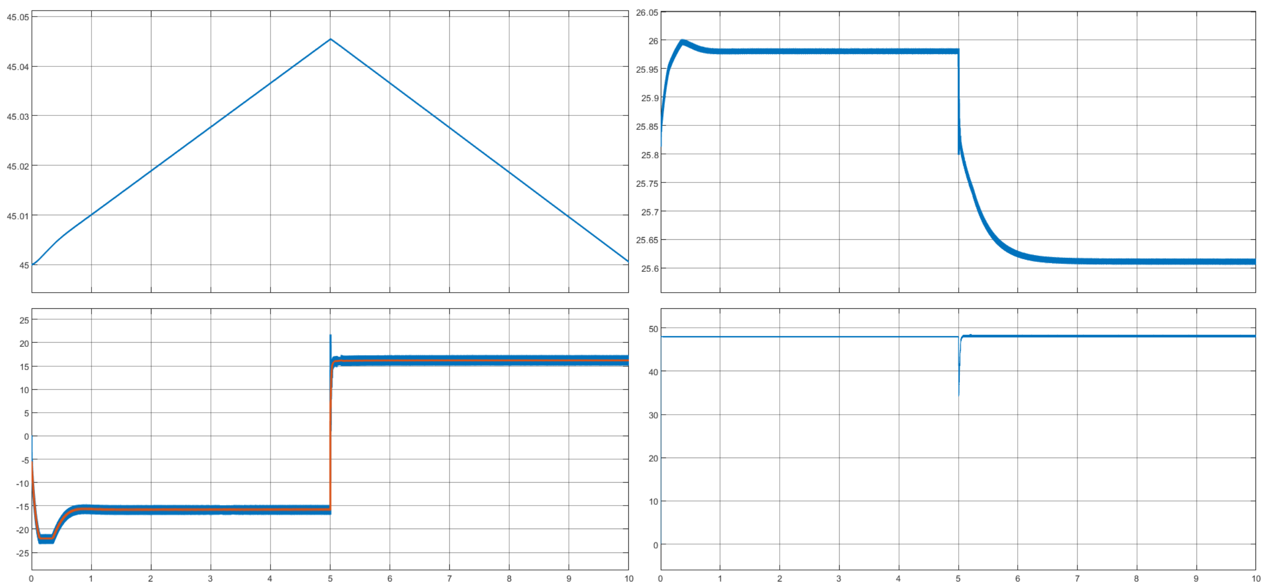


Figure 9: Final Controller Graph with Transition from Charging to Discharging at Second 5

The graph above illustrates the smooth transition from charge to discharge mode at the fifth second. This transition is achieved by the switching mechanism, which allows the system to adjust based on the voltage source's availability. The controller ensures that the load receives continuous power during the transition, preventing any power interruptions.

Conclusion

The design of the battery power flow control model effectively integrates a **bidirectional DC/DC converter** with **PI controllers** to manage both **charge** and **discharge modes**. The system demonstrates reliable and efficient power flow to the load under various operating conditions. Key outcomes from the project include:

- The **battery charges safely**, transitioning from **constant current mode** to **constant voltage mode** at a voltage of **25.98V**.
- The **load voltage remains stable at 48V**, even when the system switches to **discharge mode**, ensuring uninterrupted power delivery.
- The **mode-switching mechanism** functions effectively, allowing the system to transition seamlessly between charge and discharge modes, based on the availability of the voltage source.

The system operates efficiently, with the controllers ensuring that the battery is not overcharged or over-discharged, and the load receives a consistent voltage. The results confirm that the system is robust and can adapt to varying power demands.

Future Works

- Refining the **control algorithm** to improve charging performance beyond the **80% SOC** threshold, ensuring that the battery can be charged more efficiently to full capacity.
- Adding additional **safety features** to protect the battery from extreme conditions such as overcharging, deep discharge, or temperature fluctuations, further enhancing the reliability of the system.
- Exploring **battery management algorithms** that can optimize the overall lifespan and performance of the battery, particularly in real-world scenarios where the load and source conditions fluctuate frequently.

These enhancements would further improve the system's performance, ensuring that the battery power flow control model remains a reliable and efficient solution for power management in energy conversion systems.

References

[1] Naki GÜLER. Battery controller design in simulink, 2018.