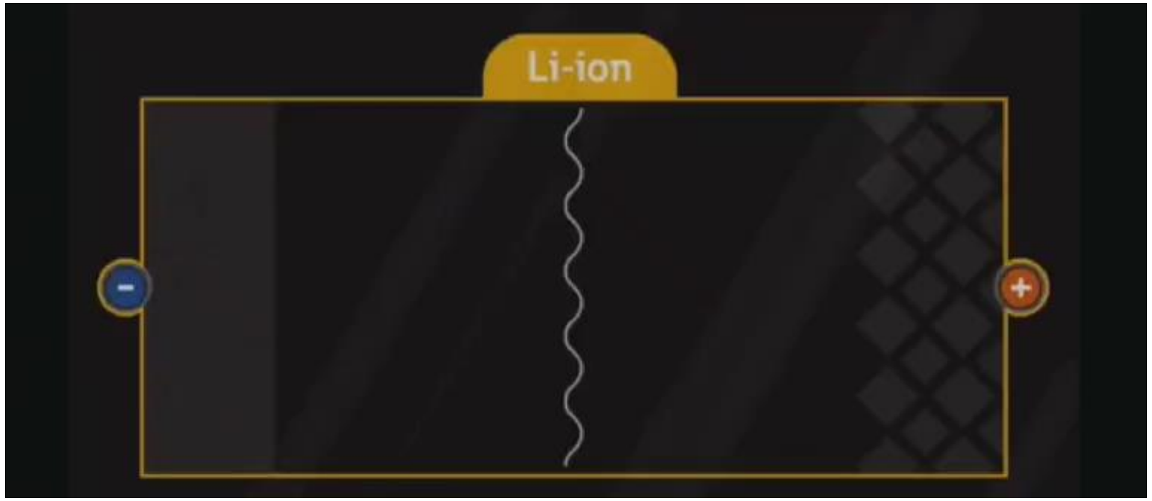
Battery-Supercapacitor Hybrid Energy Storage Systems

ESL341 PRESENTATION : PREKSHA MISHRA ; SNIKITA PENTE

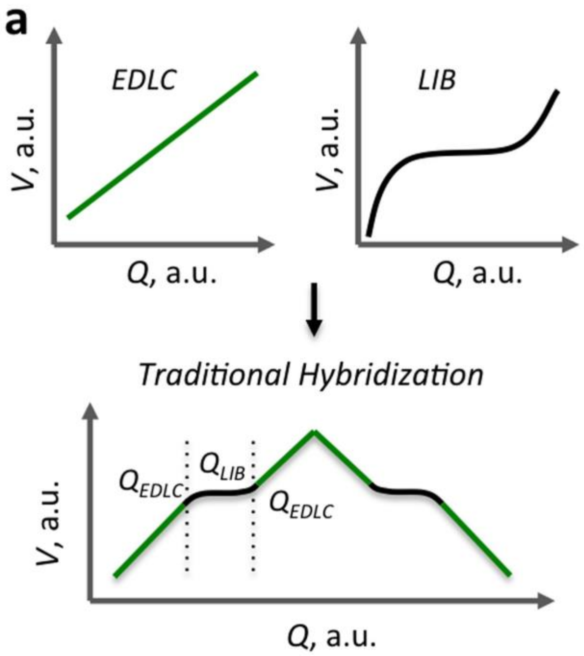
Introduction

ELDC



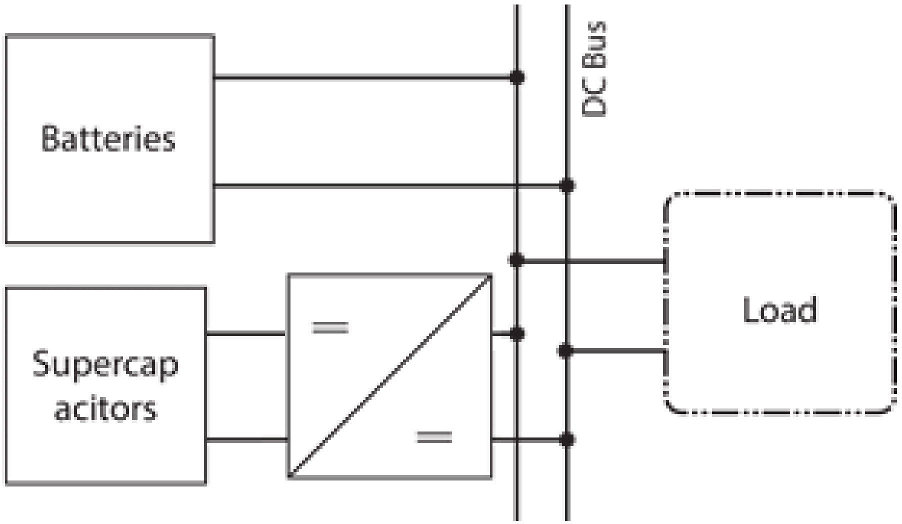
Lithium ion battery

Introduction



Parallel Configuration

The HESS controller dynamically allocates energy flow between the battery and supercapacitor, optimizing performance based on load demands in such a way that the battery provides sustained energy for longer-duration loads, while the supercapacitor handles transient power spikes and surges.



This makes it ideal for diverse applications where both steady energy delivery and fast power response are needed, such as grid stabilization, renewable energy systems, and electric vehicle acceleration.

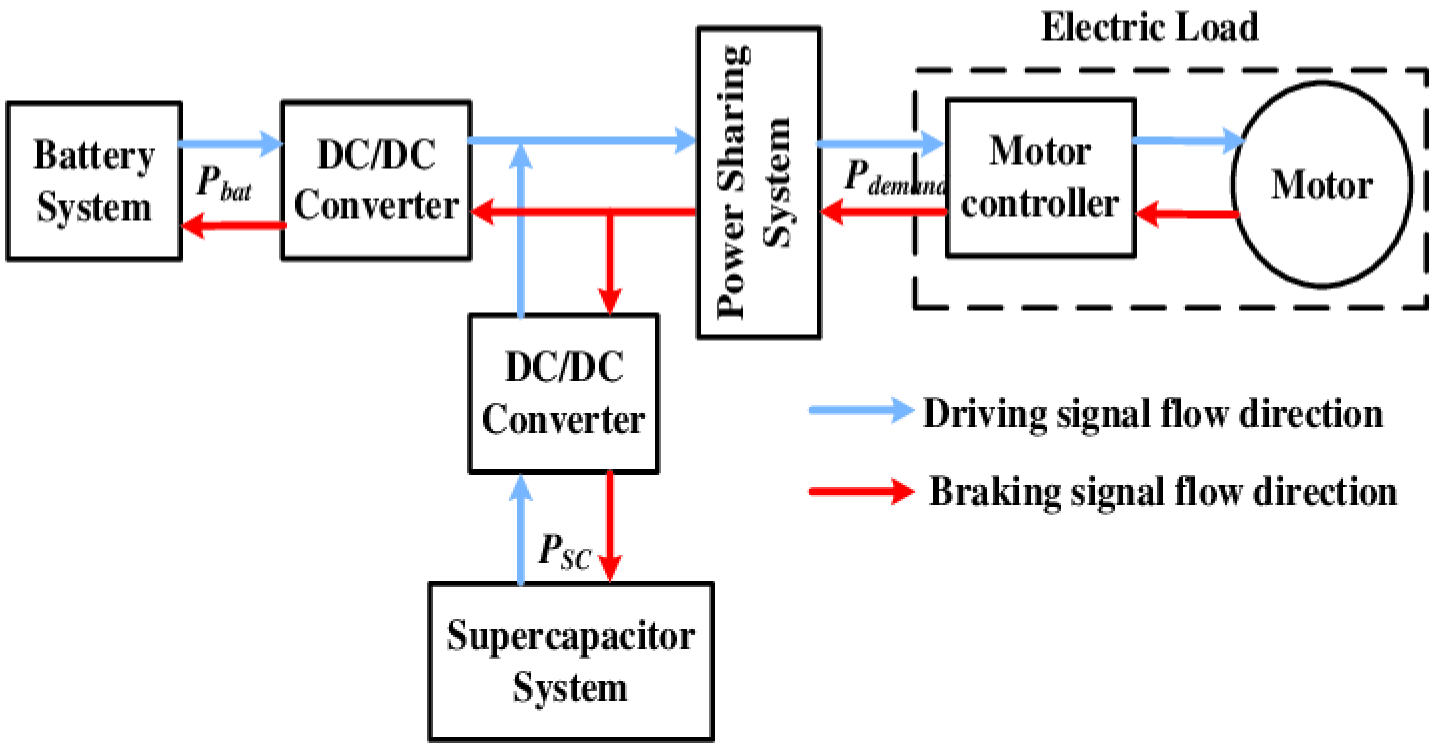
HESS Control Strategies

- Rule-Based Control: If the load power exceeds a certain threshold, the supercapacitor supplies the excess; otherwise, the battery handles it.

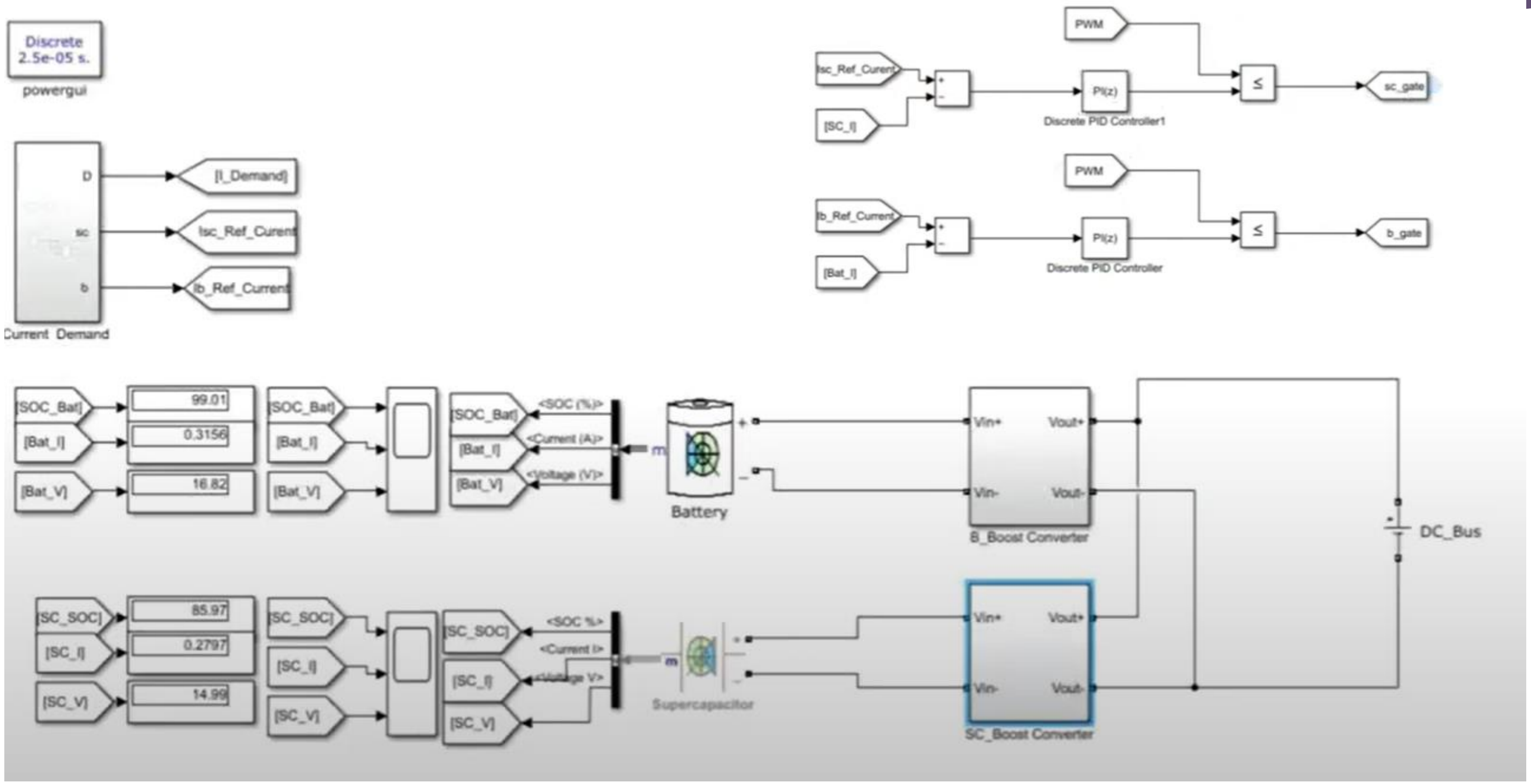
- Fuzzy Logic Control: Based on the power demand, state of charge (SOC) of the battery and supercapacitor, and other operational parameters, FLC dynamically allocates power. For instance, it might gradually shift load from the battery to the supercapacitor as demand increases, rather than switching abruptly.

- Model Predictive Control: MPC uses predictive models to forecast future load demands and determine the optimal power split between the battery and supercapacitor by minimizing a cost function (e.g., energy efficiency, battery degradation)

Block Diagram



Simulation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Vout+
Vin-
Vout-
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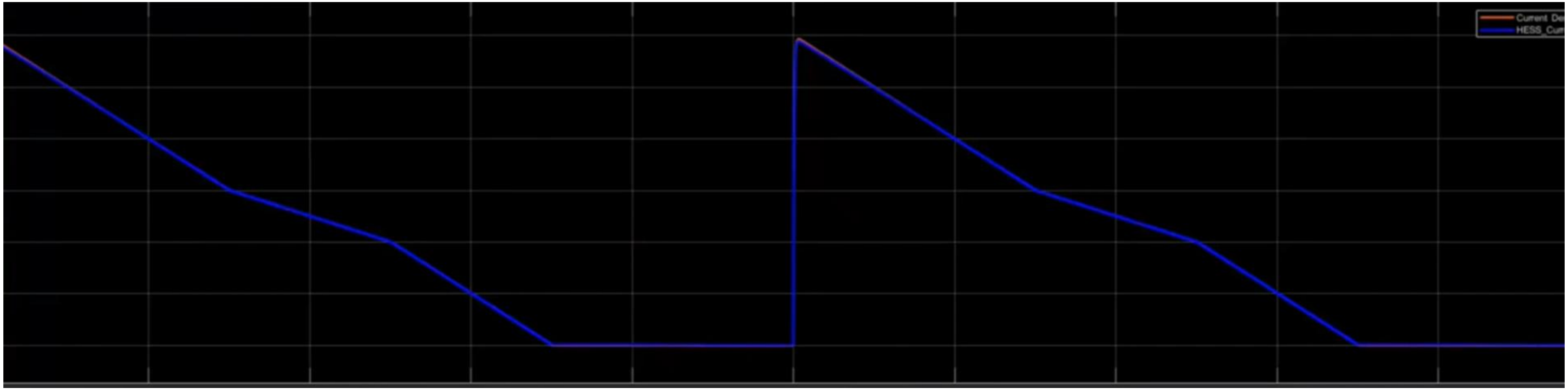
Supercapacitor
SC_Boost Converter

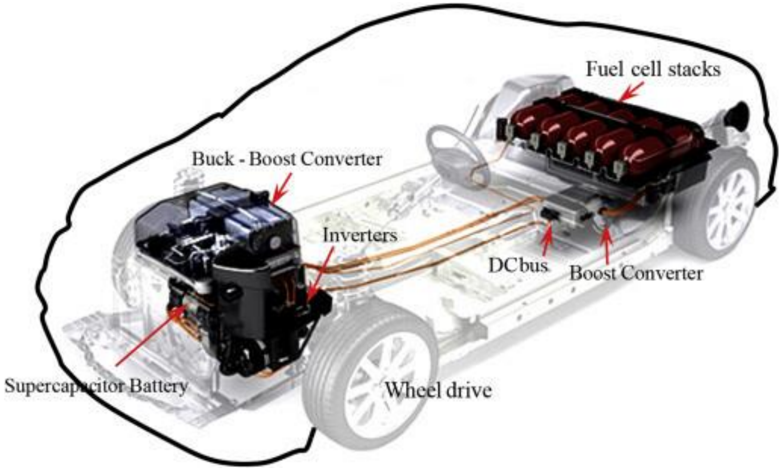
Result



Case Study: HESS in Electric Vehicles

- Acceleration and Regenerative Braking: Supercapacitors absorb the high-power demands of acceleration, significantly reducing the current drawn from the battery. During braking, supercapacitors rapidly capture and store regenerative energy, which would otherwise be lost as heat.

- Battery Longevity: By mitigating high-power spikes, the HESS prevents the battery from frequent deep discharges and high-current draws. This lessens the thermal and mechanical stress on the battery, leading to a longer cycle life and reduced degradation.



HESS in Electric Vehicles Results

- Increased Range: Vehicles using HESS reported up to a 10-15% increase in range due to the more efficient use of battery power.
- Improved Battery Lifecycle: The controlled load distribution extended battery life by approximately 20%, reducing the frequency of battery replacements and associated costs.
- Enhanced Driving Experience: With supercapacitors smoothing out power delivery during acceleration and braking, drivers experience more responsive and smoother vehicle performance.

Financial Feasiblity Study – capital costs

- 1. Battery Costs: Batteries make up a significant portion, especially lithium-ion, typically ranging from 40-60% of the CapEx. For a medium-scale project, this could range from $400,000 to $600,000.
- 2. Supercapacitor Costs: Supercapacitors are pricier per kWh than batteries, but with lower total capacity needs, they generally account for 15-20% of CapEx, approximately $150,000 to $200,000.
- 3. Power Electronics and Converters: These are crucial for managing the interaction between the battery and supercapacitor, accounting for 10-15% of CapEx, approximately $100,000 to $150,000.
- 4. Energy Management System (EMS): The EMS software and hardware for controlling charge-discharge cycles and optimizing system performance can add 5-10%, around $50,000 to $100,000.
- 5. Installation and Commissioning: Labor, site preparation, and integration with the grid or other systems make up 10-15% of the total cost, typically in the $100,000 to $150,000 range.
- Total cost 1milloin.
- Cost may vary depending on market rates.

Savings

- 1. Reduced Battery Replacement: Supercapacitors handle peak loads, reducing battery cycling frequency. This can extend battery life by up to 15-20%, saving on replacement costs—around $50,000 to $70,000 annually.
- 2. Lower Maintenance: Lower wear and optimized battery operation lead to reduced maintenance, saving an estimated $20,000 to $30,000 per year.
- 3. Grid Services Revenue: Enhanced response from supercapacitors allows participation in grid services (like frequency regulation), bringing in about $80,000 to $100,000 annually.
- 4. Energy Cost Reduction: Improved efficiency and peak shaving can save approximately $30,000 to $50,000 on energy expenses.
- Total annual savings may range from $150,000 to $200,000, depending on usage, grid participation, and system efficiency.

Operation and Maintenance costs

- 1. Routine Maintenance: Regular inspections, system calibration, and monitoring costs for the battery and supercapacitor, typically about $10,000 to $15,000 annually.
- 2. Battery Replacement and Servicing: Though reduced by the hybrid system's benefits, battery components still require occasional replacement, averaging around $15,000 to $20,000 per year spread across the system's lifespan.
- 3. Software and EMS Updates: Energy management system updates and software support can cost approximately $5,000 to $10,000 yearly.
- 4. Grid Compliance and Testing: Periodic testing and compliance checks for grid participation, averaging $5,000 annually.
- Total annual O&M costs are usually around $35,000 to $50,000, varying based on system complexity, usage, and grid requirements.

Discounted payback calculation

- B-C= 150,000
- Cinitial= 1,000,000
- d=0.08
- Tdp= {ln(b-c)-ln[(b-c)-d*cinitial]}/ln(1+d)
- = 9.9= 10 yrs
- Lithium ion battery cost recovery in 3.5 to 7 yrs depending on location.
- Average lifespan of the system is 15 yrs which can be increased by adding additional maintenance.

Net Present Value of installation

- B-C= 150,000
- Cinitial= 1,000,000
- d=0.08
- N= 16
- NPV= (B-C)[((1+d)**n-1)/(d*(1+d)**n)]
- =327,705 dollars
- Net profits low compared to investment required.

Associated risks

- Thermal Management
- System Degradation
- Control system
- Economic: Market Volatility-> grid prices
- Grid compatibility and regulatory issues

Referenes for values

- https://www.mdpi.com/2073-8994/14/6/1085
- https://www.mdpi.com/1996-1073/12/23/4559
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- https://pure.hw.ac.uk/ws/files/15659761/WenlongJING_IET_renewable_power_generation_with_Reference.pdf
- https://ieeexplore.ieee.org/document/10020167

Thank you