# Supercapacitor Integrated Battery System for Electric Vehicle

EE6109: Electric Vehicle Powertrain | Course Project Presentation

**Group 18**: Yash Udayan Paritkar (210070096), Zala Mayursinh Meghrajsinh (210070099)

## Introduction

- In this project, supercapacitor (SC) integrated batteries are analysed with respect to their feasibility
- It goes through the limitations of Li-ion batteries, advantages of using supercapacitor hybrid batteries, simulations for both the batteries and conclusions
- In this project, the **comparison of an active SC hybrid battery with a li-ion only battery in terms of range**

## Batteries in eV

- Batteries, being **primary energy storage,** unit forms an integral part of electric vehicles
- **Efficiency, energy density, power density and durability** are important parameters regarding batteries
- Most of the modern electric vehicles use Li-ion batteries
- These batteries are favoured for their high energy-to-weight ratio, low self-discharge rate, and ability to handle multiple charge cycles effectively
- Li-ion batteries have **low peak discharge rate and charge rate**
- This limits the ability to charge and accelerate quickly
- Since this is a chemical-redox-based battery, it can only last a **limited charge cycles** (~500-1000)
- This again limits our ability to regenerate energy

## Supercapacitors

- Supercapacitors (SC) are essentially **high-capacity** capacitors with capacitance of the order of 1 F [1]
- Although they have lower voltage limits than the capacitors of the order of few volts
- They use **electrostatic double-layer capacitance** and electrochemical psuedocapacitance for energy storage
- Since their main storage is not faradic, they tend to last for **high number of charge cycles**
- The main disadvantage of the supercapacitor is their **higher leakage** over time
- Hence typically used **for burst-mode power delivery** and storage

## Comparision between SC and Li-ion battery [2]

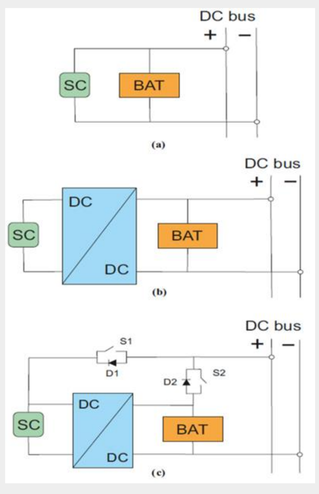
| Function | Supercapacitor | Lithium Ion |
|---|---|---|
| Charge time | 1 – 10 seconds | 10 – 60 minutes |
| Cycle life | 1 million | 500 and higher |
| Cell voltage (nominal) | 2.3 – 2.75 V | 3.6 – 3.75 V |
| Specific energy (Wh/kg) | 5 | 100 – 200 |
| Specific power (W/kg) | ~ 10,000 | 1000 – 2000 |
| Cost per Wh | ₹1600 | ₹40-80 |
| Service life | 10 – 15 years | 5 – 10 years |
| Charge temperature | -40 – 60 ºC | 0 – 30 ºC |

## SC Hybrid battery

- In order to have advantages of both, SC hybrid batteries are also used in many models historically [3]
- Depending on how both are connected to the bus, they are divided into three types [4]

**1. Passive 2. Semi-active 3. Active**

We have compared active configuration with no SC battery




## Overview of simulations in Matlab

Primary Model Data → Pre-Processing → Computation of Energy Over Drive Profile → Analysis of the Result

- **Primary Model Data**: Giving input of primary vehicle data such as vehicle mass, battery parameters, capacitor size, motor torque, etc.
- **Pre-Processing:** Supplementary parameters such as maximum acceleration, maximum power delivered by battery, etc.
- **Computation of Energy Over Drive Profile:** The vehicle run is simulated on a city drive profile obtained from the web while considering a supercapacitor for regeneration
- **Analysis of the Result:** The results are analysed with the help of plots and numbers and the gain with respect to the supercapacitor

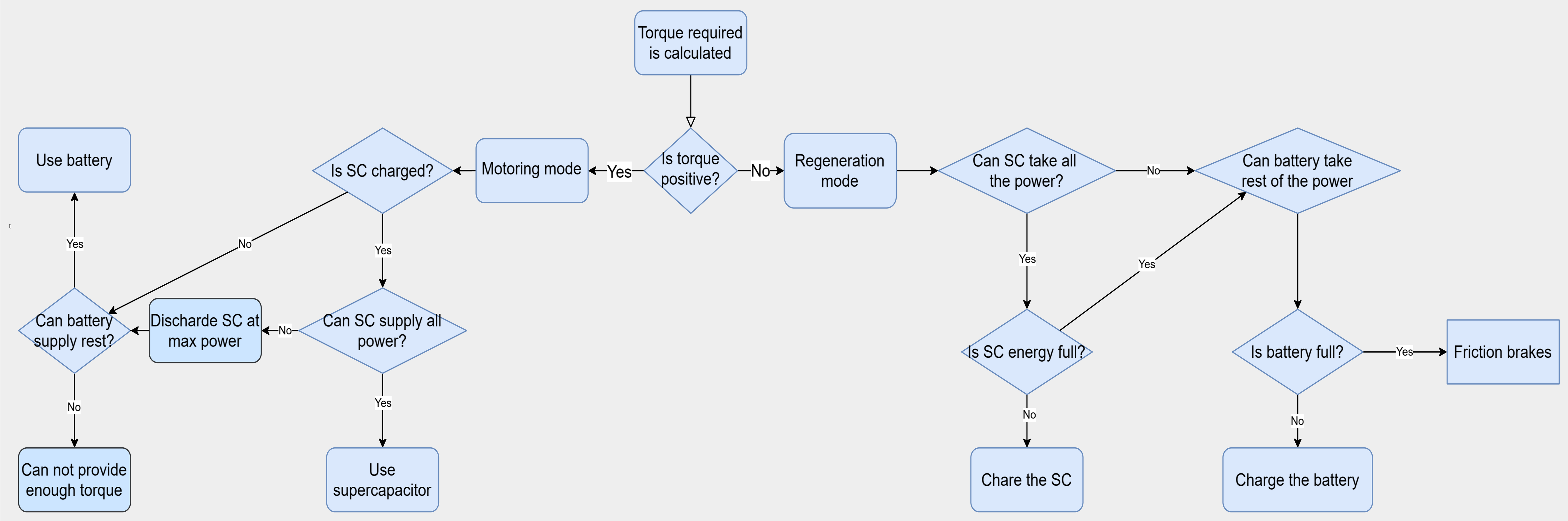
## Simulation setup

- The simulations are performed using a speed-time vehicle profile obtained from the New York City drive profile. The data is saved in Excel format.
- The feasibility of the input data is tested by comparing with the peak torque requirement with the motor capacity
- No additional package of Matlab is used apart from the standard delivery executable.

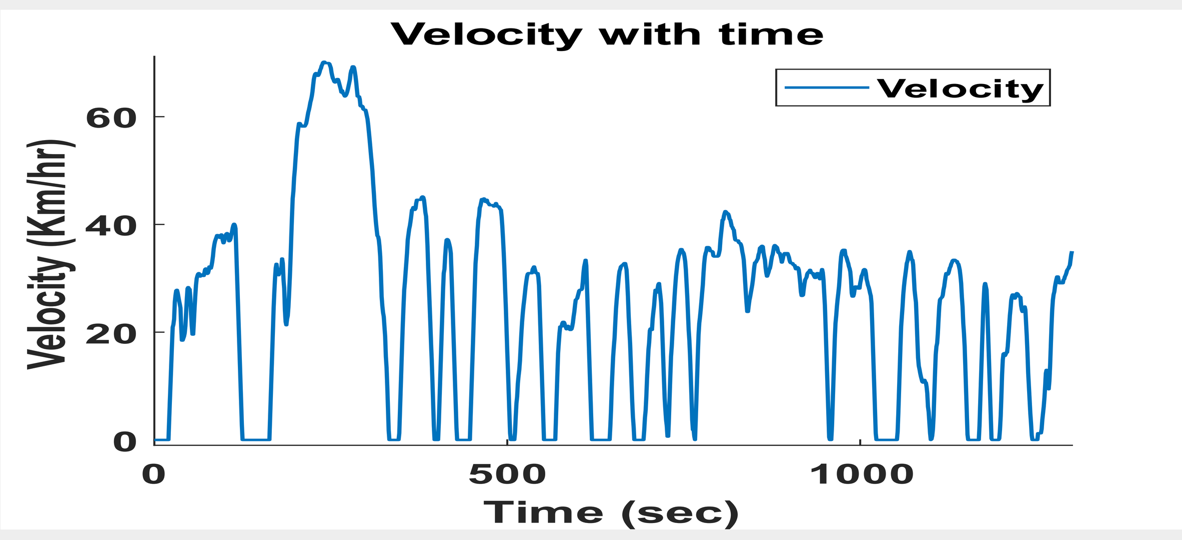
## Simulation Algorithm

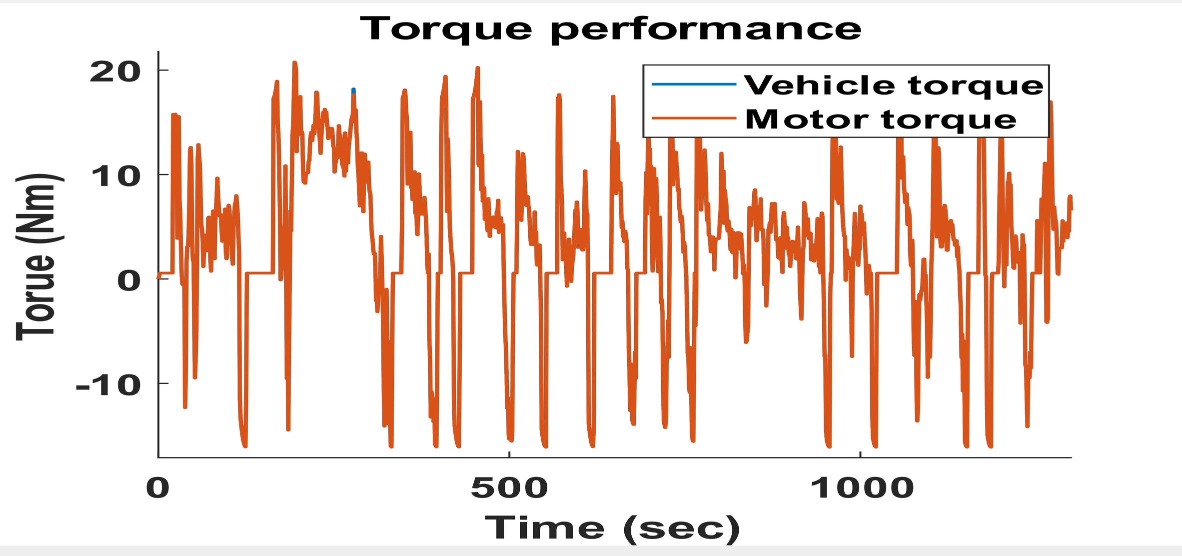
- At every time instant, the torque required is calculated with help of the speed-time profile and inertia
- At every moment, an algorithm is used to decide form where the energy and power is used
- The algorithm is run twice, with and without the supercapacitor for performance comparison
- This allows us to gauge roughly the impact of the supercapacitor on the electric vehicle performance

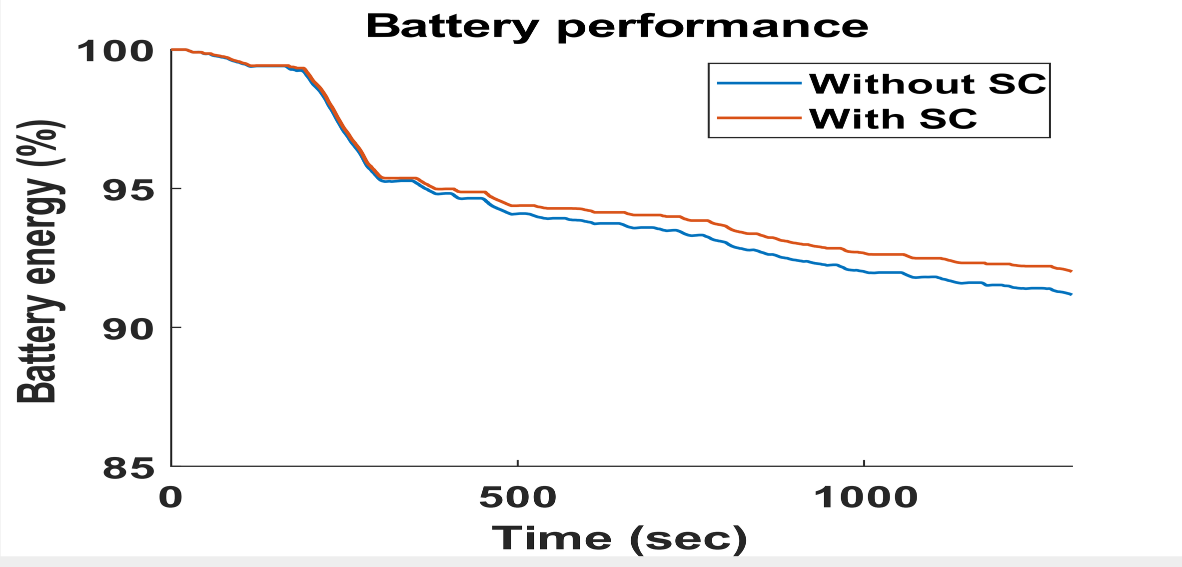
## Simulation Algorithm Flowchart

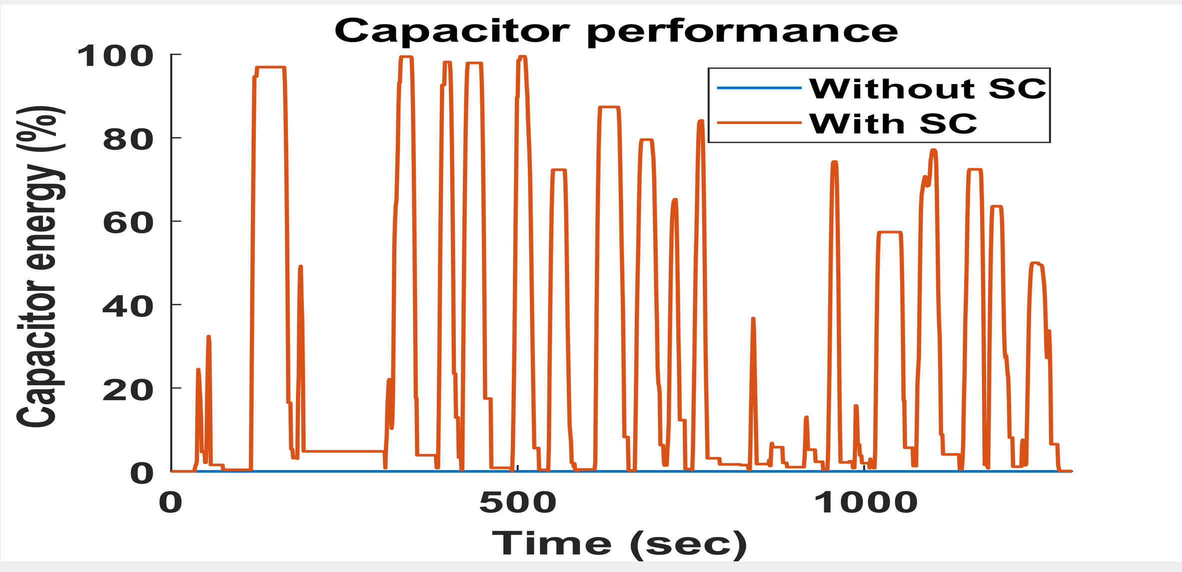


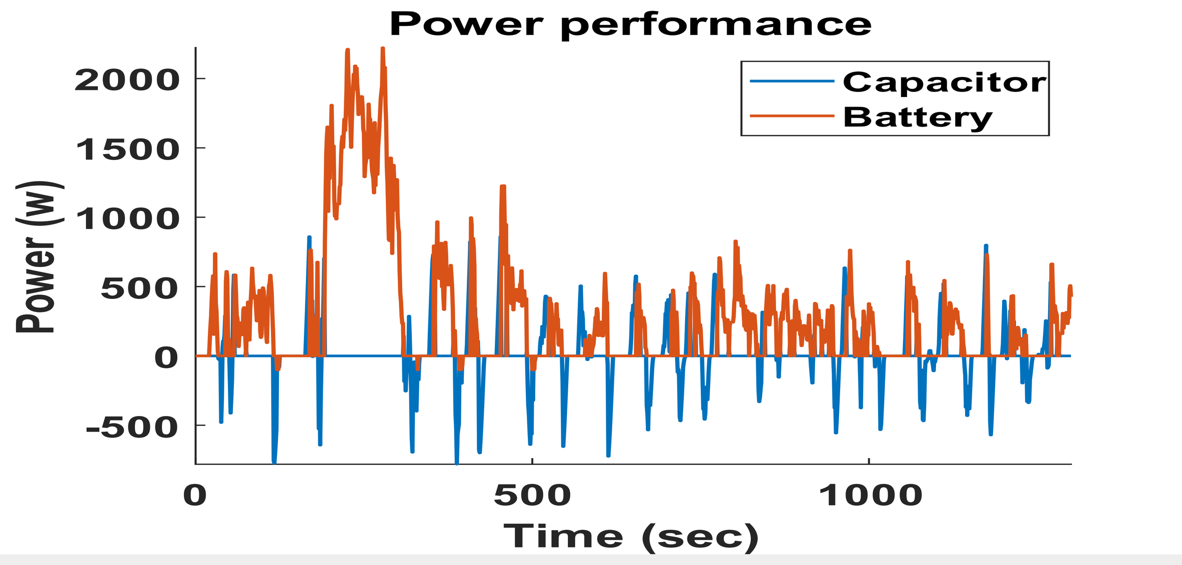

## Simulation Results




## Simulation Results and Conclusions

- As expected, the battery performance increases due to increased regeneration ability due to supercapacitor
- On a few instances, we can see that the battery also takes regenerative power which shows correctness of the model
- Even small SC helps in improving regeneration, the marginal gain of capacitor value decreases after a point due to added mass
- Using SC hybrid capacitor improved the energy saving on the current drive profile by **10.43 %** in terms of Wh/km from 28.80 Wh/km to 38.81 Wh/km
- The single charge range increases from **37.72 km to 41.66 km**
- The rough cost of the SC + added electronics amount to **₹ 2,600**
- The reduced number of charge cycles can improve the battery life by around **6 months**

## Possible future improvements

- Variation in the power due to **gradient** can be included in the simulations which will affect the required torque
- The **ESR** of the battery and the supercapacitor can be included. As batteries typically have higher ESR, the gain due to the supercapacitor will increase
- The **efficiency** of the DC/DC converter and motor is not included; simple models, such as constant efficiency model, can be added easily
- **More advanced algorithms** for battery-SC power-energy distribution can be used
- Testing can be done for more drive profiles and models for better estimates of gains due to supercapacitor

## References

[1] Forouzandeh, P.; Kumaravel, V.; Pillai, S.C. Electrode Materials for Supercapacitors: A Review of Recent Advances. *Catalysts* **2020**, *10*, 969. https://doi.org/10.3390/catal10090969

[2] A. A. Nakad, M. Madi, O. Aaker, E. L. Ntantis and K. Y. Kabalan, "Comparing supercapacitors to lithium-ion batteries through measurements and simulations," International Conference on Electric Vehicle and Vehicle Engineering (CEVVE 2023), Shenzhen, China, 2023, pp. 28-33, doi: 10.1049/icp.2023.3348.

[3] Lingcong Guo, Pan Hu, Hong Wei, Development of supercapacitor hybrid electric vehicle, Journal of Energy Storage, Volume 65, 2023, 107269, ISSN 2352-152X, https://doi.org/10.1016/j.est.2023.107269.

[4] Lemian, D.; Bode, F. Battery-Supercapacitor Energy Storage Systems for Electrical Vehicles: A Review. *Energies* **2022**, *15*, 5683.

- GitHub link for the project:
- https://github.com/paritkary25/ee6109/