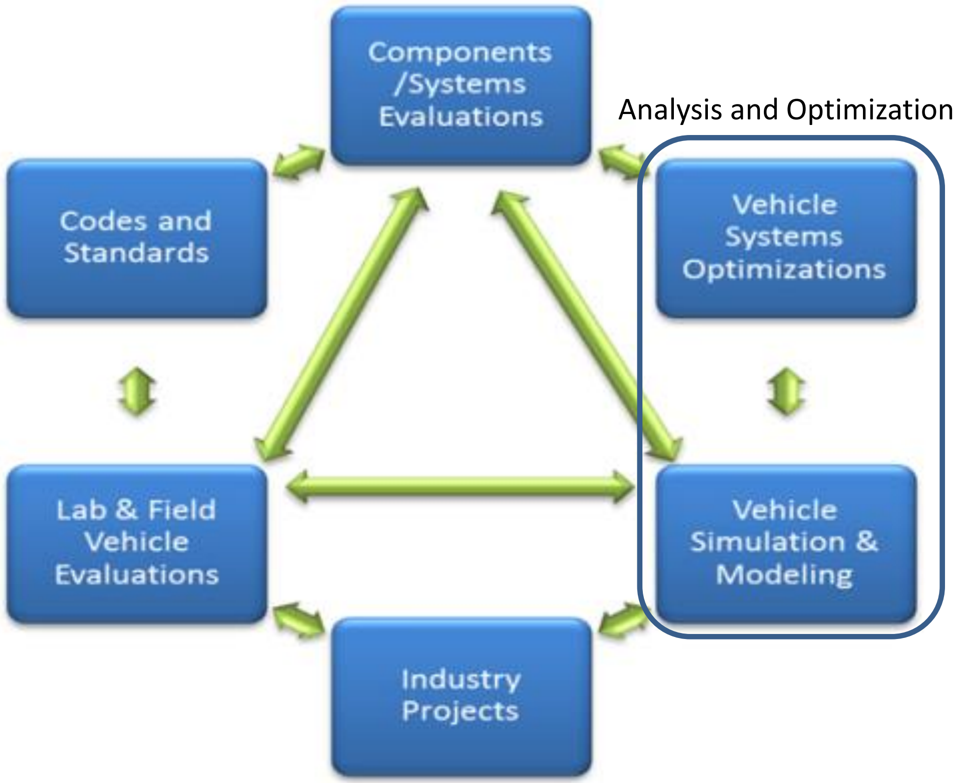
ELG4157: Open-Ended Case Study

Analysis and Optimization of a Hybrid Electric Vehicle

This case will be conducted to analyze (model and simulate) and optimize a powertrain to propel a typical passenger vehicle in an urban driving environment. There are many hybrid electric vehicle (HEV) and electric vehicle (EV) type systems on the market today, this case may chose the Toyota Prius HEV system as a baseline using a brushless AC motor.

The powertrain consists of electrical machines, power electronics and electric energy storage system (battery, super capacitors) and many other electrical loads

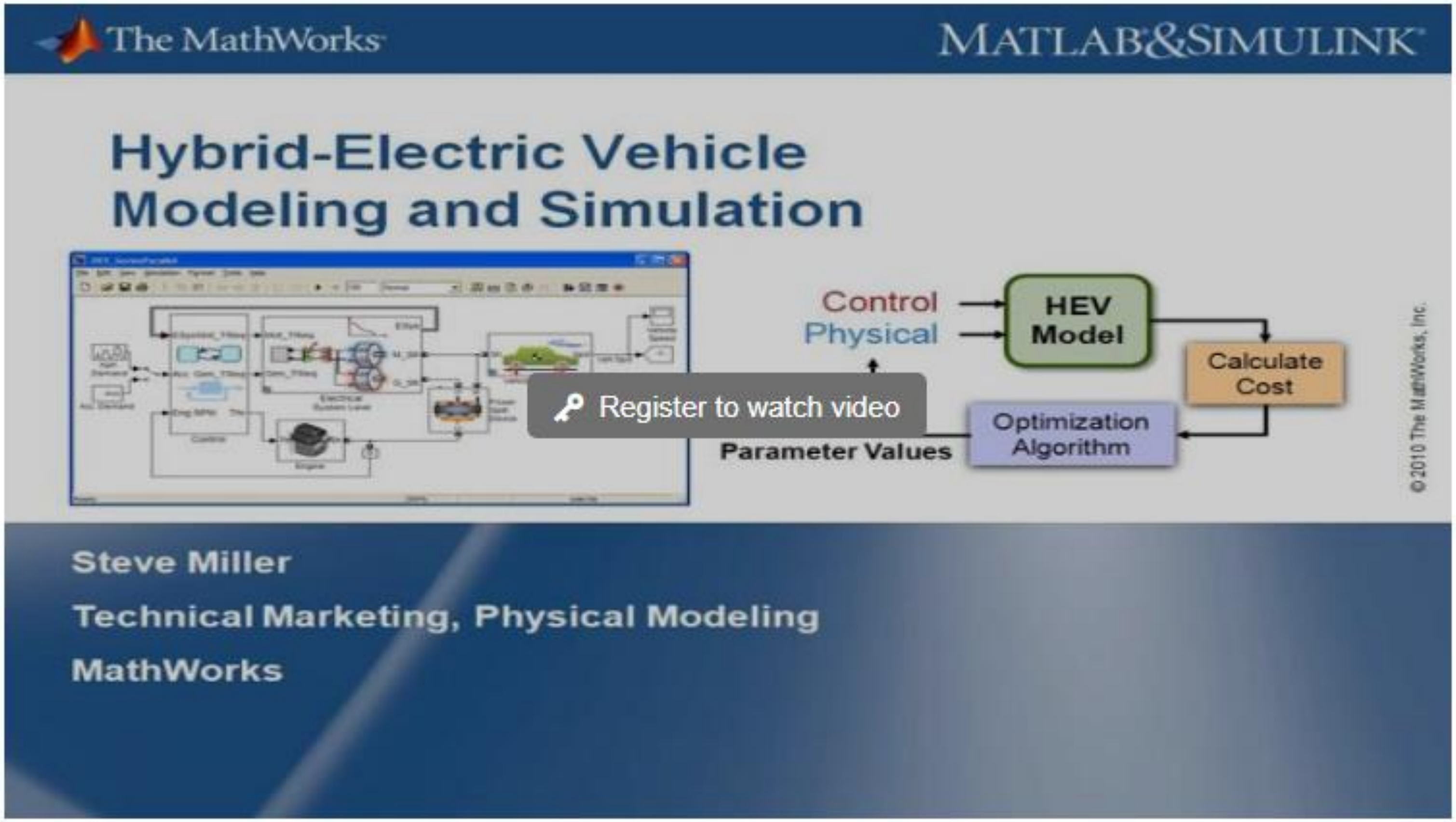
Vehicle System Development



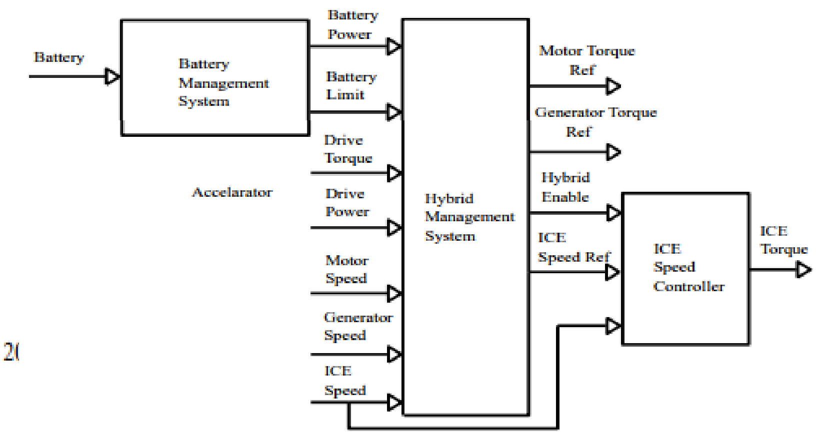
Introduction

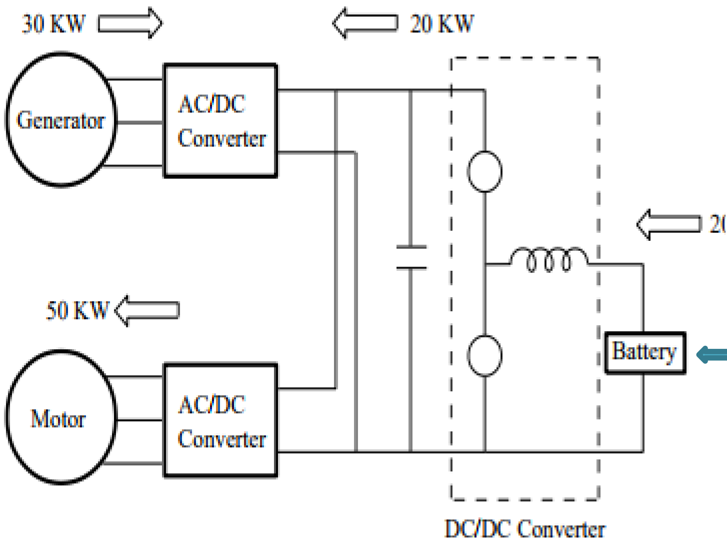
- All HEV systems are equipped with an electric motor, an ICE and a generator. They may be considered either series, parallel, or series-parallel depending on how the system is configured.
- Series hybrid is very similar to an EV, in that the electric motor moves the vehicle. The gasoline engine is there only to provide added power to the motor via the inverter, and acts as a range extender.
- A parallel hybrid is where the power to the drivetrain is shared by ICE and the motor. The concept of using the parallel hybrid system is successfully implemented in Honda Civic Hybrid.
- Finally, a series-parallel hybrid is where the vehicle can be powered by gasoline engine alone, the electric motor by itself, or by both. Toyota Prius is configured for a series parallel drive

https://www.mathworks.com/videos/hybrid-electric-vehicle-modeling-and-simulation-81751.html

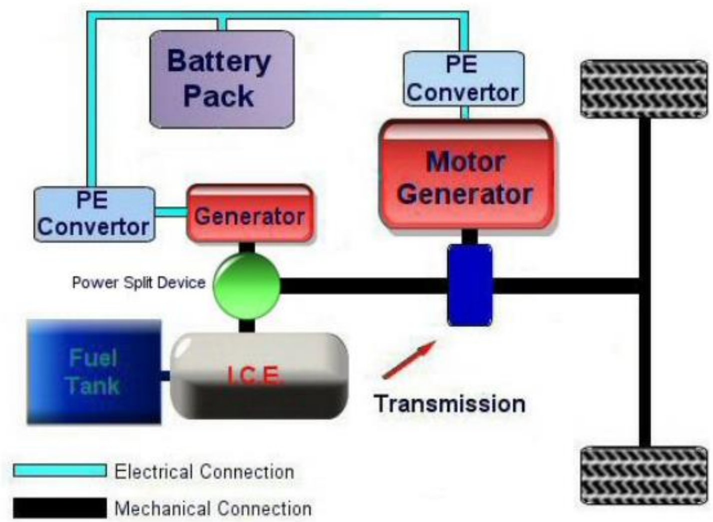


Series Parallel HEV





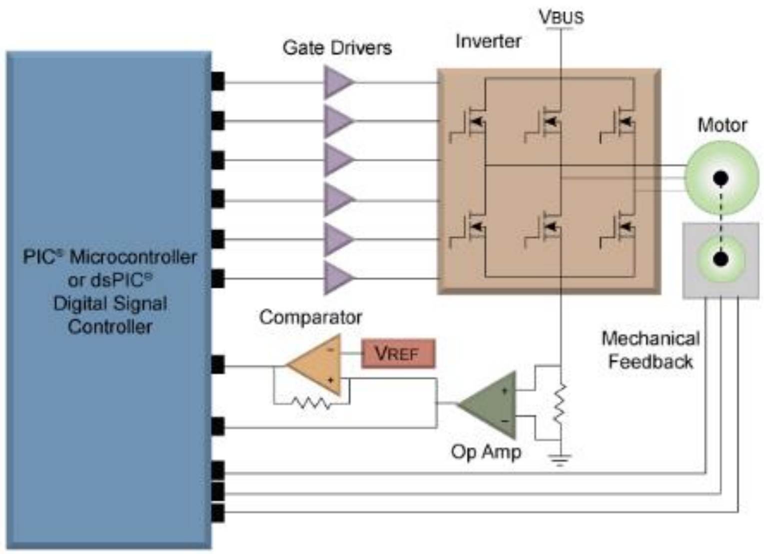
Battery: 200 V; 6.5 Ah; 21 kW

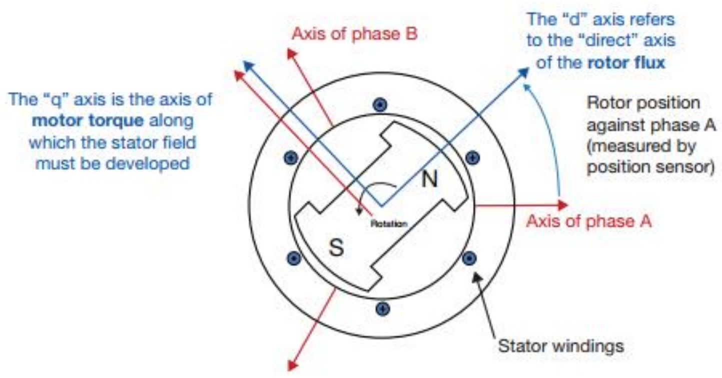


Motor: PMSM; 500 V; 50 kW; 8 poles, 6000 rpm

PMSM

The **permanent magnet synchronous motor (PMSM)** is an AC synchronous motor whose field excitation is provided by permanent magnets, and has a sinusoidal back EMF waveform. The PMSM is cross between an induction motor and brushless DC motor. Like a brushless DC motor, it has a permanent magnet rotor and windings on the stator. However, the stator structure with windings constructed to produce a sinusoidal flux density in the airgap of the machine resembles that of an induction motor.

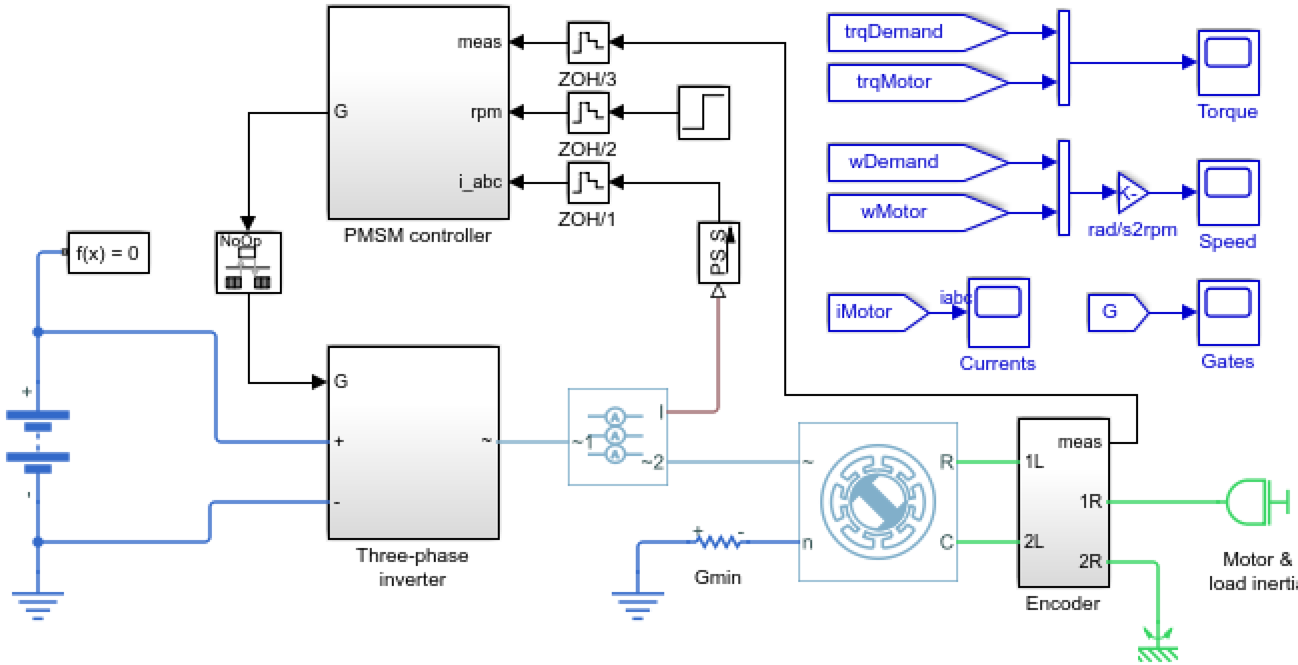




https://www.nxp.com/docs/en/brochure/BBPRMMAGSYNART.pdf

Try in Matlab

https://www.mathworks.com/help/physmod/sps/examples/three-phase-pmsm-drive.html



Three-Phase PMSM Drive

Vehicle System Modeling

Vehicle system modeling is conducted over various areas of interest to answer various questions. Traditional modeling areas include:

- Analysis of noise, vibration, and handling (NVH).
- Vehicle performance in terms of acceleration and maximum cruising speed.
- Prediction, evaluation, and optimization of fuel economy.
- Safety, stability, and crash worthiness.
- Vehicle controls.
- Structural integrity.
- Component testing and validation.
- Preliminary concept design and design exploration.
- Cost and packaging.
- Prediction of emissions.

Why Modeling and Simulation?

- While designing a HEV, it is required to:
  - Size components
  - Find the best energy control strategy, and
  - Minimize the vehicle energy consumption.
- This can be achieved through modeling and simulation since prototyping and testing are expensive and complex operations.
- Developing a simulation model with a good level of accuracy for all the different components based on different physical domains (electric, mechanical, thermal, power electronic, electrochemical and control) is a **challenge**.
- This challenge will be carried out during the semester.

Submission 1

Task 1: Hybrid Car versus Gas Car

- Draw a block diagram of the powertrain for a series PHEV car and gasoline car .
- Use systems of linear equations to find whether it is worth to pay extra, upfront, for a hybrid car as opposed to a fully gasoline powered car.
- Use actual examples!
- Write a linear equation for the total cost of each car.
- Solve the equations graphically and algebraically.
- You may explore more than one car model and compare the results of various types of hybrids to find which may be the most cost effective hybrid to purchase.
- You may explore tax breaks given on the purchase of hybrid cars and include that into the related linear equations.
- Document your solution in one page.

Design Steps

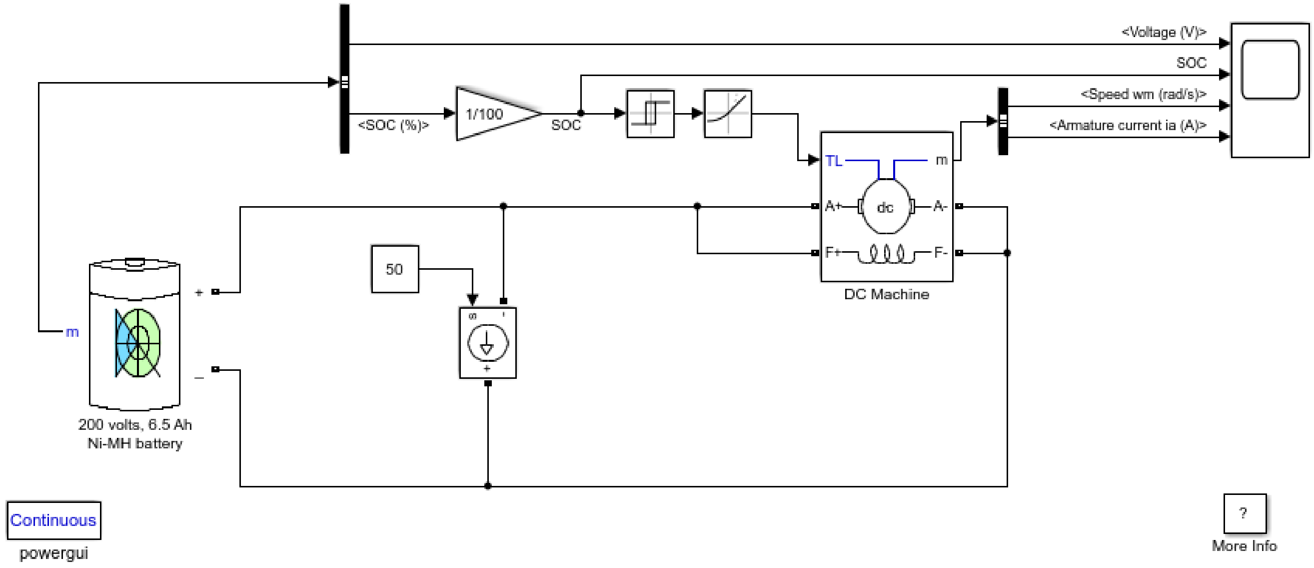
- **Battery Design**
- Engine Design
- **Motor Design**
- Power Splitters
- **Power Electronics Design**
- Vehicle Dynamics

Submission 1

Task 2: Battery Management System

- Vehicle battery being the limiting factor in the range of the HEV vehicle, the energy usage of the battery requires optimization to ensure lowest energy dissipation, therefore gaining the most mileage out of the vehicle.
  For this task:
  - Predict the mathematical model of a battery system in terms of state variables. The state space model is able to mimic the complex dynamic behavior of a battery system.
  - Adopt a dynamical RC lithium-ion battery model and take into consideration major factors of battery aging.
  - Find values of **A**, **B**, **C**, and **D**.
  - Estimate state of charge (SoC) of the battery system.
  - **Lab:** Simulate a battery/supercapacitor management system using Matlab/Simulink.

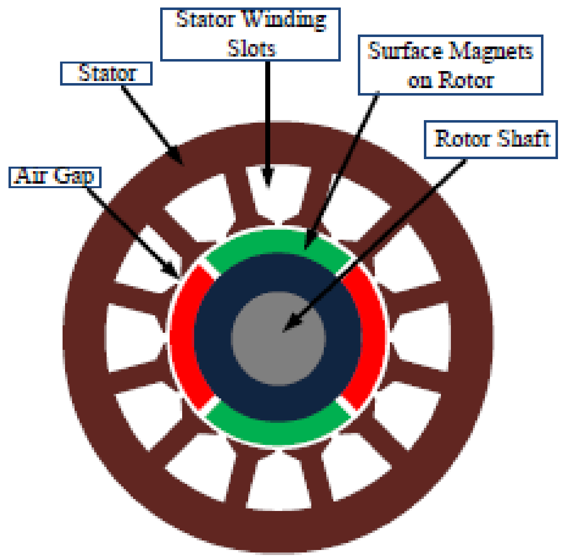
Try in Matlab



https://www.mathworks.com/help/physmod/sps/examples/ni-mh-battery-model.html?searchHighlight=Battery%20state%20of%20charge&s_tid=doc_srchtitle

Submission 2
Task 3: Motor Modeling and Design

- Model buck and boost converter using state space technique.
- The most adopted motor for PHEV is the permanent synchronous magnets motor (PMSM).
- Investigate PMSM using research literature to conduct the following task:
  - Model PMSM using the state space technique.
  - **Lab:** Simulate the PMSM motor using Matlab/Simulink.

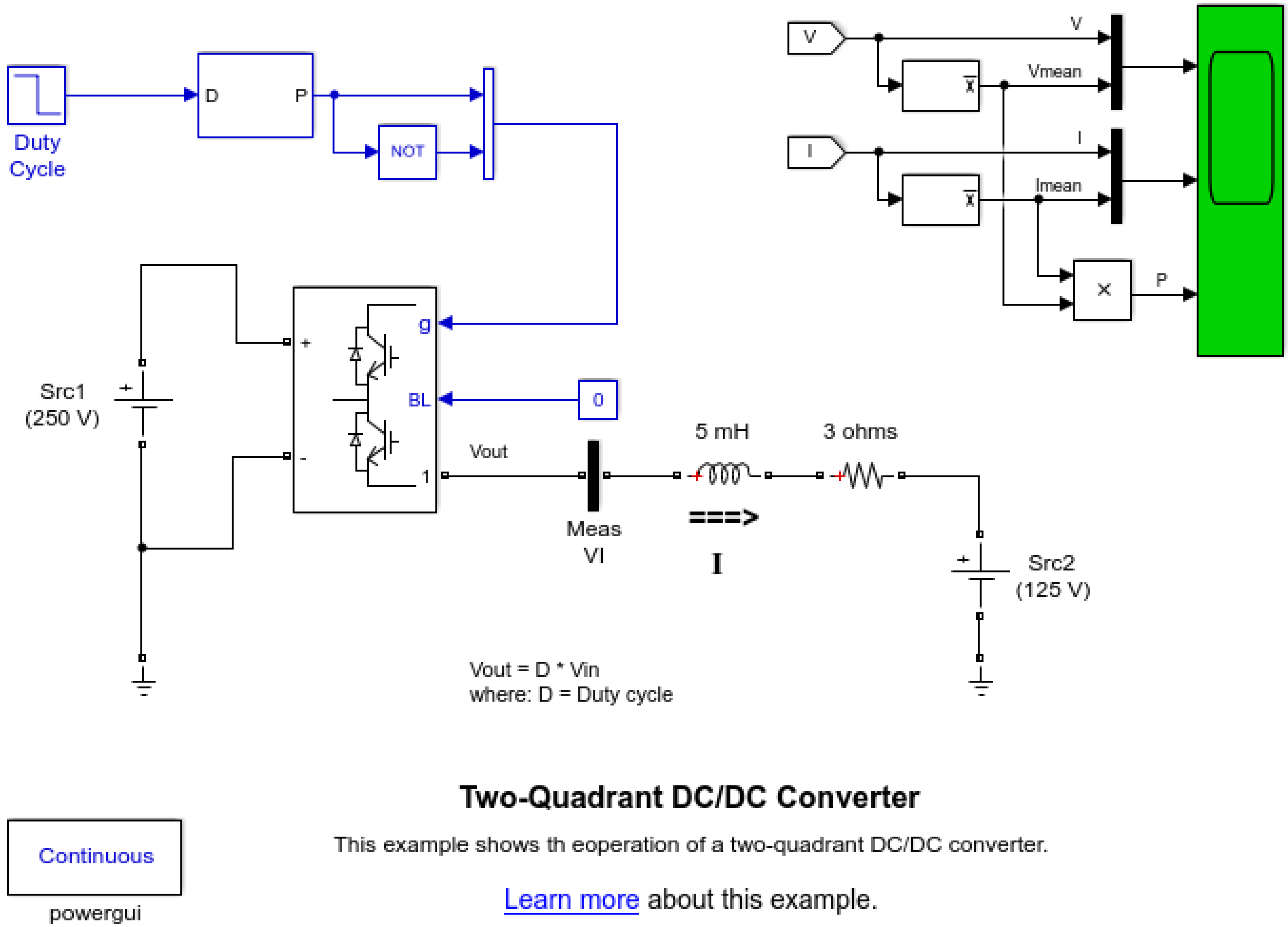


Submission 2

Task 4: DC to DC Converters

- Modeling and simulating DC to DC converters using the modelling equations is necessary to design of power electronic converter circuit with the use of closed loop scheme. **For this Task:**
  - Model buck converter.
  - Model boost converter.
  - Model buck-boost converter.
  - **Lab:** Simulate the above DC to DC converts.

Try in Matlab



Two-Quadrant DC/DC Converter

This example shows th eoperation of a two-quadrant DC/DC converter.

Learn more about this example.

Submission 3

Reflection on Submission 1 and 2

- This task addresses control and technology strategies to achieve a novel design of integrated in-wheel motor system by building a high performance motor and developing algorithms for a robust power management, torque vectoring, and traction control.
- All the components required for drive including the electric motor, power electronics, controller, braking and cooling systems are installed in an integrated wheel hub drive.
- This highly-integrated system will provide considerable advantages in terms of manoeuvrability, driving dynamics, and safety.

Back to 1900

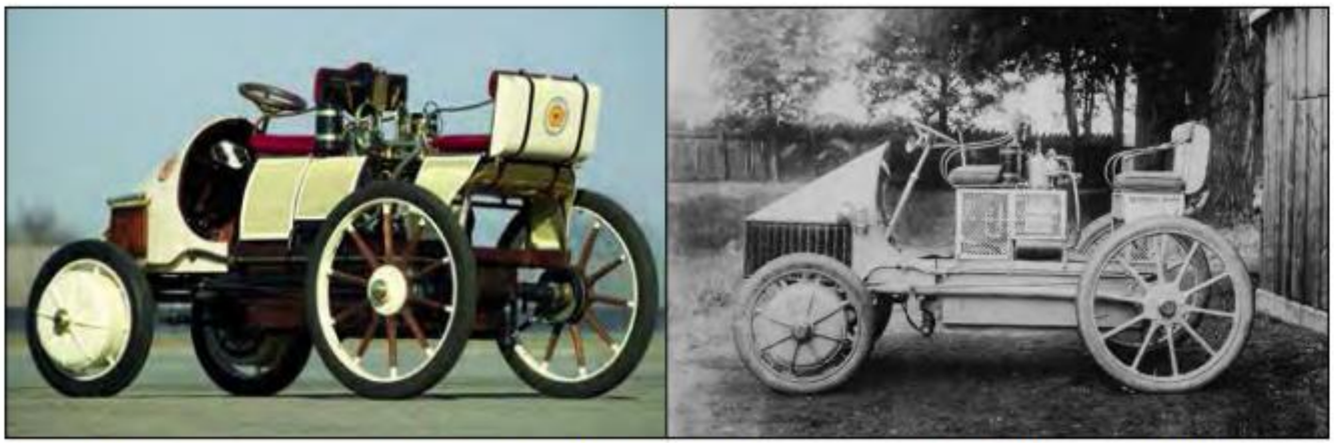
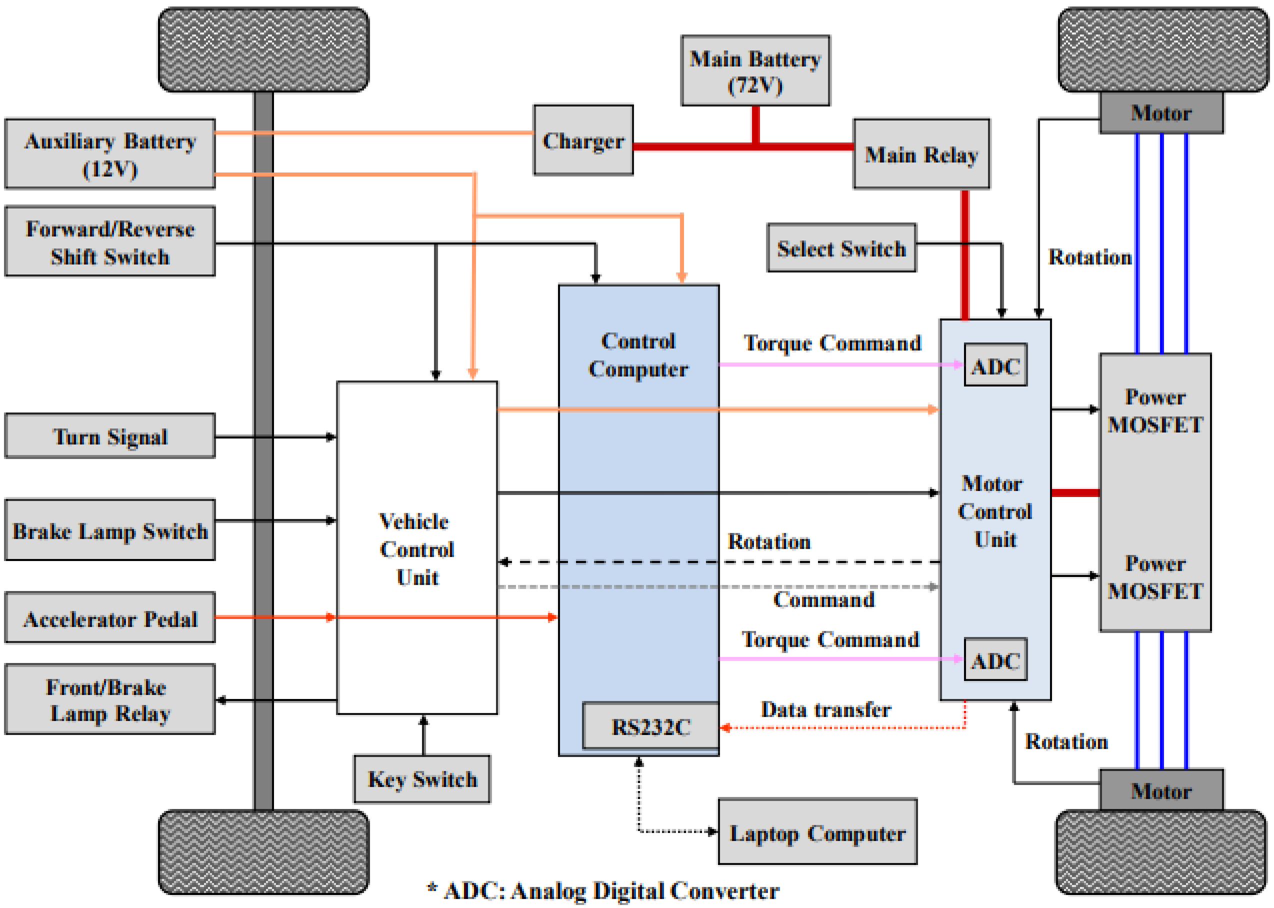
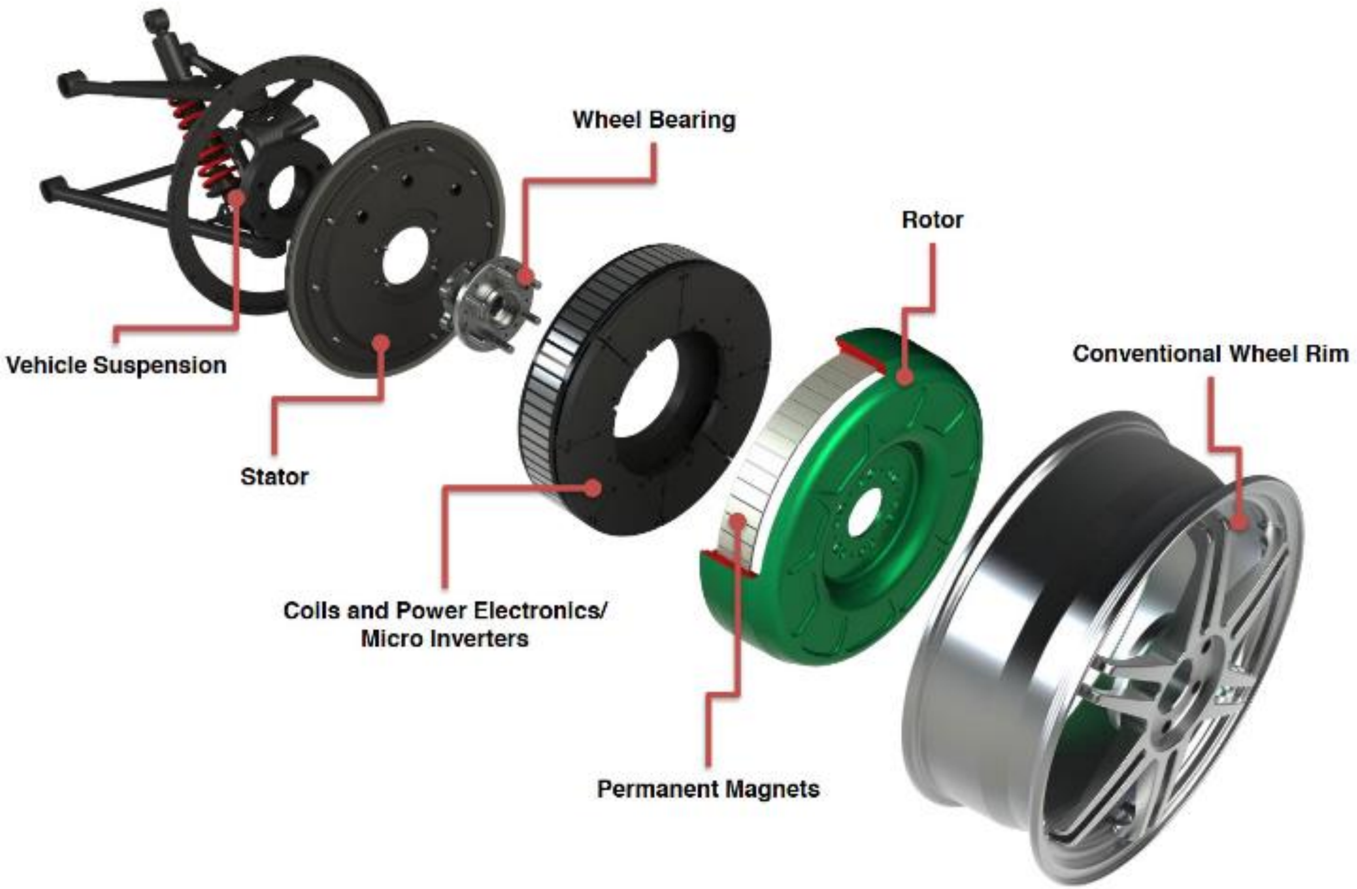


Figure 1. *Semper Vivus, a Lohner-Porsche hybrid electric vehicle (right) with front in-wheel motors, which was presented at the Paris World Exhibition in 1900.* **Right:** *original.* **Left:** *a modern recreation. Photo: Porsche Cars North America*

Components of an Electric Vehicle



In-Wheel Motor System



Reflection

- Conduct literature review about in-wheel motor system.
- Design a robust in-wheel motor system taking into consideration one or more of the following issues: power management, torque vectoring, and traction control.
- Simulate your design using MATLAB/SIMULINK or any other tool.
- Reflect your work either by developing a 2-3 min video or by writing a 5-page research paper (IEEE Format).
- Rely on research papers related to one or more of the following key topics
  - In-wheel motor systems
  - Torque vectoring
  - Traction control
  - Power management