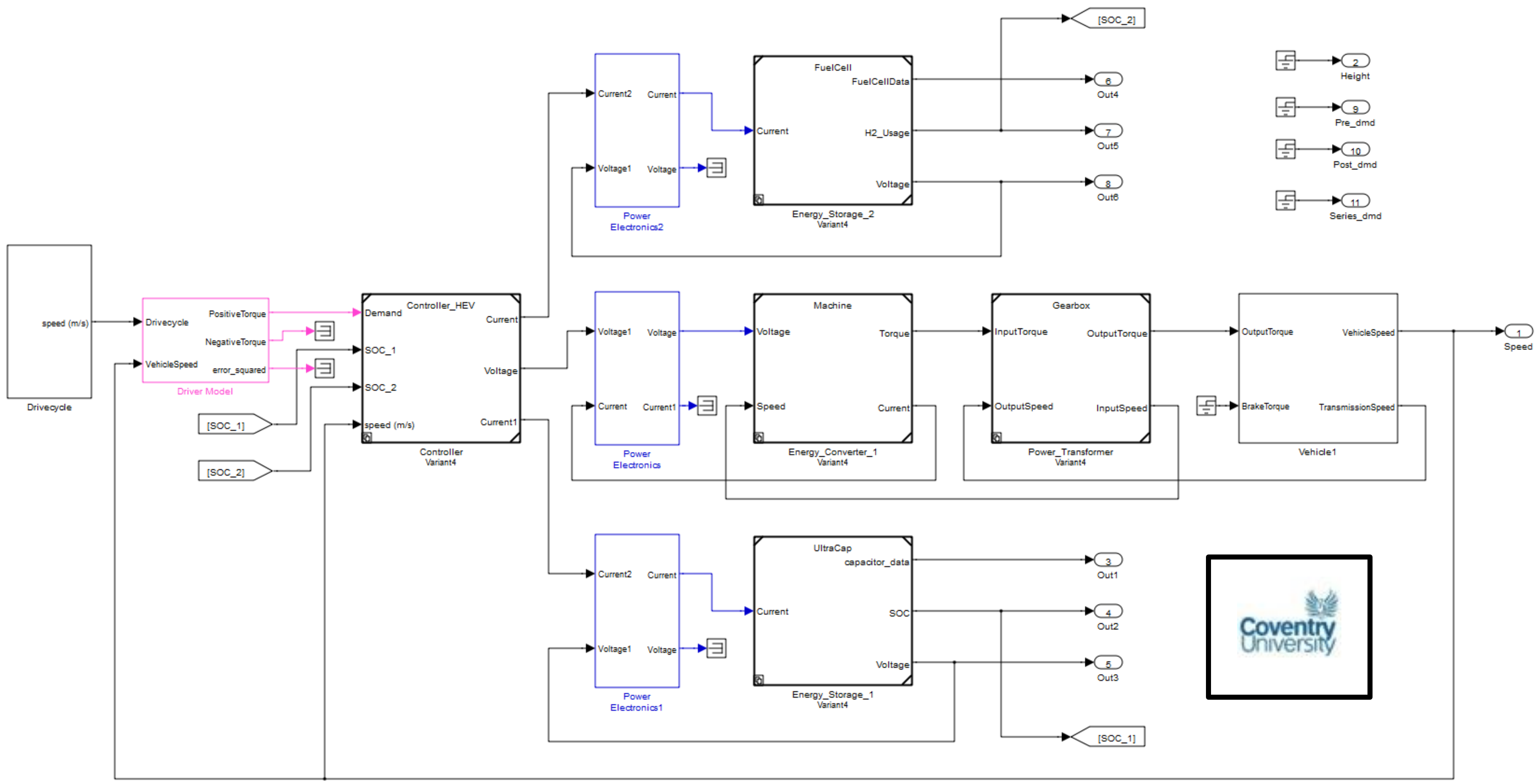
MODEL ORDER REDUCTION

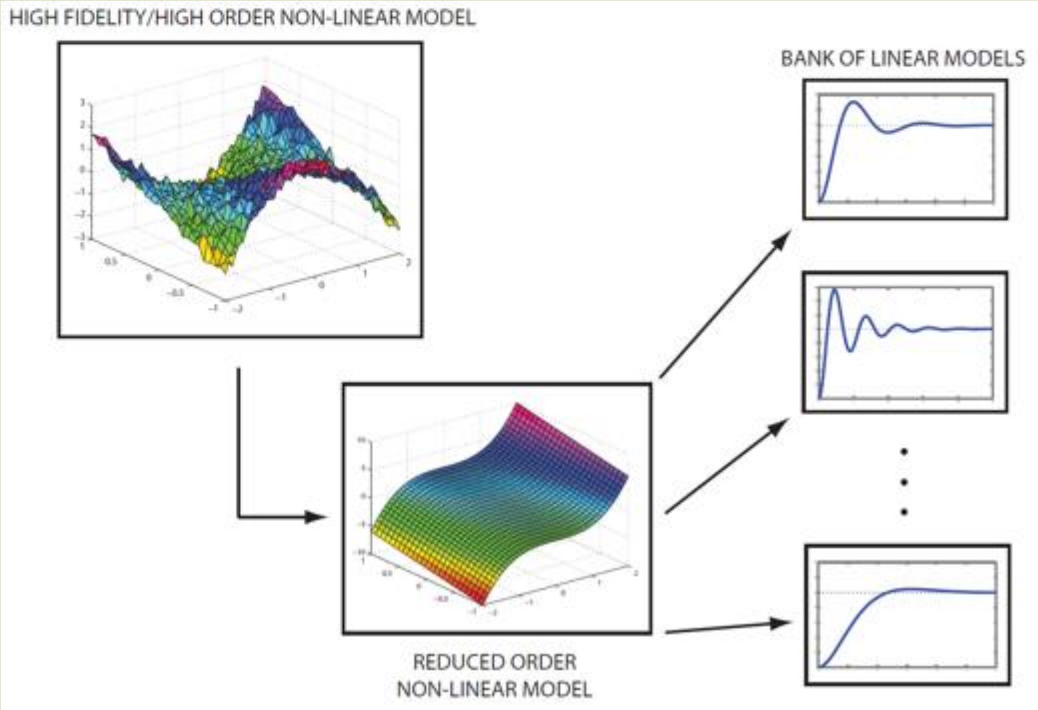


OUTLINE

- Need for model order reduction (MOR)
- Methodology for MOR
- Classical approaches
  - Supercapacitor
- Data driven approaches
  - Design of experiment
  - Linear approach: Batteries
  - Nonlinear SISO / MISO approach: Power converter
  - Nonlinear MIMO approach: Fuel cell
- Summary of findings

MODEL ORDER REDUCTION OVERVIEW

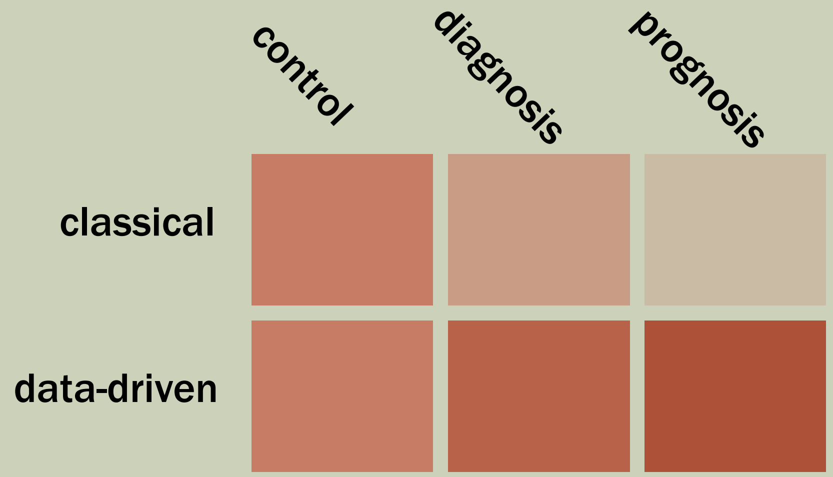
- MOR is required to reduce computational complexity of model yet retain sufficient accuracy for a specific purpose, i.e. control, diagnosis, prognosis



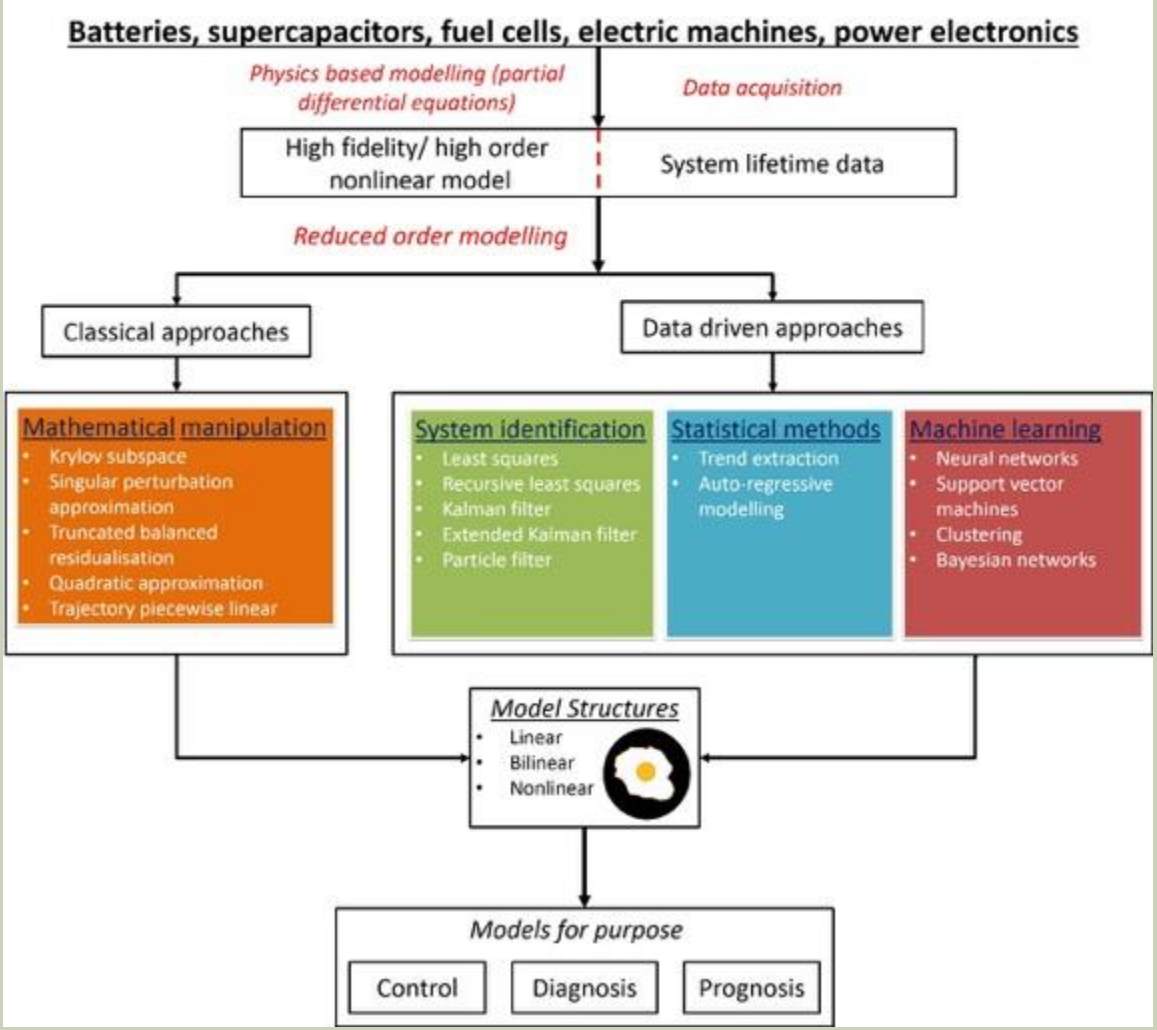
Model order reduction procedure to obtain banks
of linear models

METHODOLOGY

- Models for purpose:
  - Control
  - Diagnosis
  - Prognosis
- Approaches for MOR:
  - Classical
    - Based on mathematical manipulation of system equations
  - Data-driven
    - Models derived from data collected from complex models or hardware
    - Include System Identification and Machine Learning methods
  - All approaches retain dominant modes whilst discarding modes with low contribution to system dynamics

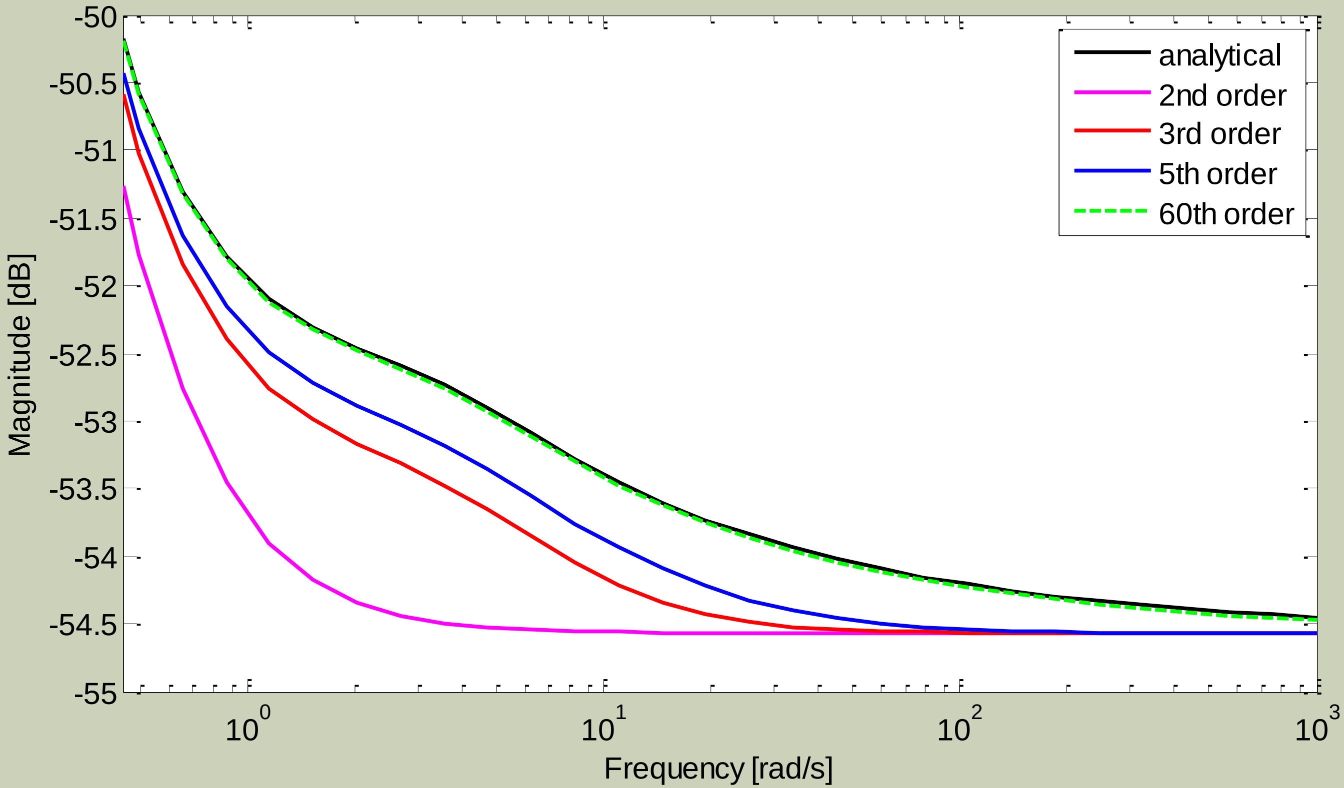


METHODOLOGY



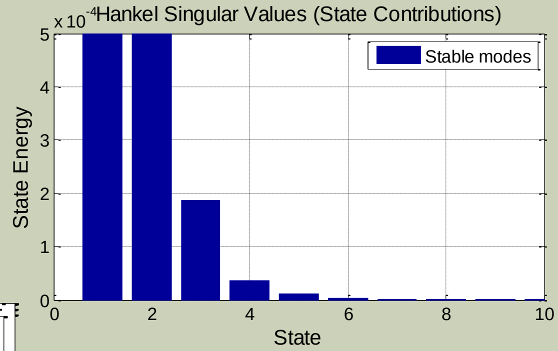
CASE STUDY: SUPERCAPACITOR

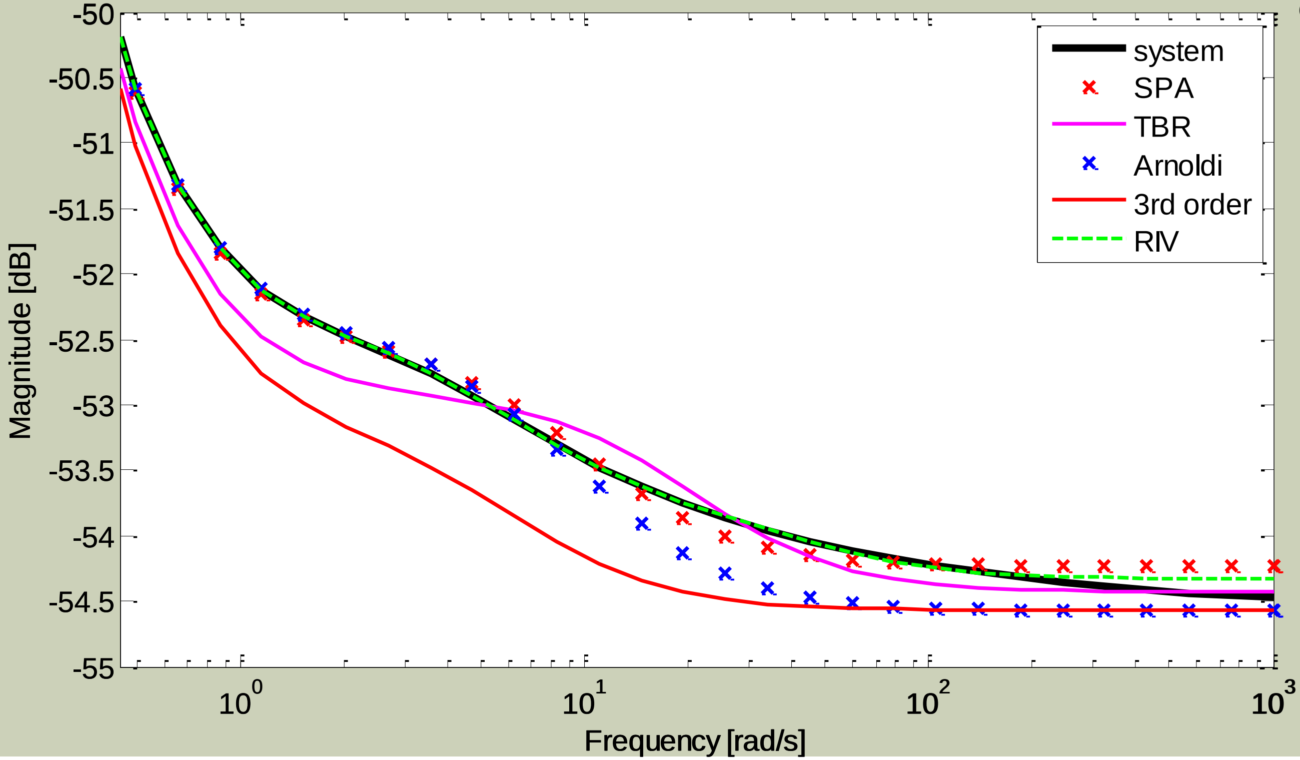
- Single input single output (SISO) nonlinear model
- 60th order model used as baseline for model order reduction
- Truncation without model order reduction methods



CASE STUDY: SUPERCAPACITOR

- Comparison of 3rd order model variants obtained via selected reduced order modelling techniques





SPA – Singular perturbation approximation

TBR – Truncated balanced residualisation

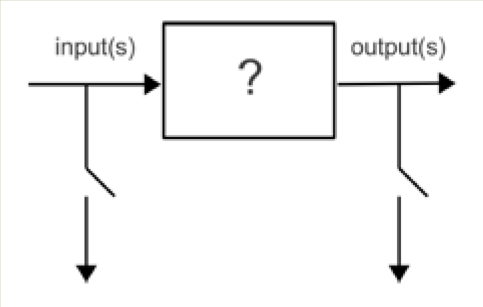
Arnoldi – Krylov subspace method

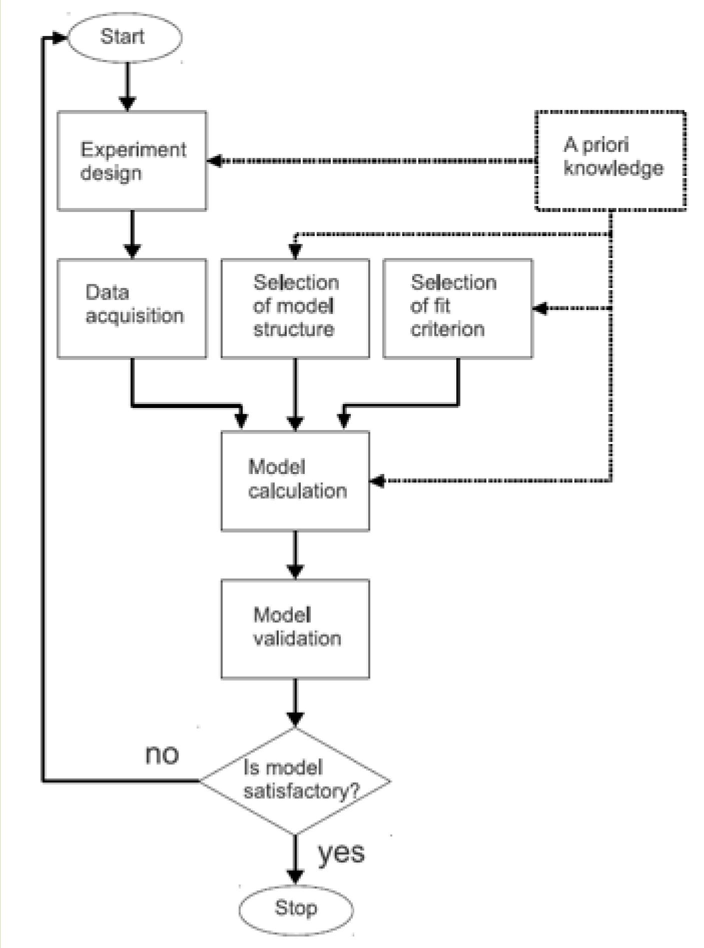
RIV – refined instrumental variable

DATA DRIVEN APPROACHES

- An experimental process, whereby making use of available input-output data and *a priori* knowledge, one aims to mathematically describe causalities that govern behaviour of system

- Different approaches to modelling based on *a priori* knowledge
  - White box
  - Black box
  - Grey box

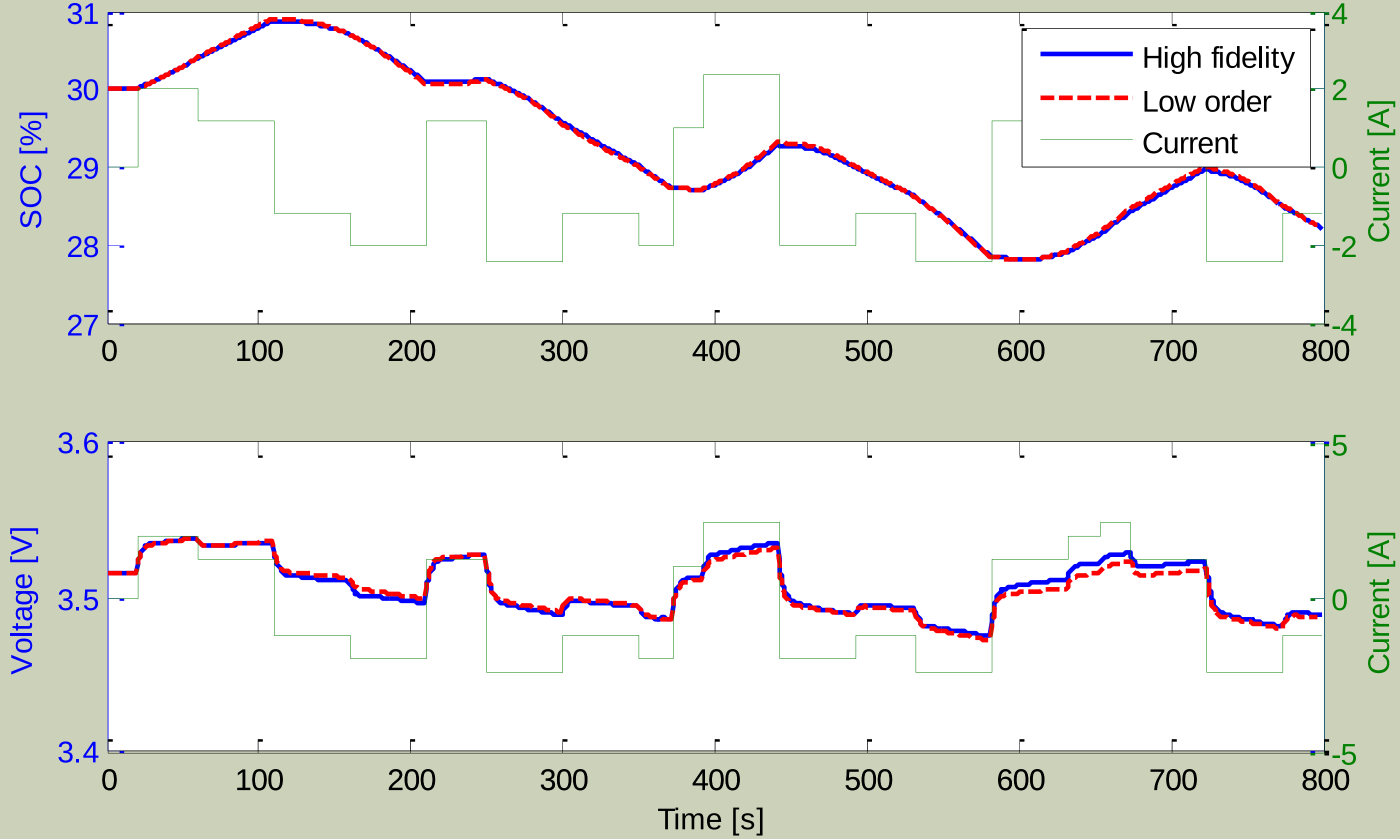




CASE STUDY: BATTERY

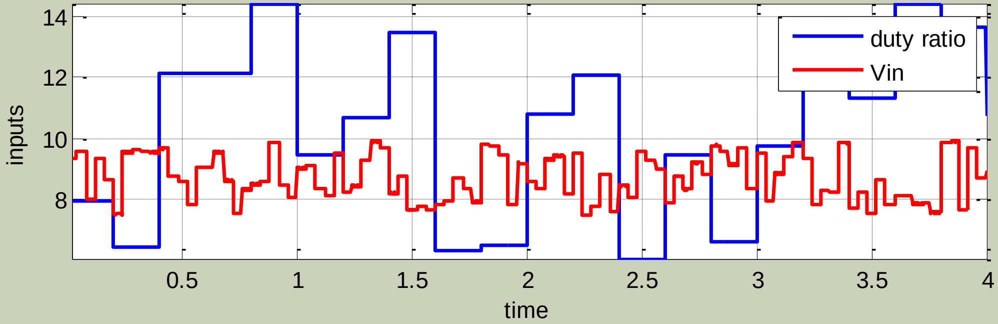
1. Data acquisition
   - **Voltage** and **SOC** (outputs) responses to **current** input
   - 36 short (80 seconds) data sets starting at different SOC (positive current input – charge mode)
   - Experiment repeated for negative current (discharging)
2. Obtained set of 144 LTI models using simplified refined instrumental variable (SRIVC) method
   - Current to SOC models
   - Current to voltage models
3. **Assumption:** low order model can have linear structure, where parameters depend on SOC and sign of current

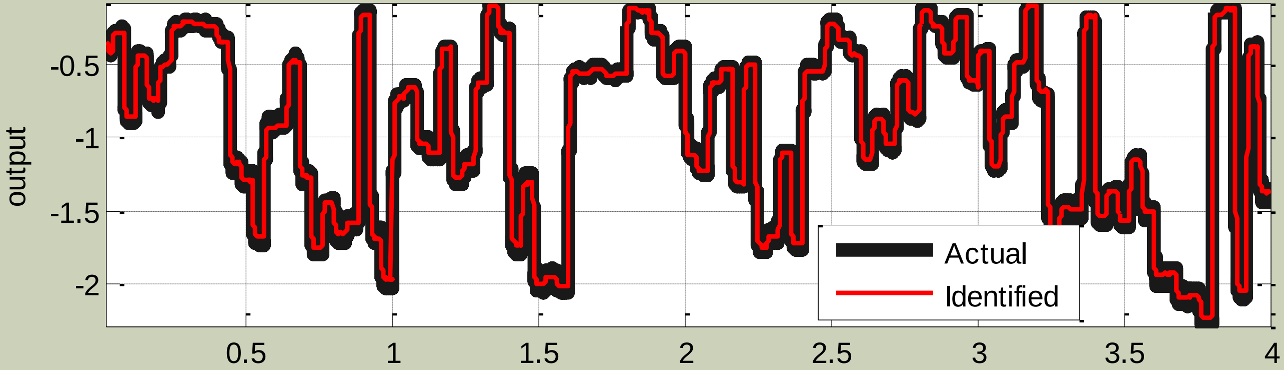
CASE STUDY: BATTERY



CASE STUDY: BUCK-BOOST CONVERTER

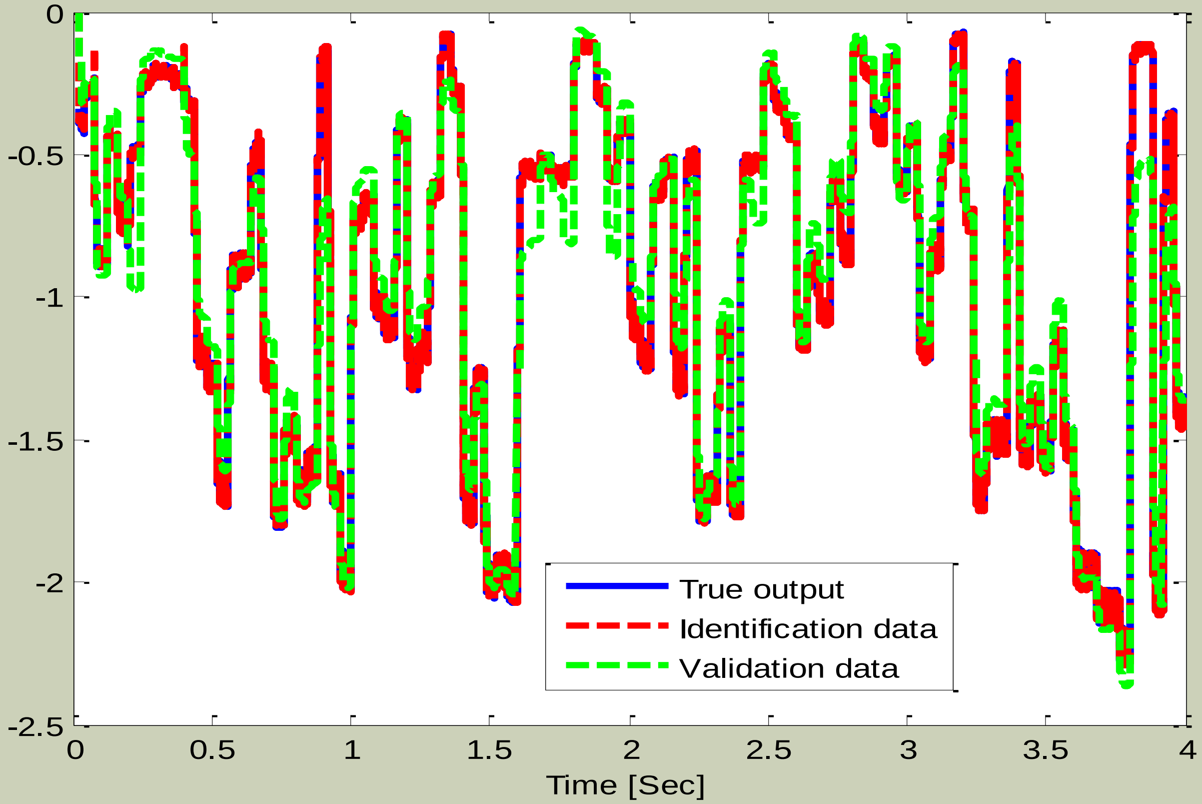
- ***Model structure : 10 single input - single output (SISO) Hammerstein models with 4th order polynomial static nonlinearity***
  - ***Inputs: Input voltage and duty cycle***
  - ***Output: Output current***
  - ***Model order: 1***
  - ***R_T^2= 99.83 %***



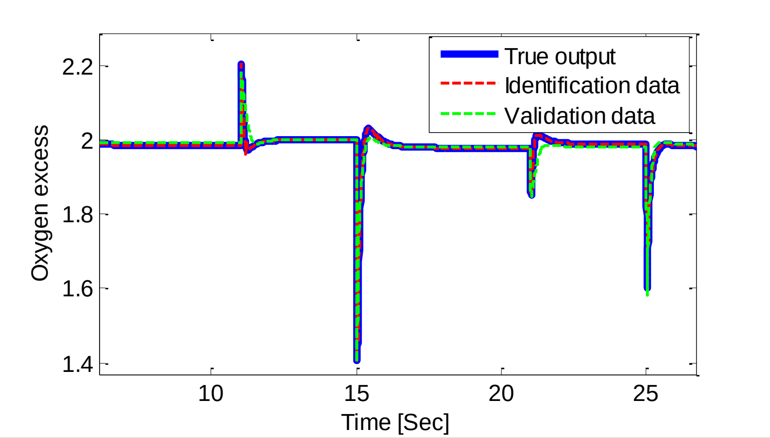


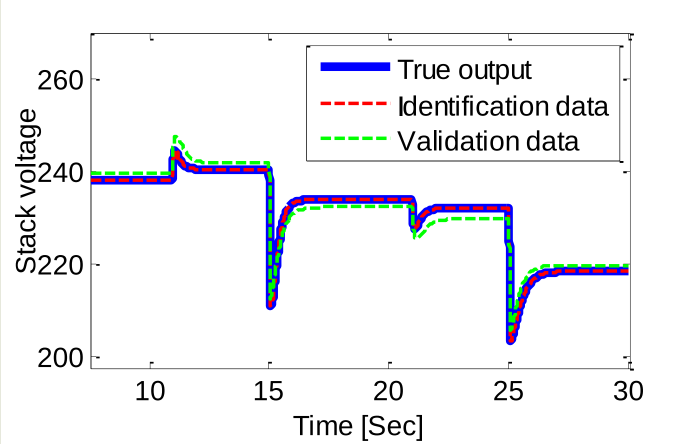
CASE STUDY: BUCK-BOOST CONVERTER

- ***Model structure : Bilinear multiple inputs – single output (MISO)***
  - ***Inputs: Input voltage and duty cycle***
  - ***Output: Output current***
  - ***Model order: 5***
  - R_T^2 ***= 93.7 %***
  - ***a – 5***
  - ***b – 2***
  - ***Bilinear term – 1***

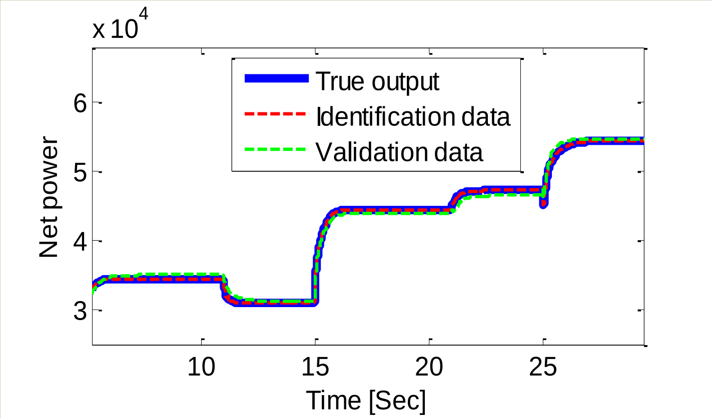


CASE STUDY: FUEL CELL STACK





- ***Model structure : MIMO NARX***
  - ***Inputs: stack current, compressor voltage***
  - ***Outputs: stack voltage, oxygen excess, net power***
  - ***Logarithmic type nonlinearity on the input***
  - ***Model order: 15***
  - ***Oxygen excess R_T^2= 96.8 %***
  - ***Stack voltage R_T^2 =94.2 %***
  - ***Net power R_T^2 =99.3 %***



J. Pukrushpan, A. Stefanopoulou, and H. Peng, “Control of fuel cell breathing,” IEEE Contr. Syst. Mag., vol. 24, no. 2, pp. 30–46, Apr. 2004.

SUMMARY OF FINDINGS

- MOR effectively retains fidelity of high order model whilst reducing the model order
- Data driven approaches are effective for reduced order modelling
- Purpose of model and a priori information determines the modelling method

- Outline of methodology for model order reduction
  - Control
  - Diagnosis
  - Prognosis
- Guidelines for MOR
- Methodology is robust for multiple case studies