Diagnosis of Faults in an Electrical Conversion Chain
Application on Electric Vehicles

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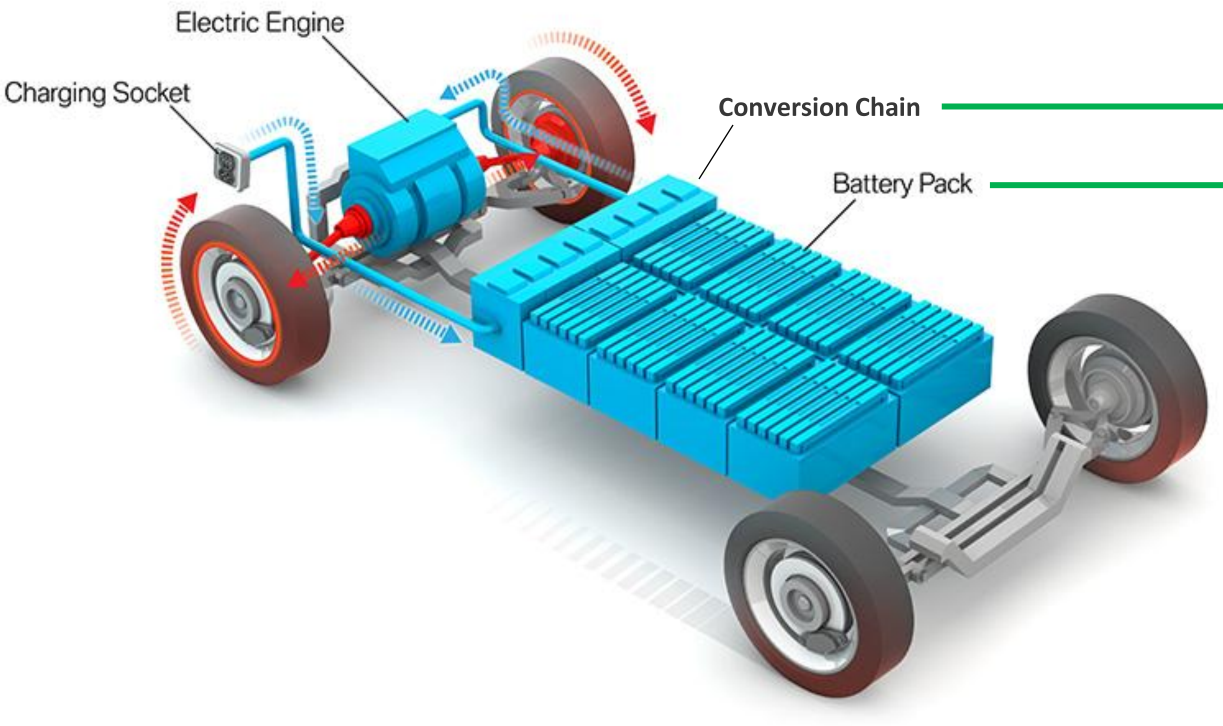
PLAN

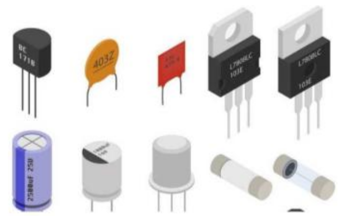
1. Introduction & Objective
2. Literature Review
3. Methodology
4. Proposed Approach & Results
5. Conclusions & Perspectives

Introduction

As an important part of the electric vehicle, the power battery pack and the power electronic conversion chain are the main fault sources of the electric vehicle, and they're also the focus of fault diagnosis



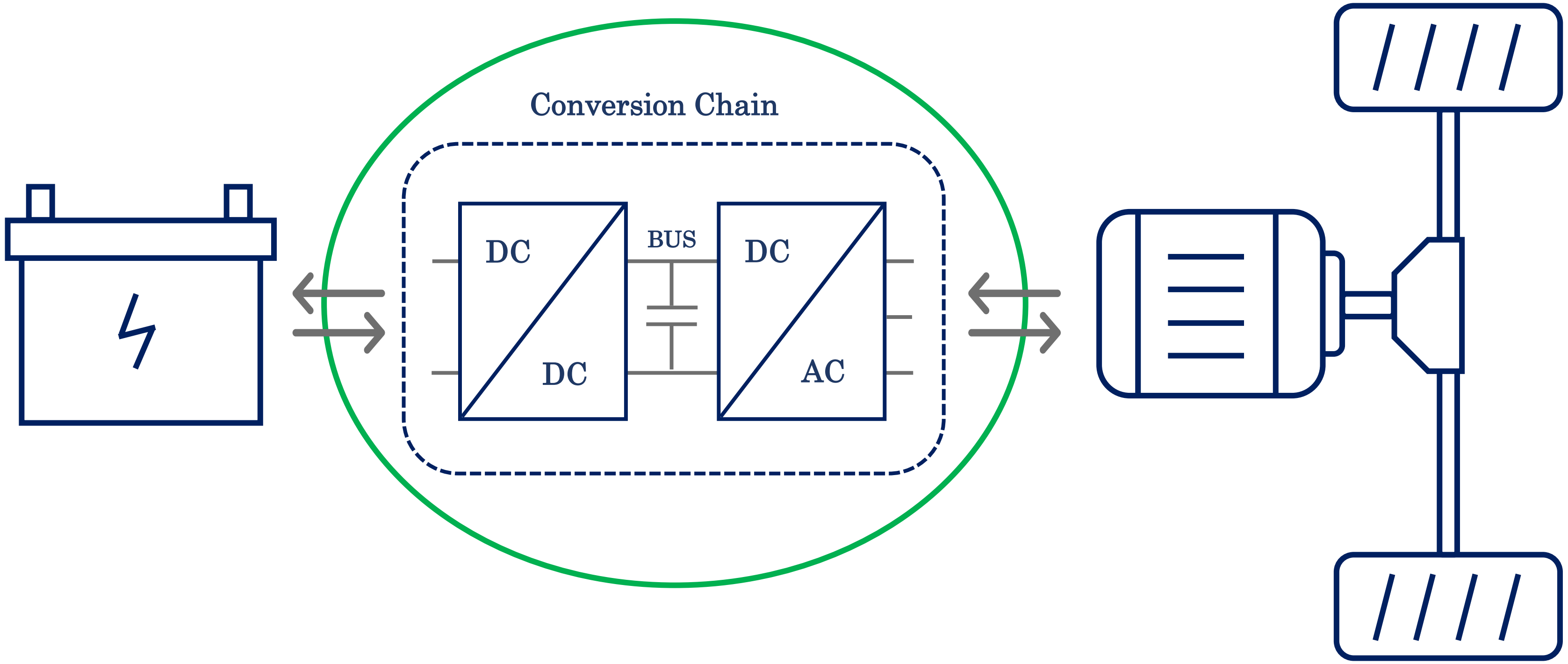
Related to faults occurred in P.E. components and sensors



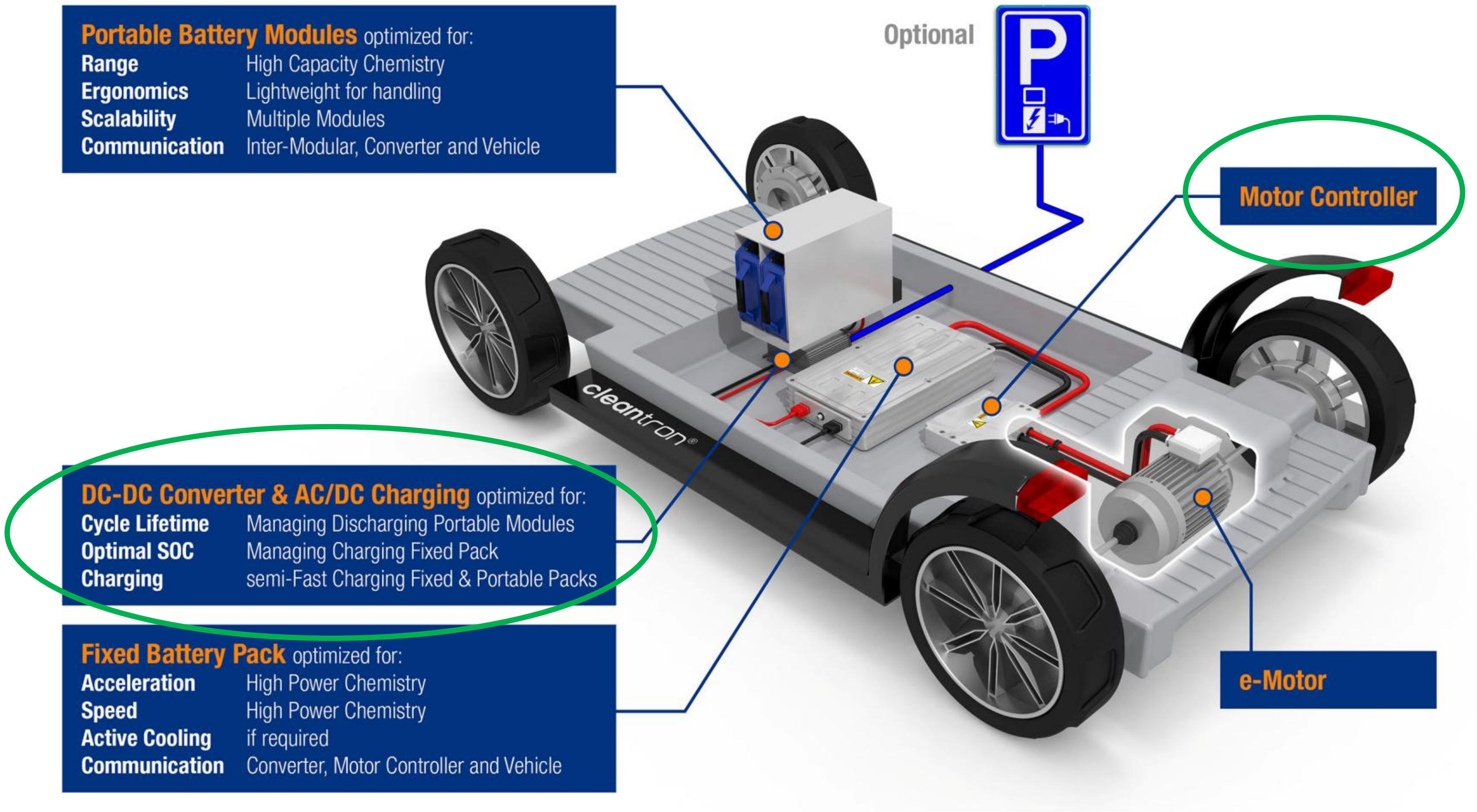
Related to material faults

Conversion Chain

It consists of two power electronic conversion stages



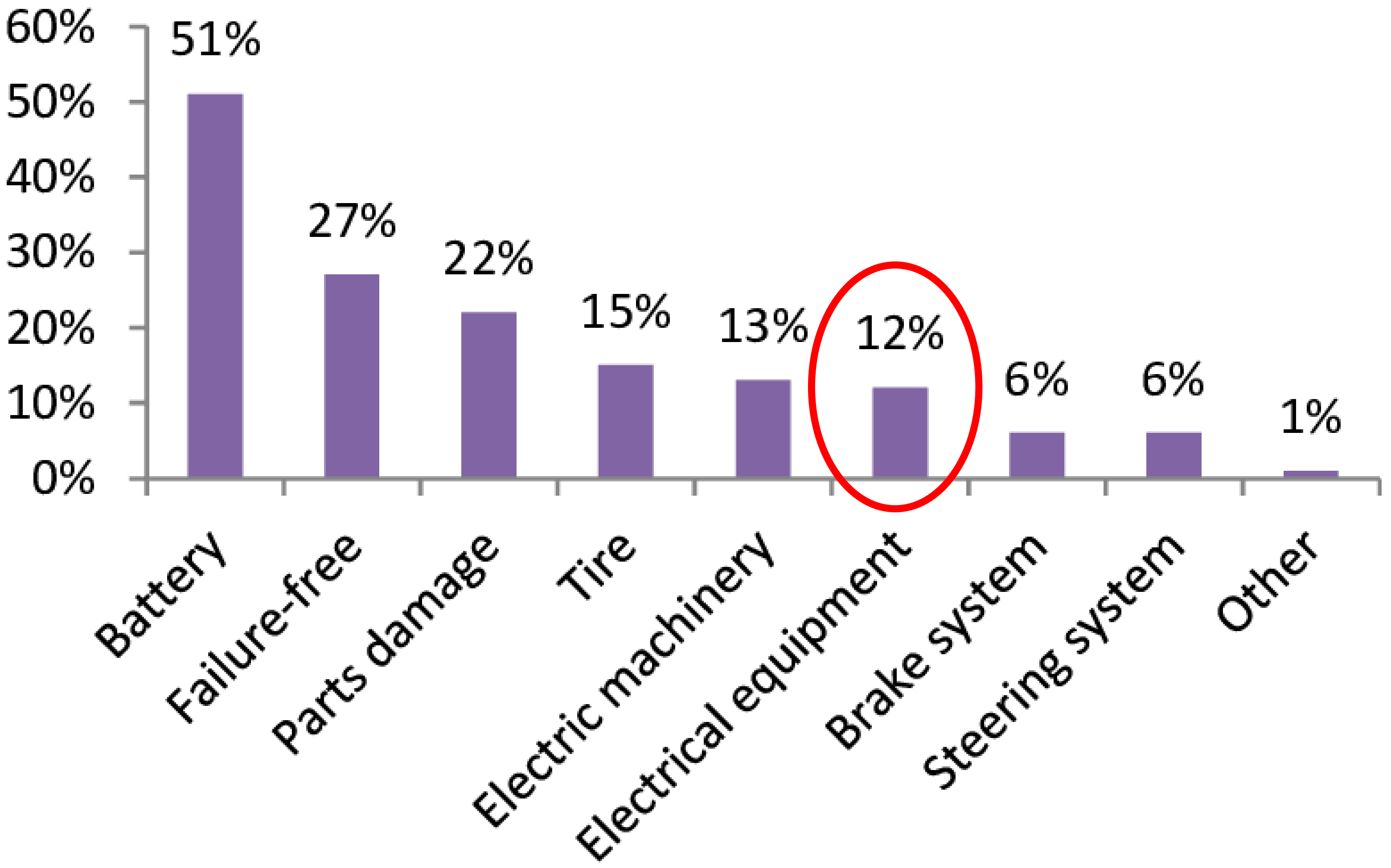
EV Architect



It’s obvious how conversion chain failure or breakdown can cause interruptions and make the electric vehicle un-functional

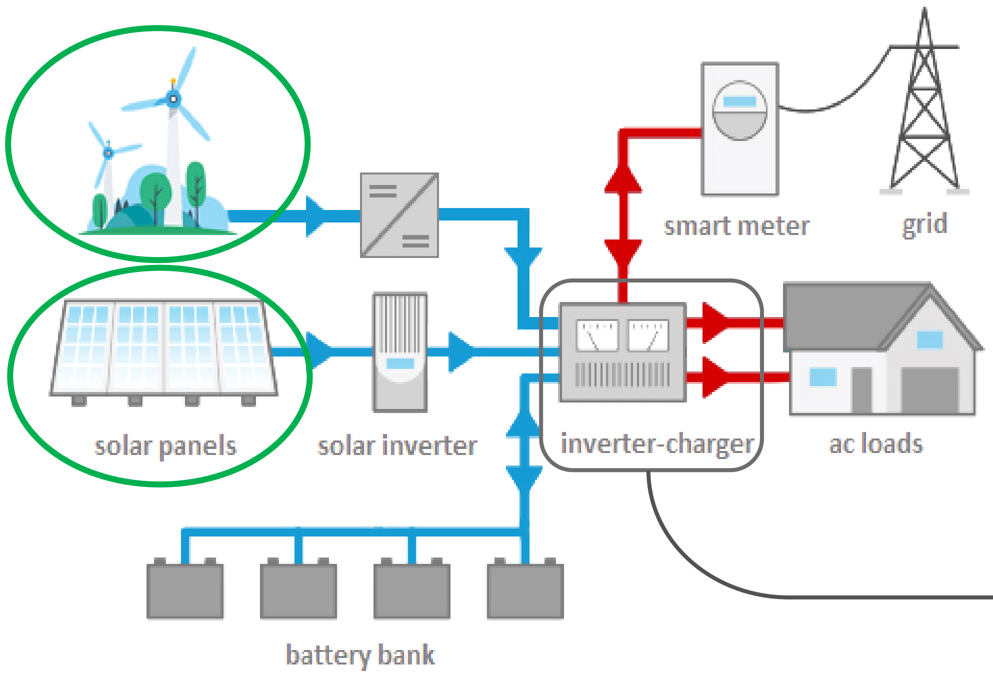
Focusing on Electric Failures in EVs

Failure distribution

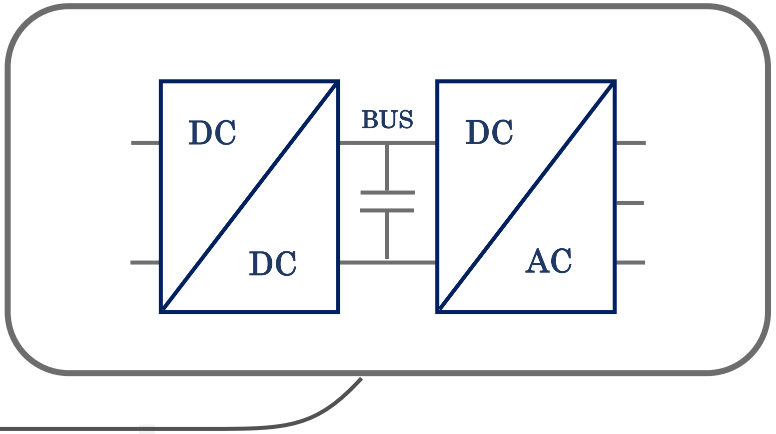


Other Fields

Fields that have the conversion chain in common with EVs

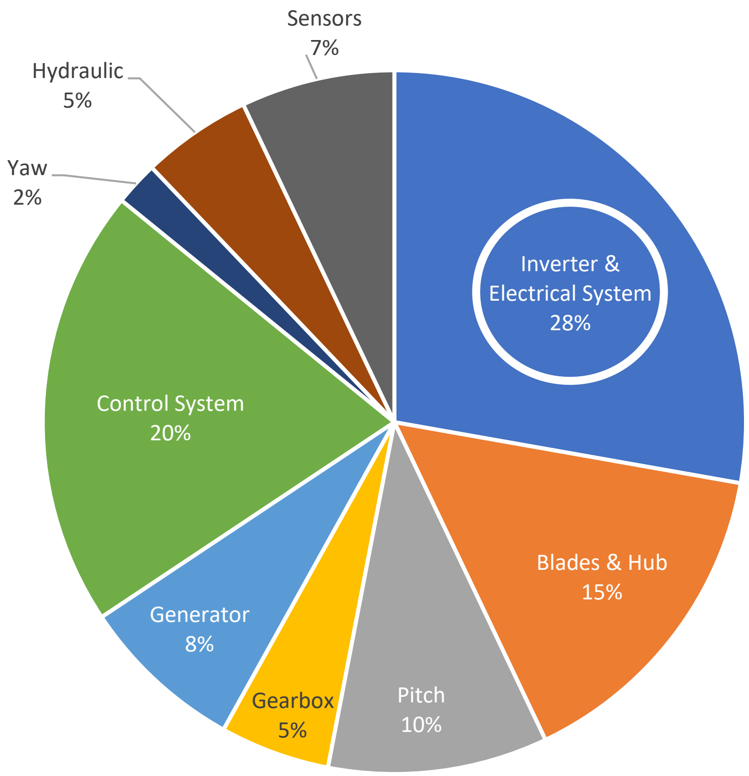


Any damage or failing in the conversion chain can affect the system

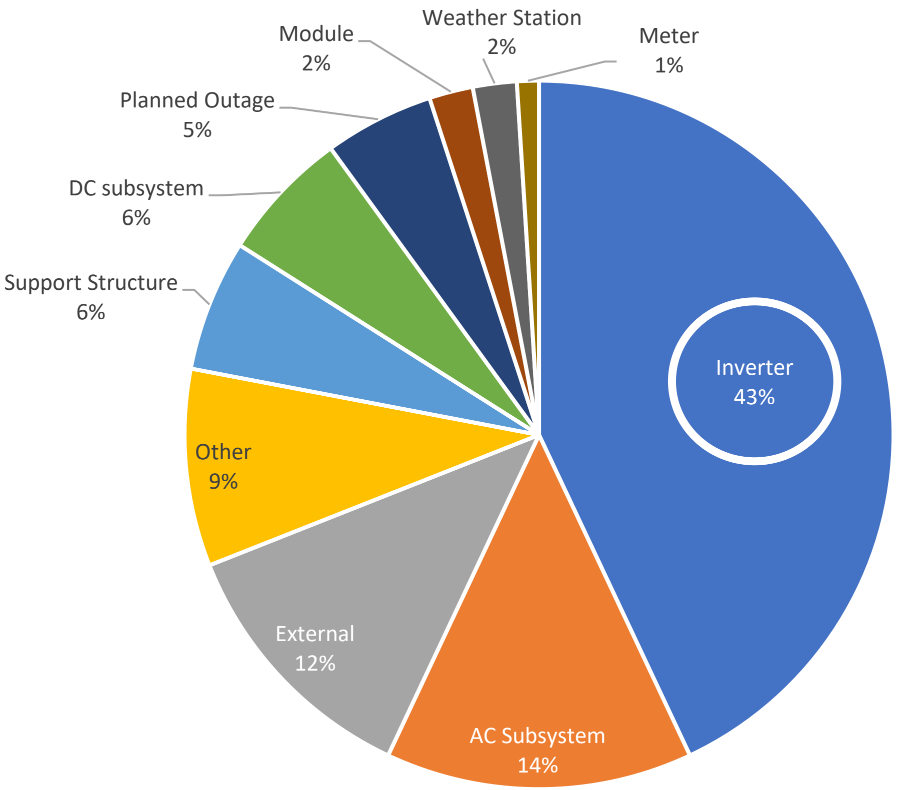


Other Fields

Failure distribution for wind and solar energy systems



WIND ENERGY



SOLAR ENERGY

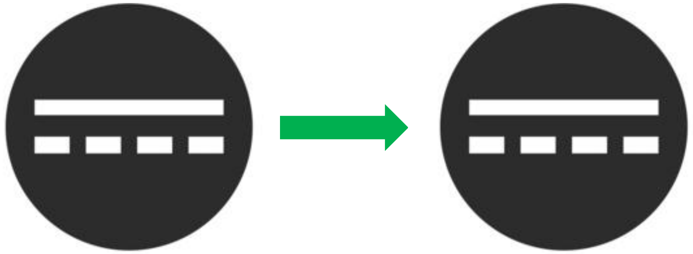
Objective

- Mathematical modelling of the healthy and faulty systems using state-space representation
- Impact of sensors and system faults on the proper functioning of a conversion chain and the effect of fault propagation
- Classifing and reviewing FDD approaches used in similar systems
- Development of a robust diagnostic technique for faults in a conversion chain (Open/Short Switch, Inductor & Capacitor faults, Sensor faults)
- Result interpretation (Simulation and Experimental)

Literature Review

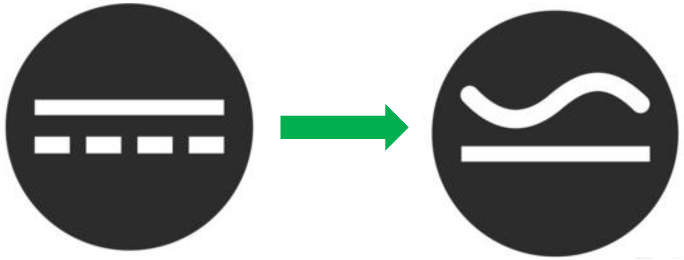
1st Review

DC-DC Converter Topologies



2nd Review

DC-AC Inverter Topologies



3rd Review

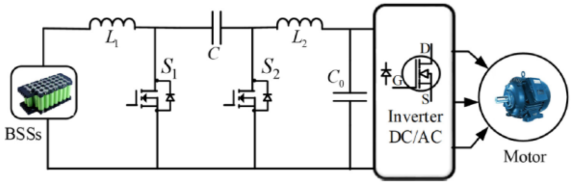
FDD Approaches

HARDWARE SELECTION

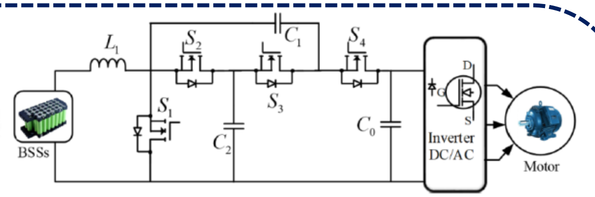
DC-DC Converter Topologies

1st Type

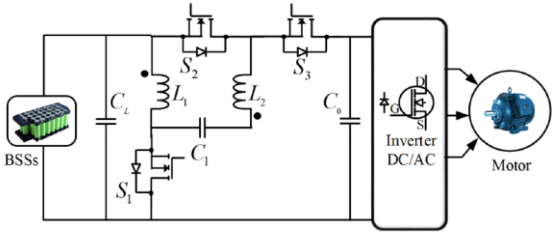
Non-Isolated



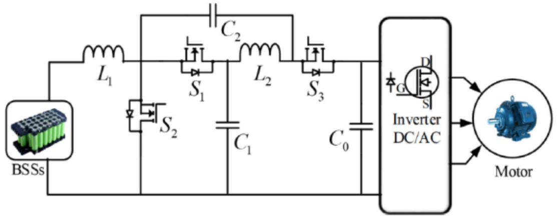
Cuk converter



Switched capacitor bidirectional converter



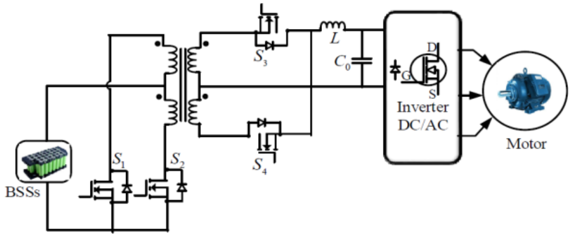
Couple inductor bidirectional converter



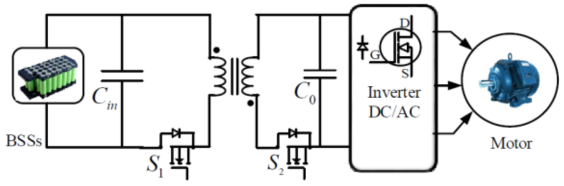
Quasi-Z-source converter

2nd Type

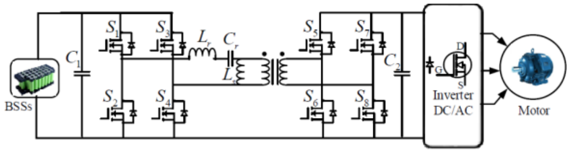
Isolated



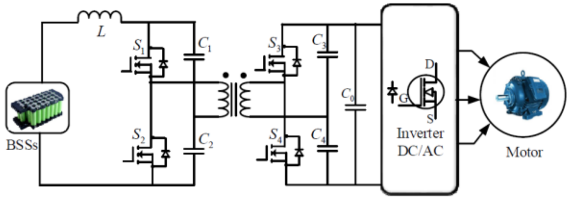
Push–Pull Converter



Flyback Converter



Resonant Converter



Zero-Voltage Switching Converter

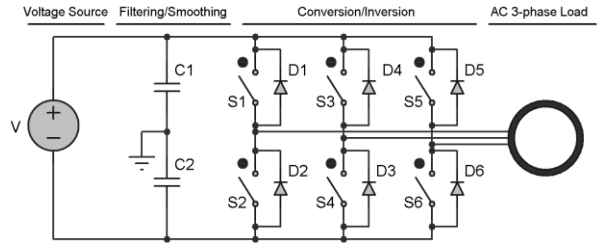
- Weight
- Efficiency
- Volume
- EMI
- Current Ripple
- Range of input voltage

HARDWARE SELECTION

Inverter Topologies

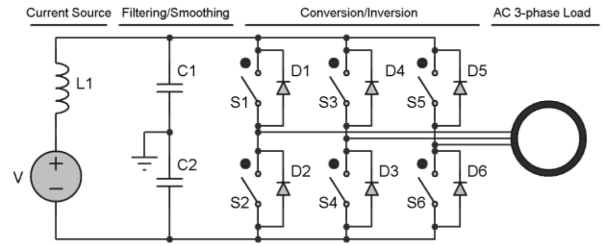
1st Type

VSI



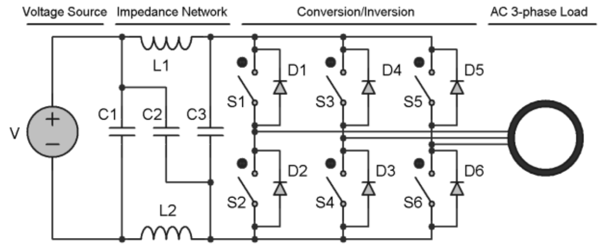
2nd Type

ISI



3rd Type

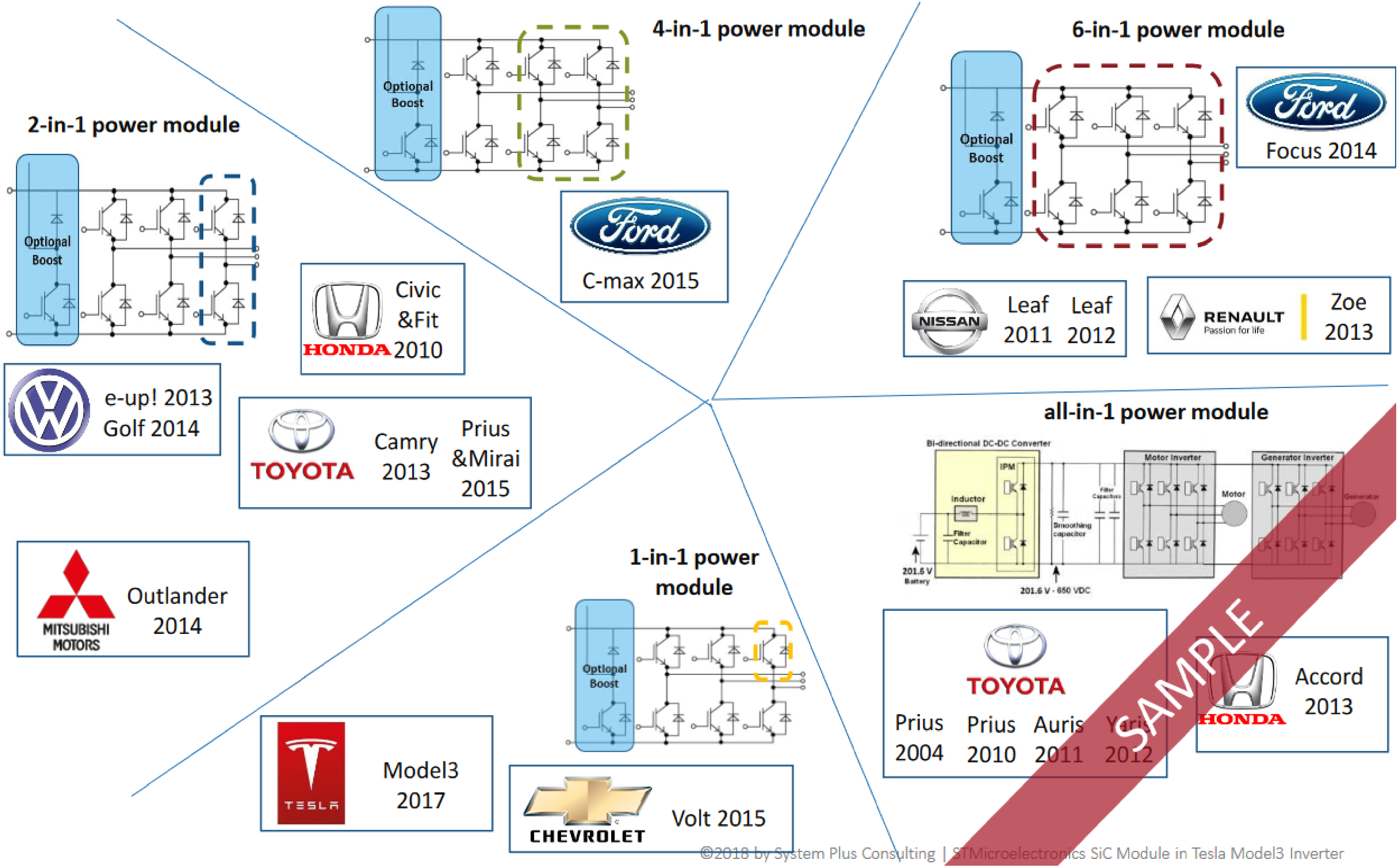
ZSI



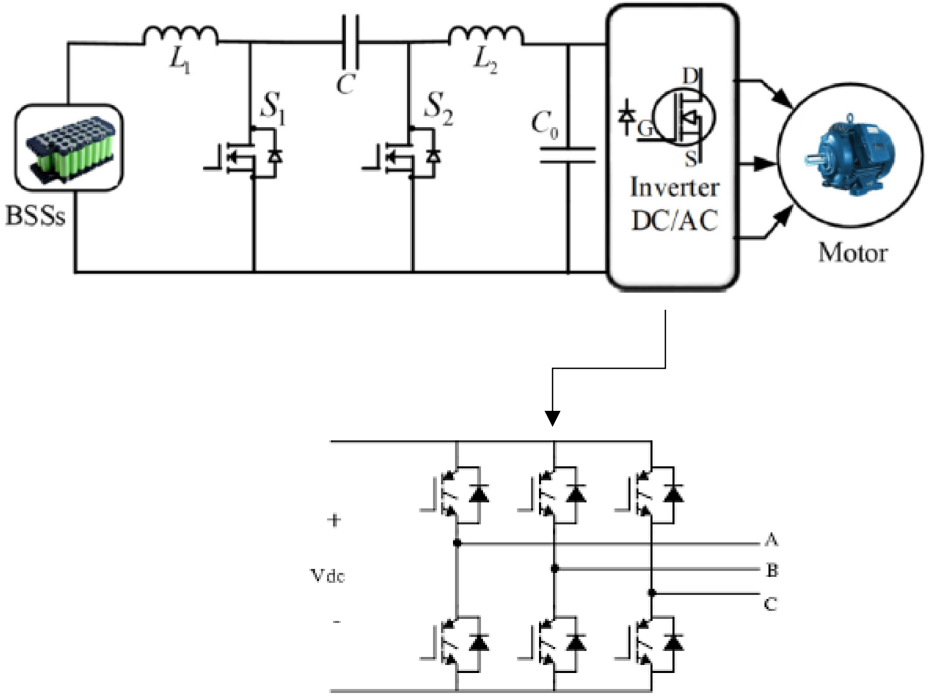
- Popularity
- Control Simplicity
- Continoeous Input Current
- Current Boosting Ability
- Limiting Inrush Current
- Overall Cost
- Size and Weight
- Limiting Current Spikes

HARDWARE SELECTION

Power Semiconductor report 2018



HARDWARE SELECTION

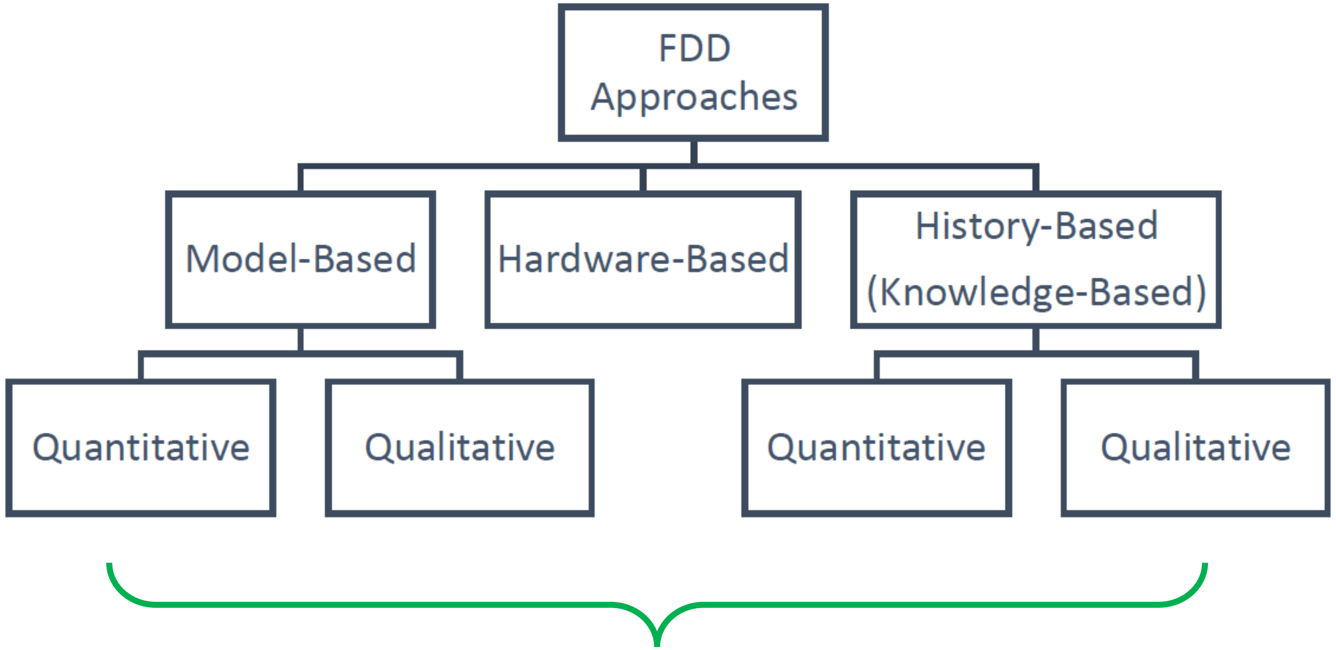


Cuk converter + Inverter

	CUK
Weight	↓
Efficiency	94.2 %
Volume	↓
EMI	↑ ↑
Current Ripple	↓
Wide input voltage variation	40-300v

FDD Approaches

A comprehensive review with the advantages and limitations of each of the techniques used is performed with a final comparative table for the corresponding fault type Summarizing their characteristics based on evaluation indicators

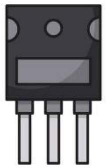


- Robustness
- Computational Complexity
- Detection Speed
- Multiple Fault Detection
- Non-Linear Systems
- Adaptability with changes

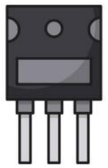
Introduction
Conversion Chain
EV Failures
Objective
Literature Review
DC-DC Converters
Inverters
FDD Approaches
Methodology
Converter Model
Inverter Model
Filter Model
Current Work & Results
DC-DC Converter
Kalman Filter Bank
Results
Conclusion & Perspective

FDD Approaches

Open Transistor

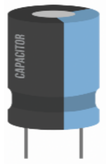


Short Transistor



FDD Method	*FDD Family*	*Robustness*	*Computational Complexity*	*Detection Speed*	*Multiple Fault Detection*	*Non-Linear Systems*	*Adaptability with changes*
Voltage Space Patterns [63]	Qualitative History-based	Low	Average	Fast (2 ms)[63]	False	True	Low
S-Transform [64], [65]	Qualitative History-based	Average	High	Average (20 ms) [64]	False	True	Low
di/dt Feedback Control [66]	Qualitative History-based	Average	High	Very Fast (0.5 µs)[66]	True	True	High
Gate Signal [67], [68]	Qualitative History-based	Low	Low	Very Fast (100-150 ns)[67] (0.5-0.6 µs)[68]	True	True	High
Transient Current [69], [70]	Qualitative Model-based	Average	Average	Very Fast (0.25 µs)[70]	True	True	Average
Bond wire [71], [72]	Qualitative Model-based	High	Average	Very Fast (2-5 µs)[72]	True	True	Average

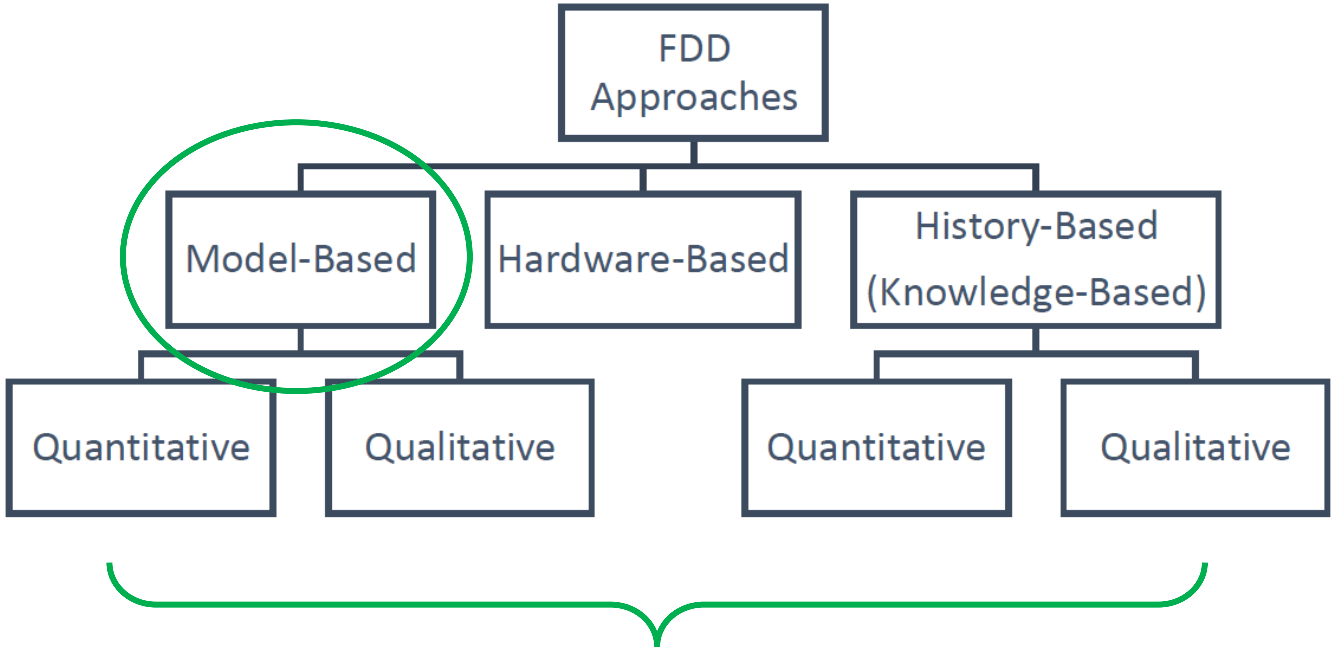
Capacitor Aging



FDD Method	*FDD Family*	*Robustness*	*Computational Complexity*	*Estimation error*	*Multiple Fault Detection*	*Non-Linear Systems*	*Adaptability with changes*
ER [78]	Qualitative History-based	High	Low	6.25-18.75% [78]	True	True	Average
RLS [80]	Quantitative Model-based	High	Low	0% [80]	True	True	Average
Thermal Modelling [82]	Qualitative Model-based	High	Average	Used to monitor capacitors and avoiding faults	True	True	Average
Transient Current [83]	Qualitative History-based	Average	Average	Used for instant capacitor faults	True	True	Average
ANFIS [84]	Quan.& Qual. History-based	High	High	6.5% [84]	True (more than one ANFIS is required)	True if trained	High
ANN [85]–[88]	Quantitative Model-based	High	Average	0.35-0.4% [85] 1.2-1.3% [86]	True (more than one ANN is required)	True if trained	High

FDD Approaches

According to the results, model-based approaches show good results especially in their robustness and low complexity and estimation error with respect to other approaches



- Robustness

- Computational Complexity

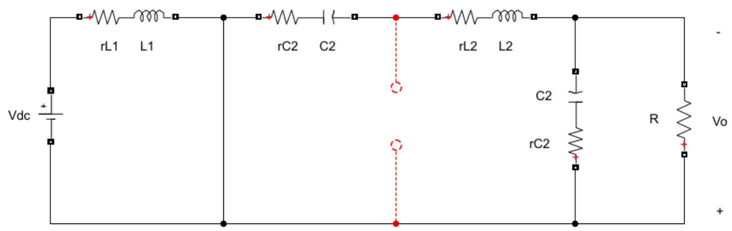
- Detection Speed

- Multiple Fault Detection

- Non-Linear Systems

- Adaptability with changes

DC-DC Converter Modeling



Mode 1: Switch is closed, Diode is opened

Input

$$u1 = \begin{bmatrix} V_{dc} \\ i_o \end{bmatrix}$$

Variables

$$x_1 = \begin{bmatrix} i_{L1} \\ v_{C1} \\ i_{L2} \\ v_{C2} \end{bmatrix} \qquad \dot{x}1 = \begin{bmatrix} \frac{\partial iL1}{\partial t} \\ \frac{\partial vC1}{\partial t} \\ \frac{\partial iL2}{\partial t} \\ \frac{\partial vC2}{\partial t} \end{bmatrix}$$

$$A11 = \begin{bmatrix} -\frac{rL1}{L_1} & 0 & 0 & 0 \\ 0 & 0 & -\frac{1}{C_1} & 0 \\ 0 & \frac{1}{L_2} & -\frac{\left(rC1 - rL2 - \frac{R.rC2}{R + rC2}\right)}{L_2} & \frac{\left(\frac{2rC2 - R}{R - rC2}\right)}{L_2} \\ 0 & 0 & \frac{1}{C_2}\left(\frac{R}{R + rC2}\right) & -\frac{1}{C_2}\left(\frac{1}{R + rC2}\right) \end{bmatrix}$$

$$B11 = \begin{bmatrix} \frac{1}{L_1} & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}$$

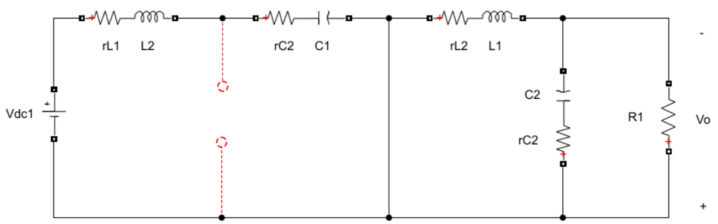
$$C11 = \begin{bmatrix} 0 & 0 & -rC2 & 1 \\ 1 & 0 & 0 & 0 \end{bmatrix}$$

$$D11 = \begin{bmatrix} 0 & rC2 \\ 0 & 0 \end{bmatrix}$$

Output

$$y1 = \begin{bmatrix} V_o \\ i_{dc} \end{bmatrix}$$

DC-DC Converter Modeling



Mode 2: Switch is opened, Diode is closed

Input

$$u1 = \begin{bmatrix} V_{dc} \\ i_o \end{bmatrix}$$

Variables

$$x_1 = \begin{bmatrix} i_{L1} \\ v_{C1} \\ i_{L2} \\ v_{C2} \end{bmatrix} \qquad \dot{x}1 = \begin{bmatrix} \frac{\partial iL1}{\partial t} \\ \frac{\partial vC1}{\partial t} \\ \frac{\partial iL2}{\partial t} \\ \frac{\partial vC2}{\partial t} \end{bmatrix}$$

Output

$$y1 = \begin{bmatrix} V_o \\ i_{dc} \end{bmatrix}$$

$$A12 = \begin{bmatrix} -\frac{(rL1 + rC1)}{L_1} & -\frac{1}{L_1} & 0 & 0 \\ \frac{1}{C_1} & 0 & 0 & 0 \\ 0 & 0 & -\frac{\left(rL2 + \frac{R.rC2}{R + rC2}\right)}{L_2} & -\frac{\left(\frac{R}{R - rC2}\right)}{L_2} \\ 0 & 0 & \frac{1}{C_2}\left(\frac{R}{R + rC2}\right) & -\frac{1}{C_2}\left(\frac{1}{R + rC2}\right) \end{bmatrix}$$

$$B12 = \begin{bmatrix} \frac{1}{L_1} & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}$$

$$C12 = \begin{bmatrix} 0 & 0 & -rC2 & 1 \\ 1 & 0 & 0 & 0 \end{bmatrix}$$

$$D12 = \begin{bmatrix} 0 & rC2 \\ 0 & 0 \end{bmatrix}$$

DC-DC Converter Modeling

Average Model

Input

$$u1 = \begin{bmatrix} V_{dc} \\ i_o \end{bmatrix}$$

Variables

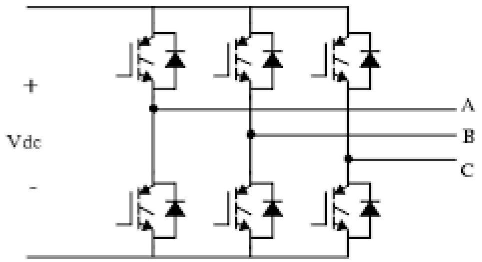
$$x_1 = \begin{bmatrix} i_{L1} \\ v_{C1} \\ i_{L2} \\ v_{C2} \end{bmatrix} \qquad \dot{x}1 = \begin{bmatrix} \frac{\partial iL1}{\partial t} \\ \frac{\partial vC1}{\partial t} \\ \frac{\partial iL2}{\partial t} \\ \frac{\partial vC2}{\partial t} \end{bmatrix}$$

Output

$$y1 = \begin{bmatrix} V_o \\ i_{dc} \end{bmatrix}$$

$$\begin{cases} \dot{x} = A_{avg}x + B_{avg}u \\ y = C_{avg}x + D_{avg}u \\ A_{avg} = A_1 d + A_2(1-d) \\ B_{avg} = B_1 d + B_2(1-d) \\ C_{avg} = C_1 d + C_2(1-d) \\ D_{avg} = D_1 d + D_2(1-d) \end{cases}$$

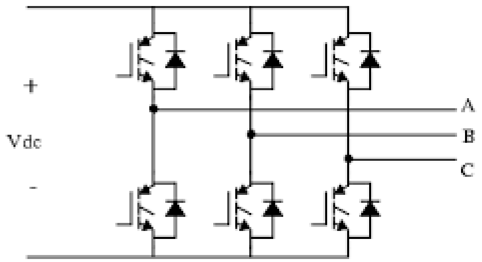
DC-AC Inverter Modeling



Modes of Operation at 180^{o} conduction

Mode	S1	S2	S3	S4 ($\overline{S_1}$)	S5 ($\overline{S_2}$)	S6 ($\overline{S_3}$)	Output		
							Vab	Vbc	Vca
1	1	0	1	0	1	0	Vdc	-Vdc	0
2	1	0	0	0	0	1	Vdc	0	-Vdc
3	1	1	0	0	0	1	0	Vdc	-Vdc
4	0	1	0	1	0	1	-Vdc	Vdc	0
5	0	1	1	1	1	0	-Vdc	0	Vdc
6	0	0	1	1	1	0	0	-Vdc	Vdc

DC-AC Inverter Modeling



Input

$u_2 = [S1\ S2\ S3\ S4\ S5\ S6\ ]$

Variables

$x2 = [0]$

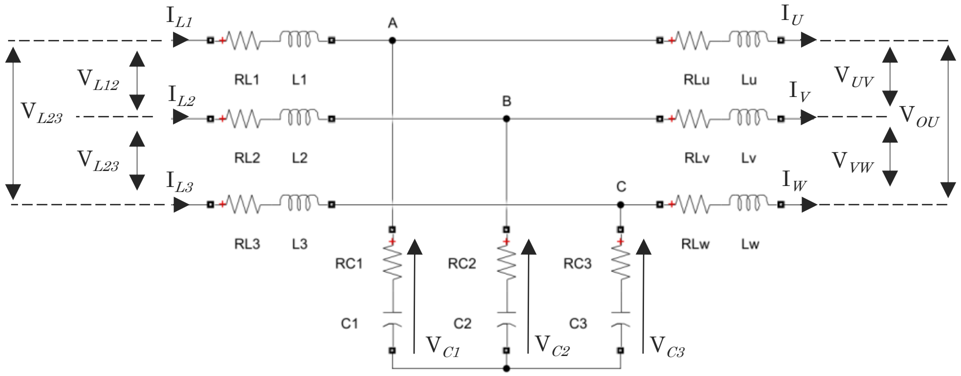
$\dot{x}2 = [0]$

Output

$$y_2 = \begin{bmatrix} V_{AB} \\ V_{BC} \\ V_{CA} \end{bmatrix}$$

$$\underbrace{\begin{bmatrix} V_{AB} \\ V_{BC} \\ V_{CA} \end{bmatrix}}_{y2} = Vdc.\underbrace{\begin{bmatrix} 1 & 1 & 0 & -1 & -1 & 0 \\ -1 & 0 & 1 & 1 & 0 & -1 \\ 0 & -1 & -1 & 0 & 1 & 1 \end{bmatrix}}_{D2}.\underbrace{\begin{bmatrix} S1 \\ S2 \\ S3 \\ S4 \\ S5 \\ S6 \end{bmatrix}}_{u2}$$

LCL filter modeling



Input

$$u_3 = \begin{bmatrix} V_{AB} \\ V_{BC} \\ V_{CA} \end{bmatrix}$$

Variables

$$x_3 = \begin{bmatrix} V_{C1} \\ V_{C2} \\ V_{C3} \\ I_{L1} \\ I_{L2} \\ I_{L3} \\ I_{Lu} \\ I_{Lv} \\ I_{Lw} \end{bmatrix} \qquad \dot{x}_3 = \begin{bmatrix} \frac{\partial V_{C1}}{dt} \\ \frac{\partial V_{C2}}{dt} \\ \frac{\partial V_{C3}}{dt} \\ \frac{\partial I_{L1}}{dt} \\ \frac{\partial I_{L2}}{dt} \\ \frac{\partial I_{L3}}{dt} \\ \frac{\partial I_{Lu}}{dt} \\ \frac{\partial I_{Lv}}{dt} \\ \frac{\partial IL_{w}}{dt} \end{bmatrix}$$

Output

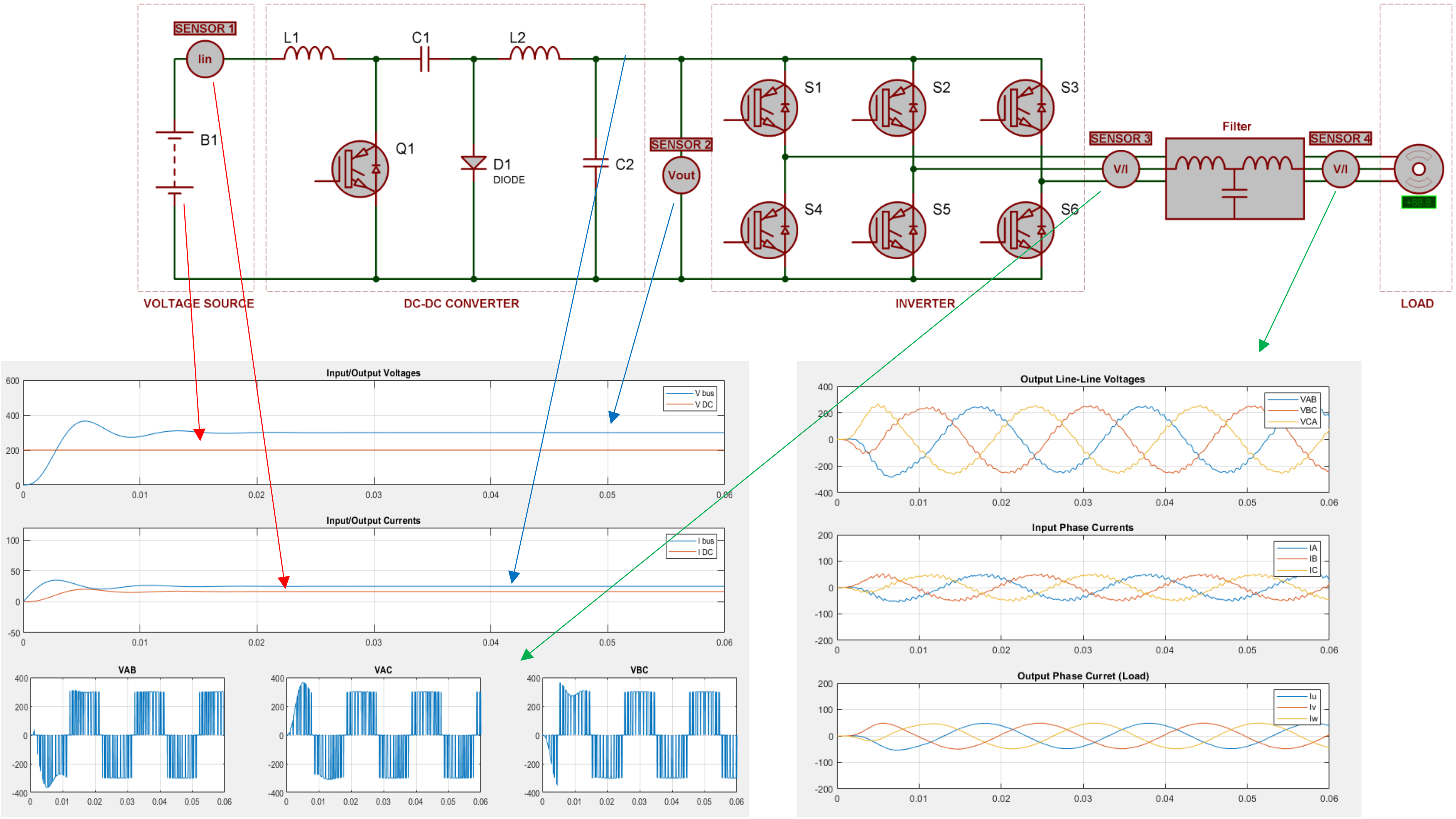
$$y_3 = \begin{bmatrix} V_{AB} \\ V_{BC} \\ V_{CA} \\ I_{AB} \\ I_{BC} \\ I_{CA} \\ I_U \\ I_V \\ I_W \end{bmatrix}$$

$$\underbrace{\begin{bmatrix} \frac{\partial V_{C1}}{dt} \\ \frac{\partial V_{C2}}{dt} \\ \frac{\partial V_{C3}}{dt} \\ \frac{\partial I_{L1}}{dt} \\ \frac{\partial I_{L2}}{dt} \\ \frac{\partial I_{L3}}{dt} \\ \frac{\partial I_{Lu}}{dt} \\ \frac{\partial I_{Lv}}{dt} \\ \frac{\partial IL_{w}}{dt} \end{bmatrix}}_{\dot{x}3} = \underbrace{\begin{bmatrix} 0 & 0 & 0 & \frac{1}{3C1} & 0 & 0 & -\frac{1}{3C1} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{3C1} & 0 & 0 & -\frac{1}{3C1} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{3C1} & 0 & 0 & -\frac{1}{3C1} \\ -\frac{1}{L1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -\frac{1}{L1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -\frac{1}{L1} & 0 & 0 & 0 & 0 & 0 & 0 \\ \frac{1}{L2+Lo} & 0 & 0 & 0 & 0 & 0 & -\frac{r_{L2}+Ro}{L2+Lo} & 0 & 0 \\ 0 & \frac{1}{L2+Lo} & 0 & 0 & 0 & 0 & 0 & -\frac{r_{L2}+Ro}{L2+Lo} & 0 \\ 0 & 0 & \frac{1}{L2+Lo} & 0 & 0 & 0 & 0 & 0 & -\frac{r_{L2}+Ro}{L2+Lo} \end{bmatrix}}_{A31} . \underbrace{\begin{bmatrix} V_{C1} \\ V_{C2} \\ V_{C3} \\ I_{L1} \\ I_{L2} \\ I_{L3} \\ I_{Lu} \\ I_{Lv} \\ I_{Lw} \end{bmatrix}}_{x3} + \underbrace{\begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ \frac{1}{L1} & 0 & 0 \\ 0 & \frac{1}{L1} & 0 \\ 0 & 0 & \frac{1}{L1} \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}}_{B31} . \underbrace{\begin{bmatrix} V_{AB} \\ V_{BC} \\ V_{CA} \end{bmatrix}}_{u3}$$

$$\underbrace{\begin{bmatrix} V_{uv} \\ V_{vw} \\ V_{wu} \\ I_{AB} \\ I_{BC} \\ I_{CA} \\ I_U \\ I_V \\ I_W \end{bmatrix}}_{y3} = \underbrace{\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}}_{C31} . \underbrace{\begin{bmatrix} V_{C1} \\ V_{C2} \\ V_{C3} \\ I_{L1} \\ I_{L2} \\ I_{L3} \\ I_{Lu} \\ I_{Lv} \\ I_{Lw} \end{bmatrix}}_{x3} + \underbrace{\begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}}_{D31} . \underbrace{\begin{bmatrix} V_{AB} \\ V_{BC} \\ V_{CA} \end{bmatrix}}_{u3}$$

Cascaded System Modeling

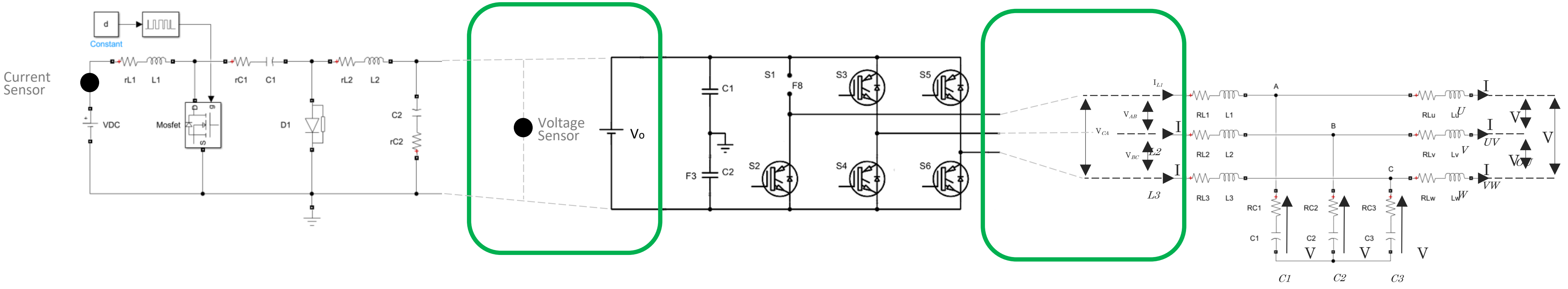
The three healthy models will be combined in a single healthy model of the chain



Introduction
Conversion Chain
EV Failures
Objective
Literature Review
DC-DC Converters
Inverters
FDD Approaches
Methodology
Converter Model
Inverter Model
Filter Model
Current Work & Results
DC-DC Converter
Kalman Filter Bank
Results
Conclusion & Perspective

Cascaded System

Real case scenario – Merging the Chain



Common section containing sensors

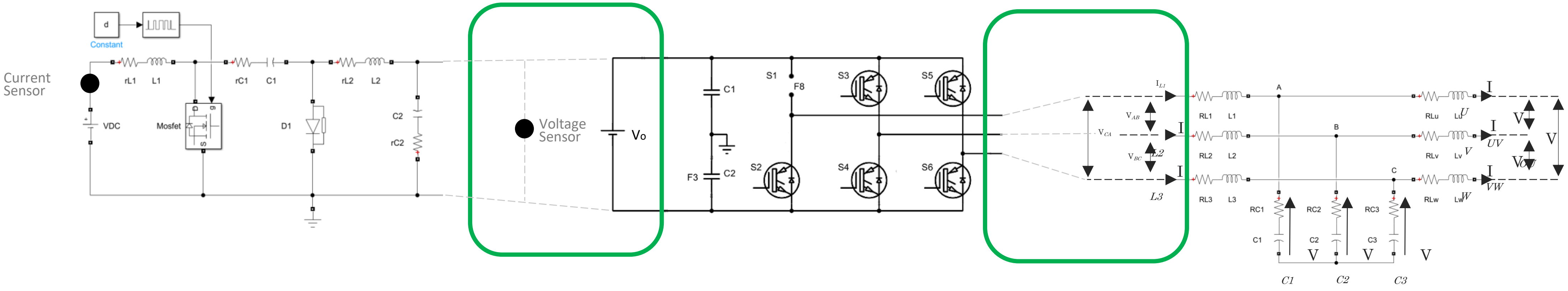
Common section containing sensors

Result

Loosing the controllability and the observability (variable load across the output of DC-DC converter)

Cascaded System

Real case scenario – Merging the Chain



Common section containing sensors

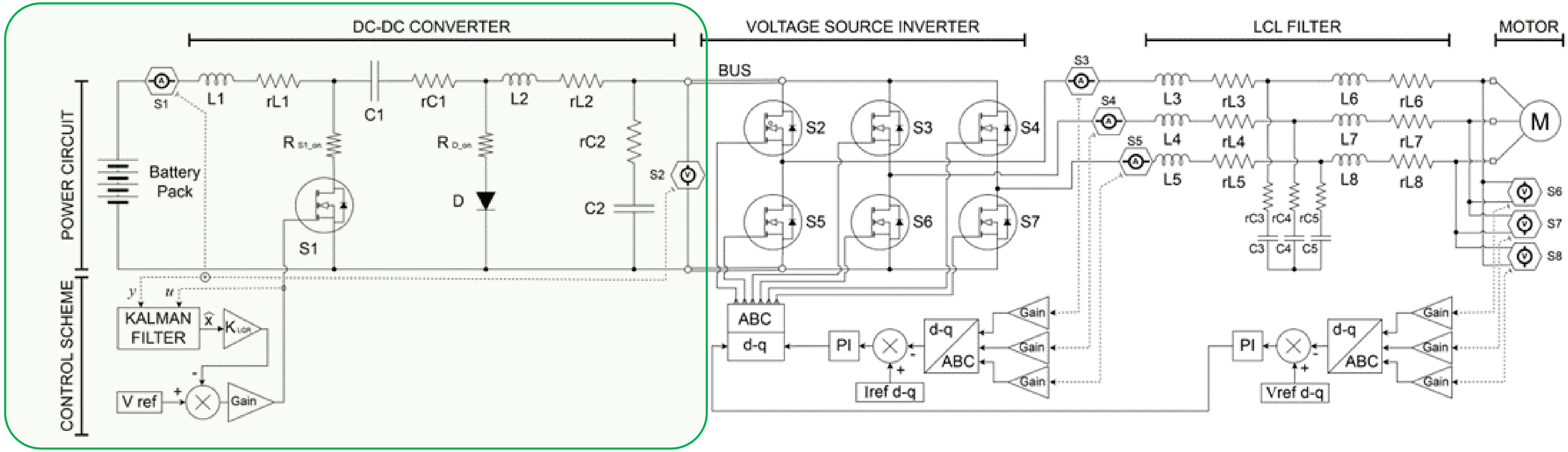
Common section containing sensors

Solution

Making the DC-DC converter close-loop

Kalman Filter

Open/close loop comparison



Close-loop system

Fault

Kalman Filter

Residual Generation

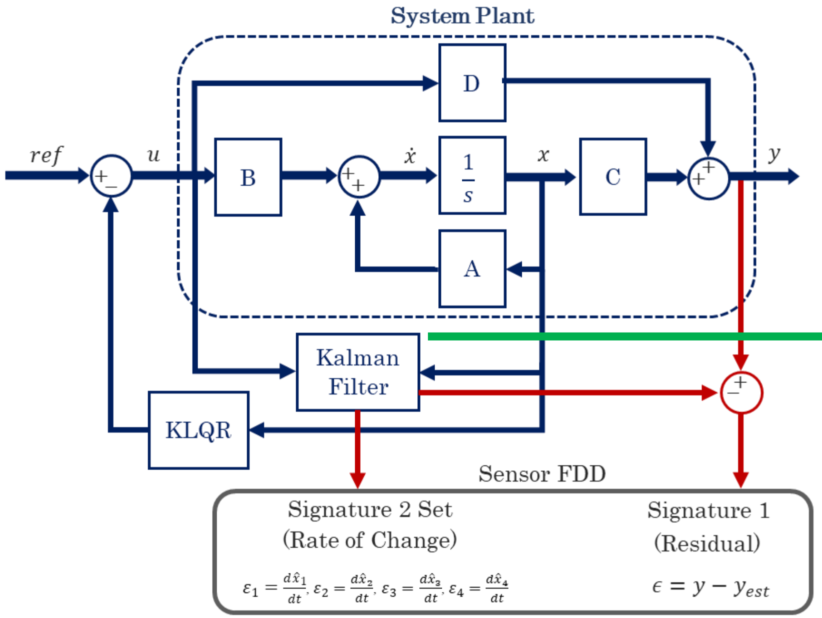
Sensor

- **Accurate**
- **Reliable**
- **Insensitive to measurement noise**

Comparison

Open Loop **Closed Loop**

Kalman Filter
Prediction/Update



Prediction Step:

$$\hat{x}_{k|k-1} = A\hat{x}_{k-1|k-1} + Bu_{k-1}$$

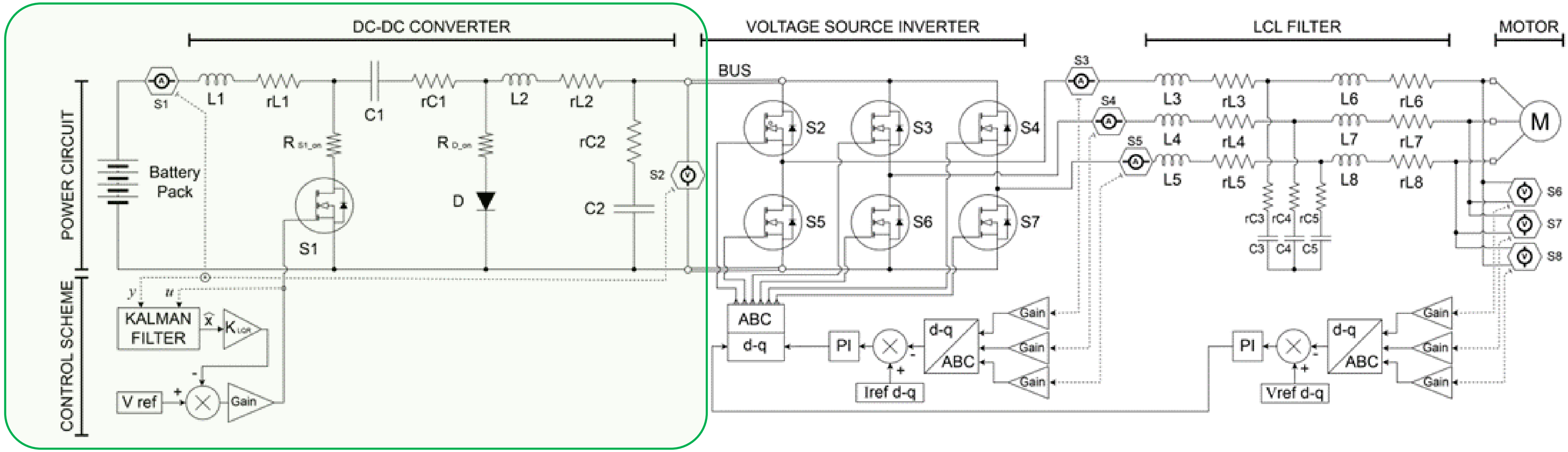
$$P_{k|k-1} = AP_{k-1|k-1}A^T + Q$$

Update Step:

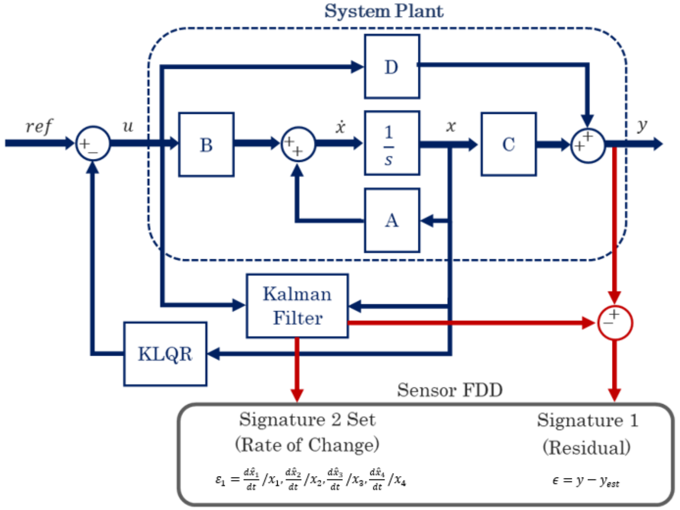
$$\begin{cases} K_k = P_k^- H^T (HP_k^- H^T + Rn)^{-1} \\ \hat{x}_k = \hat{x}_k^- + K_k((y_k + F_{bias}) - H\hat{x}_k^-) \\ P_k = (I - K_k H)P_k^- \end{cases}$$

Kalman Filter

Signature generation



Close-loop system



Signature 1

$$\epsilon = y - yest$$

Signature 2

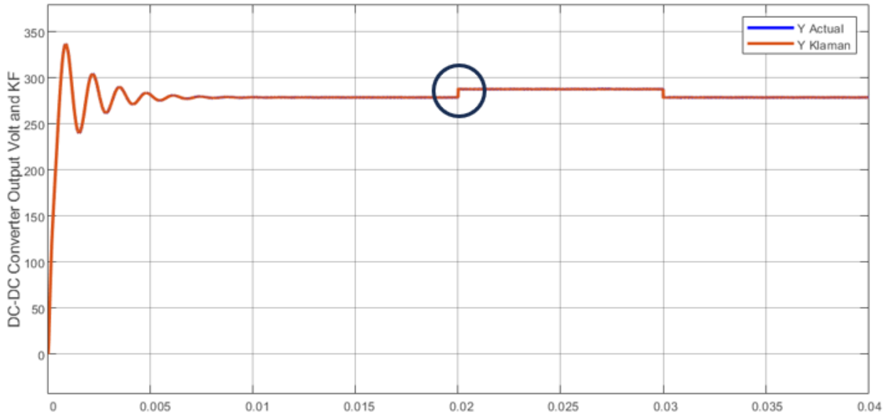
Relative rate of change:

$$\begin{cases} \varepsilon_1 = \frac{d\hat{x}_1}{dt}/x_1 \\ \varepsilon_2 = \frac{d\hat{x}_2}{dt}/x_2 \\ \varepsilon_3 = \frac{d\hat{x}_3}{dt}/x_3 \\ \varepsilon_4 = \frac{d\hat{x}_4}{dt}/x_4 \end{cases}$$

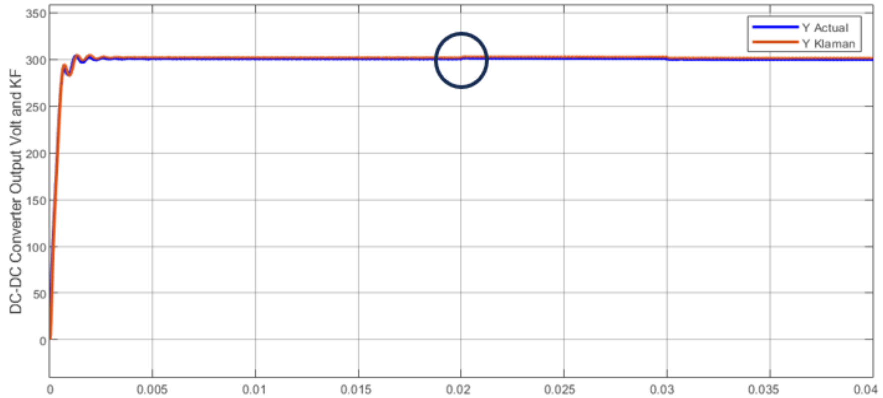
Kalman Filter

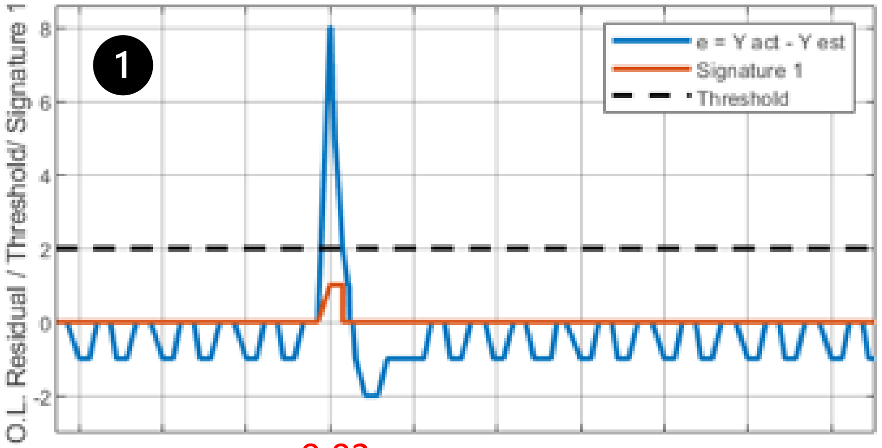
Real case scenario – Sensor Bias Fault in DC-DC Converter

Open-loop (+3% bias fault)

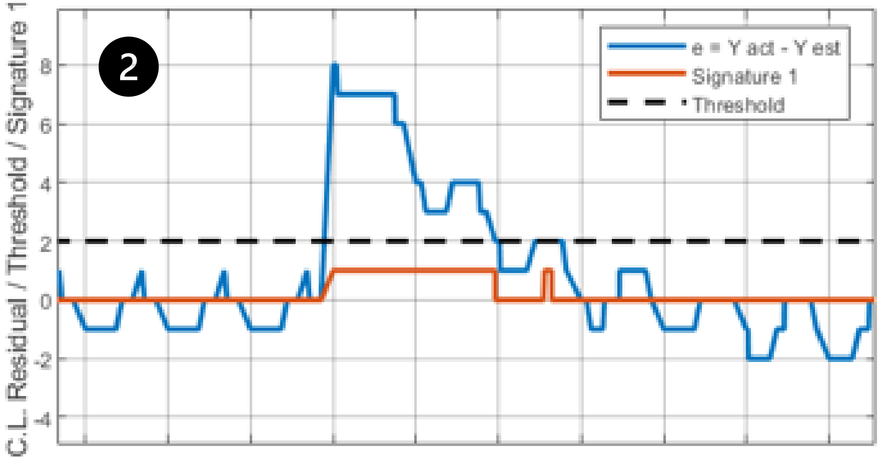


Close-loop (+3% bias fault)





0.02

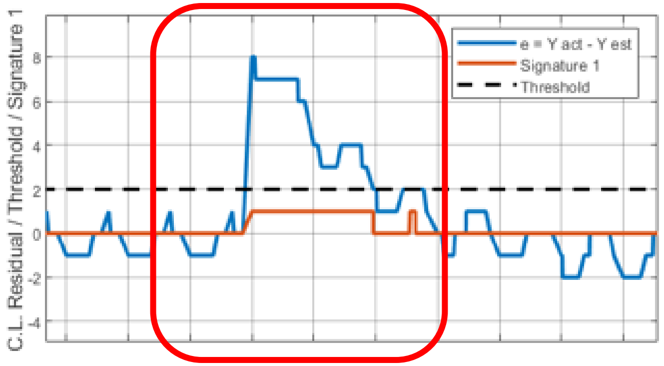


0.02

Fault Detection was evaluated between O.L. & C.L.

Results

Problem



Although the in C.L. control system the duration of the fault increased

Making the FDD algorithm able to detect fault in C.L. system more efficient than O.L. system

---

The magnitude of sensor Bias fault is not obtained

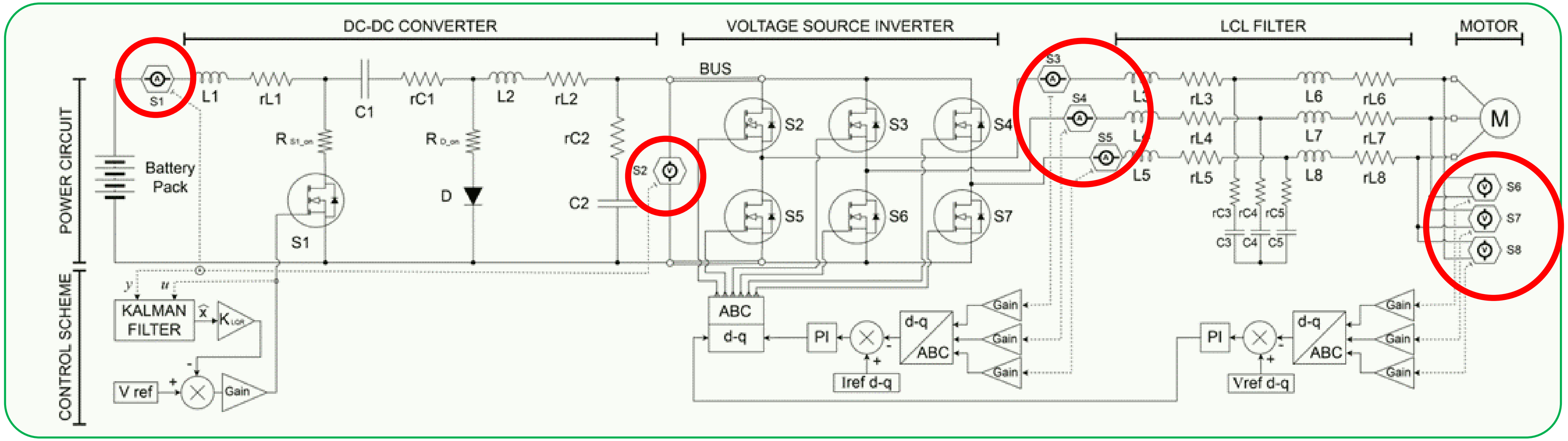
Not able to detect sensor fault after it occurs

We need 2nd sensor and a bank of Kalman filters

Faults can be isolated and reconfigured

Conversion Chain

Sensors used



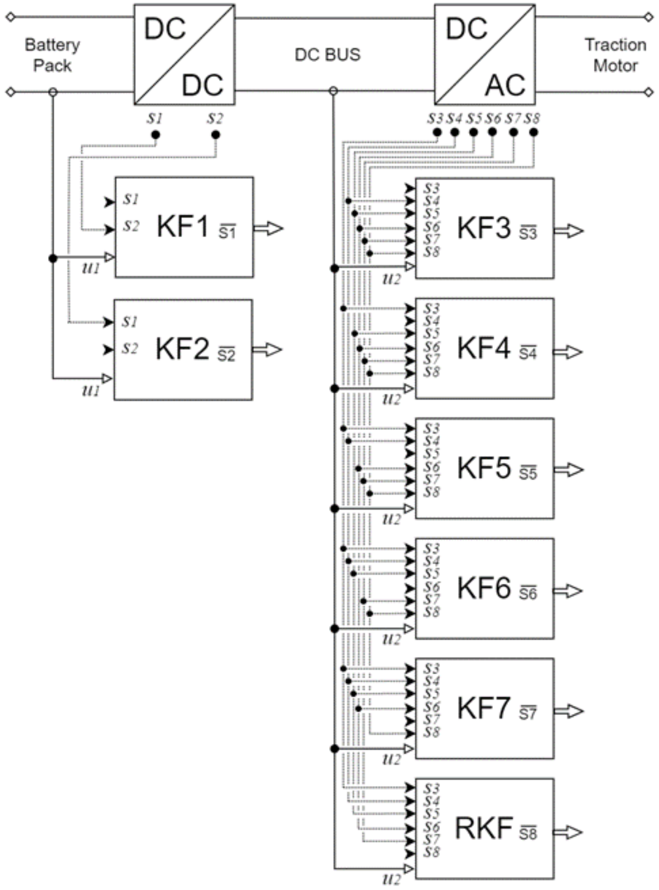
2 Sensors in the DC-DC Sub-system

6 Sensors in the Inverter-LCL filter Sub-system

8 Total sensors

Proposed Approach

Bank of Kalman filters – GOS Configuration



$$\text{Prediction:}\begin{cases} \hat{x}_k^- = A\hat{x}_{k-1} + Bu_k \\ P_k^- = AP_{k-1}A^T + Qf \end{cases}$$

$$\text{Correction:}\begin{cases} K_k = P_k^- H^T (HP_k^- H^T + Rn)^{-1} \\ \hat{x}_k = \hat{x}_k^- + K_k((y_k + F_{bias}) - H\hat{x}_k^-) \\ P_k = (I - K_k H)P_k^- \end{cases}$$

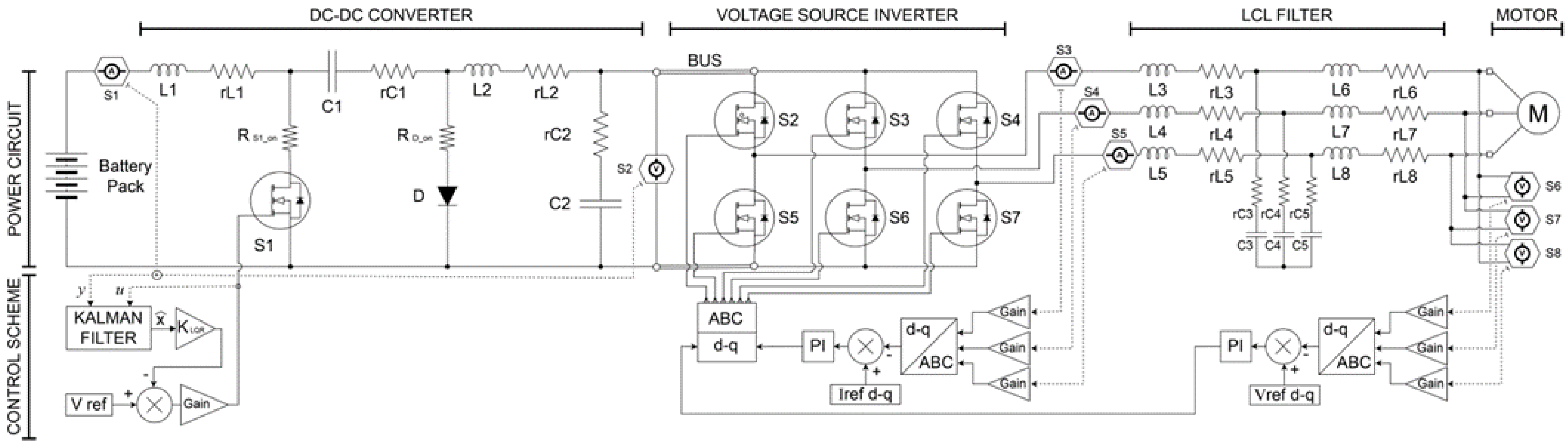
$$\begin{cases} \dot{\epsilon} = (A - KfC)\epsilon + wd - Kfwn \\ \epsilon = y - yest = y - (C\hat{x} + Du) \Rightarrow Signature\ 1 \\ = y - (C(\hat{x}_k^- + K_k((y_k + F_{bias}) - H\hat{x}_k^-) + Du) \end{cases}$$

$$\text{Residual:}\begin{cases} \epsilon_1 = y_{11} - GKF_{\overline{S1}} = V_{S1} - GKF_{\overline{S1}} \\ \epsilon_2 = y_{12} - GKF_{\overline{S2}} = I_{S2} - GKF_{\overline{S2}} \\ \epsilon_3 = y_{21} - GKF_{\overline{S3}} = I_{S3} - GKF_{\overline{S3}} \\ \epsilon_4 = y_{22} - GKF_{\overline{S4}} = I_{S4} - GKF_{\overline{S4}} \\ \epsilon_5 = y_{23} - GKF_{\overline{S5}} = I_{S5} - GKF_{\overline{S5}} \\ \epsilon_6 = y_{24} - GKF_{\overline{S6}} = V_{S6} - GKF_{\overline{S6}} \\ \epsilon_7 = y_{25} - GKF_{\overline{S7}} = V_{S7} - GKF_{\overline{S7}} \\ \epsilon_8 = y_{26} - GKF_{\overline{S8}} = V_{S8} - GKF_{\overline{S8}} \end{cases}$$

✔ Fault can be isolated and reconfigured

Proposed Approach

Open and Close Loop for Conversion Chain Comparison



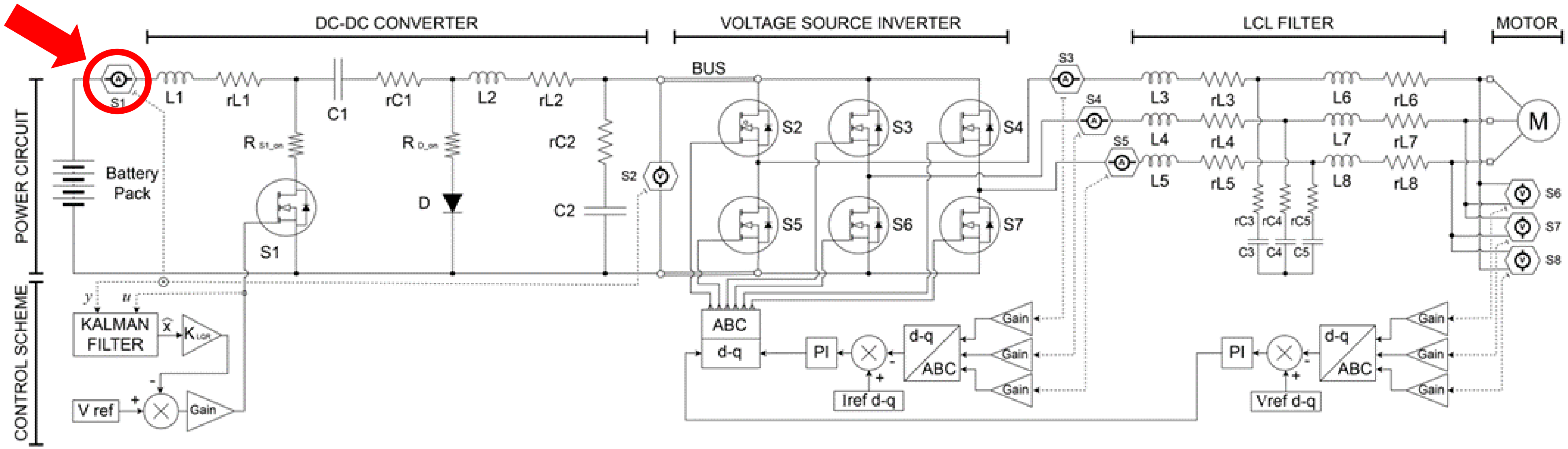
Open-loop

Close-loop

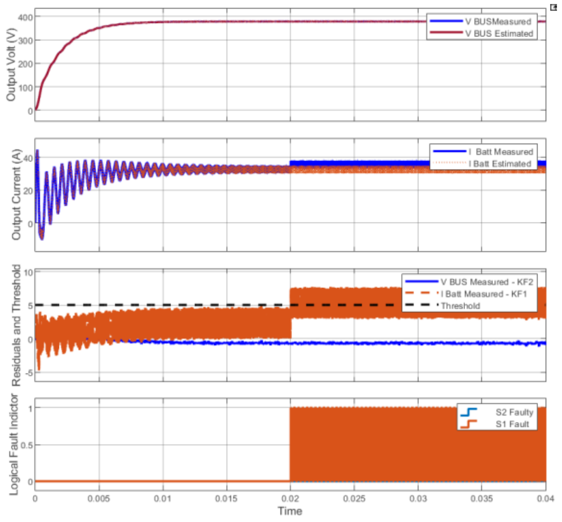
8 Single Sensor Fault

Results

Using bank of Kalman filters – Example 1 – Current Sensor Fault

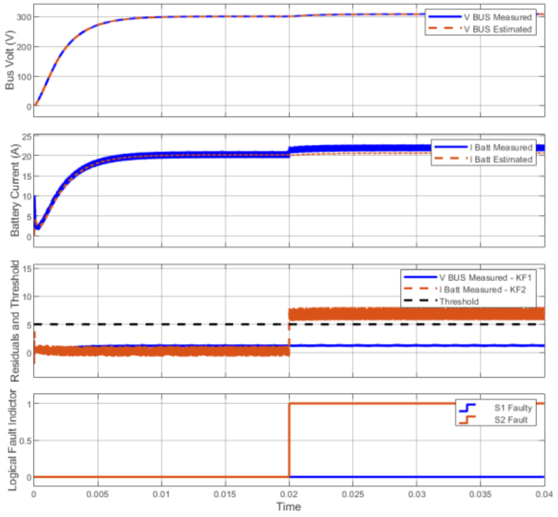


Open-loop



1

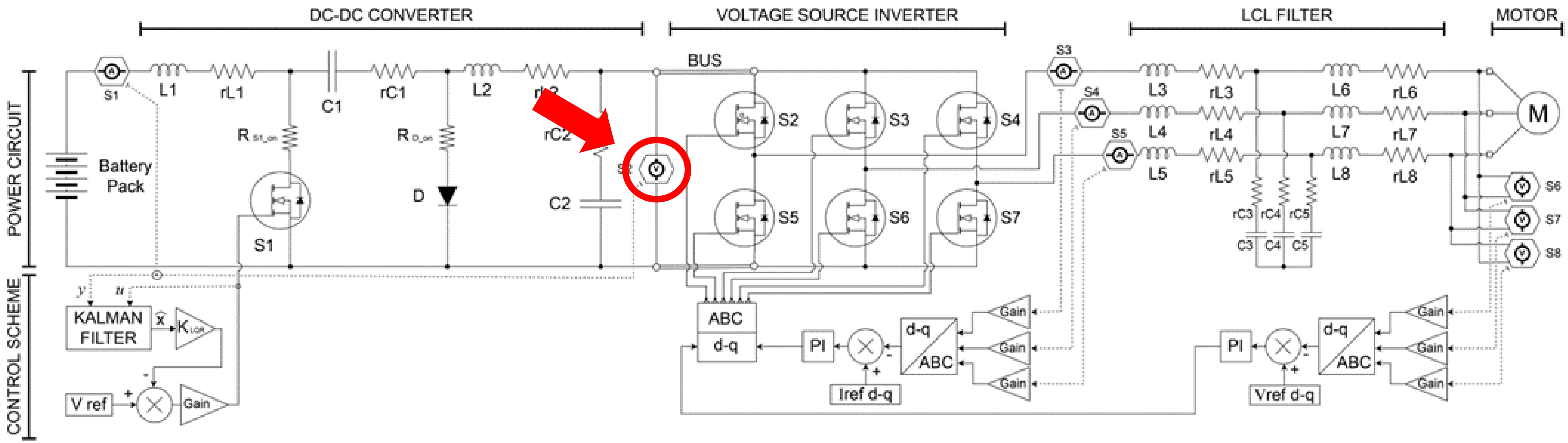
Close-loop



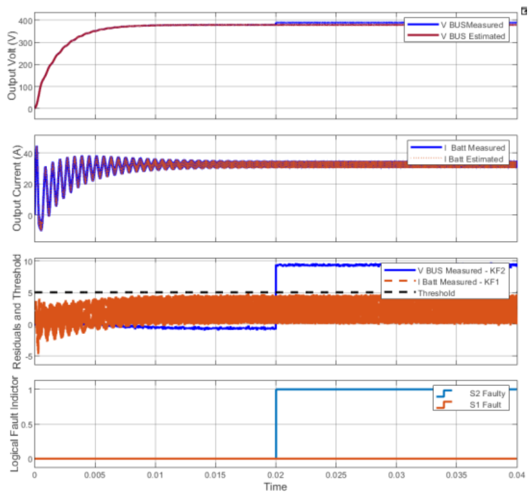
2

Results

Using bank of Kalman filters – Example 2 – Voltage Sensor Fault

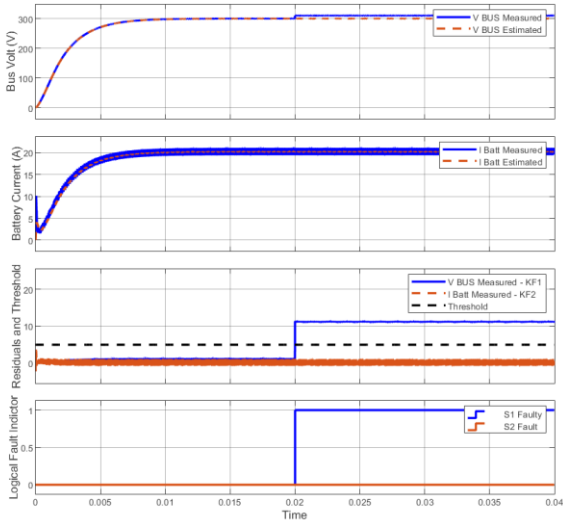


Open-loop



1

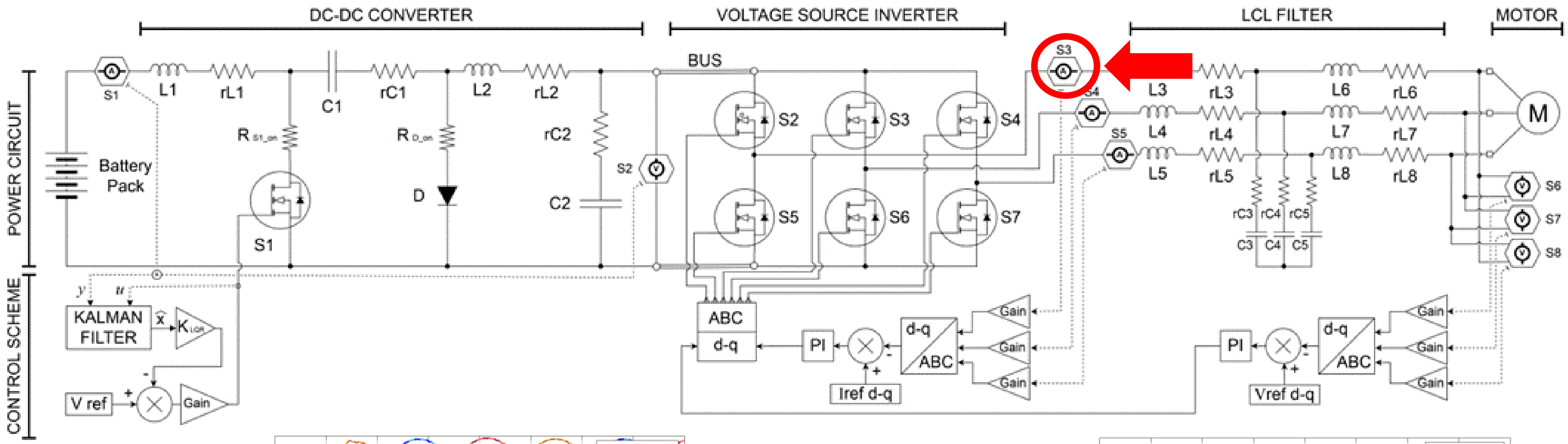
Close-loop



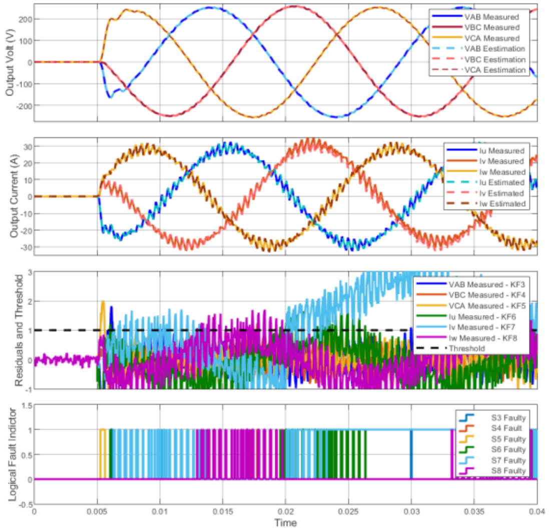
2

Results

Using bank of Kalman filters – Example 3 – Current Sensor Fault

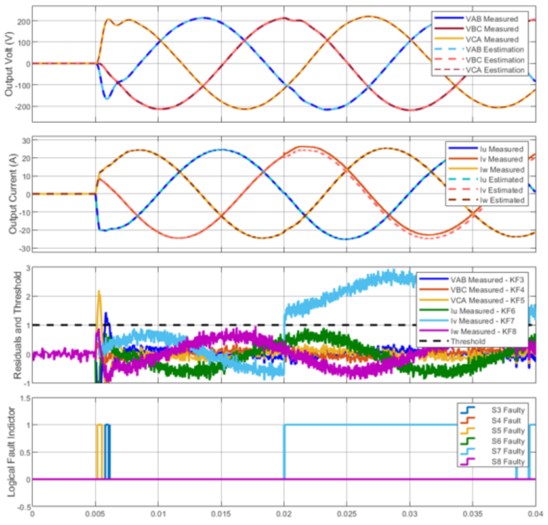


Open-loop



1

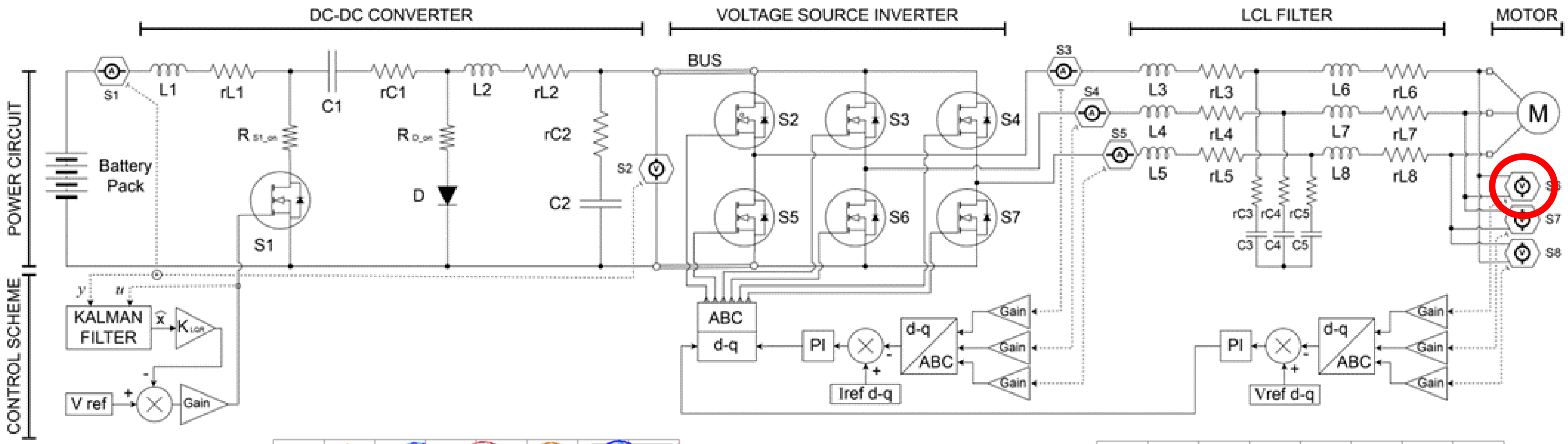
Close-loop



2

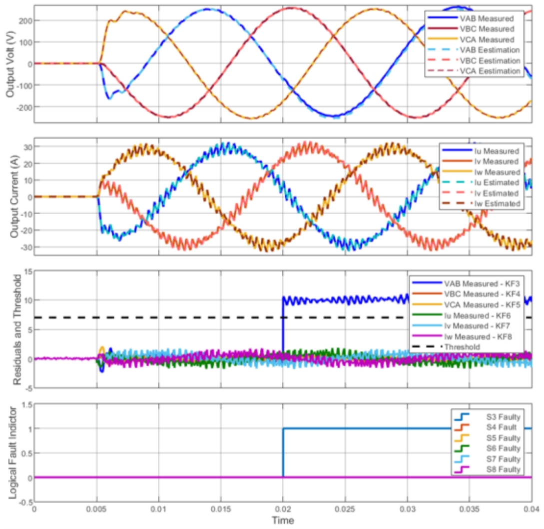
Results

Using bank of Kalman filters – Example 4 – Voltage Sensor Fault



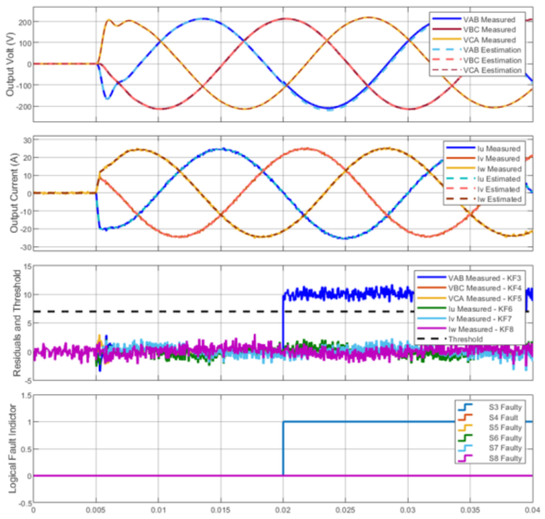
Open-loop

1



Close-loop

2



Conclusions & Perspectives

- ✓ The technique can sense the faulty sensor, even in a closed control loop configuration using Kalman filter estimation and residual generation with the ability of combining eight different fault residuals and banks to be analyzed by the FDD approach.
- ✓ Propagation of fault makes sensor fault detection in close-loop achievable and increase the residual duration than a regular open-loop system
- ✓ Diagnosis of 8 different single sensor faults in VSI and filter
- ⏭ Current work is diagnosing system uncertainties of component faults

Merci de votre attention