Fault detection and operation for in-vehicle power converters

For the application of Electromagnetic Active Suspension System

Electromechanics and Power Electronics (EPE) Group
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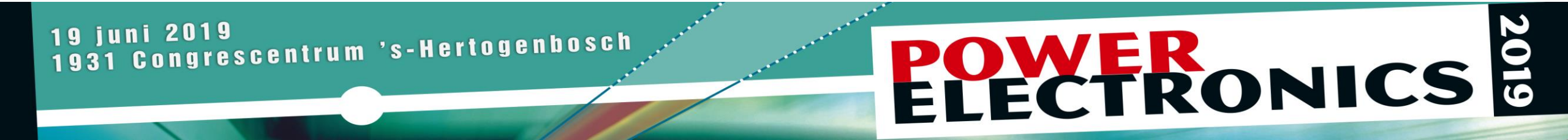
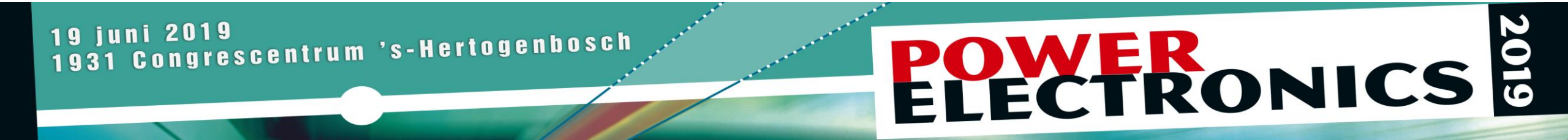


Agenda

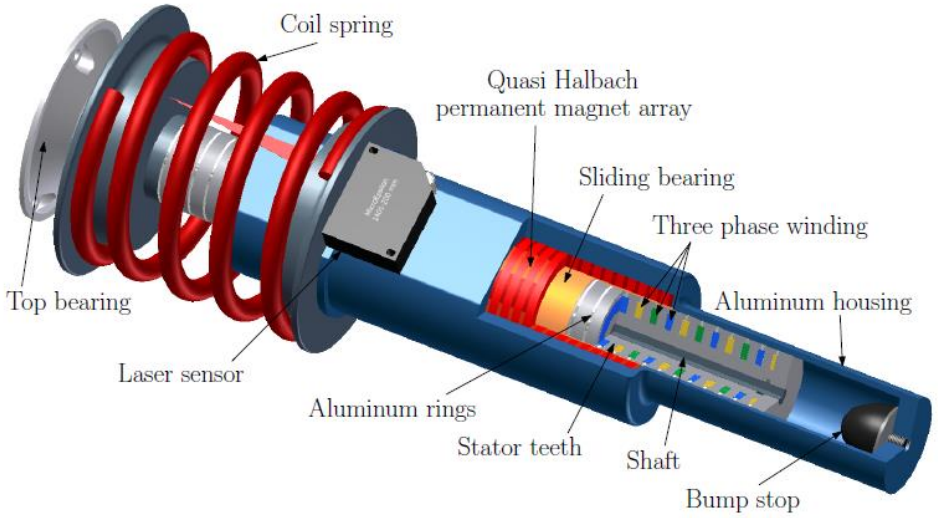
- Project Description
- Problem Formulation and Failure Analysis
- Control Formulation
- Power Electronics Fault-Detection
- Power Electronics Fault-Reconfiguration



Project Description

Advancing fail-operational electronics components and Systems for Future Mobility

Auto Drive X electromechanics power electronics epe



Fail-operational
Electromagnetic Suspension System

4 corners of 48V Bus System
BOSCH urban Automated Shuttle

Demonstration of Controlled Suspension

Electromagnetic system

Hydraulic system

Controller

Drive

Sensors

Sprung Mass

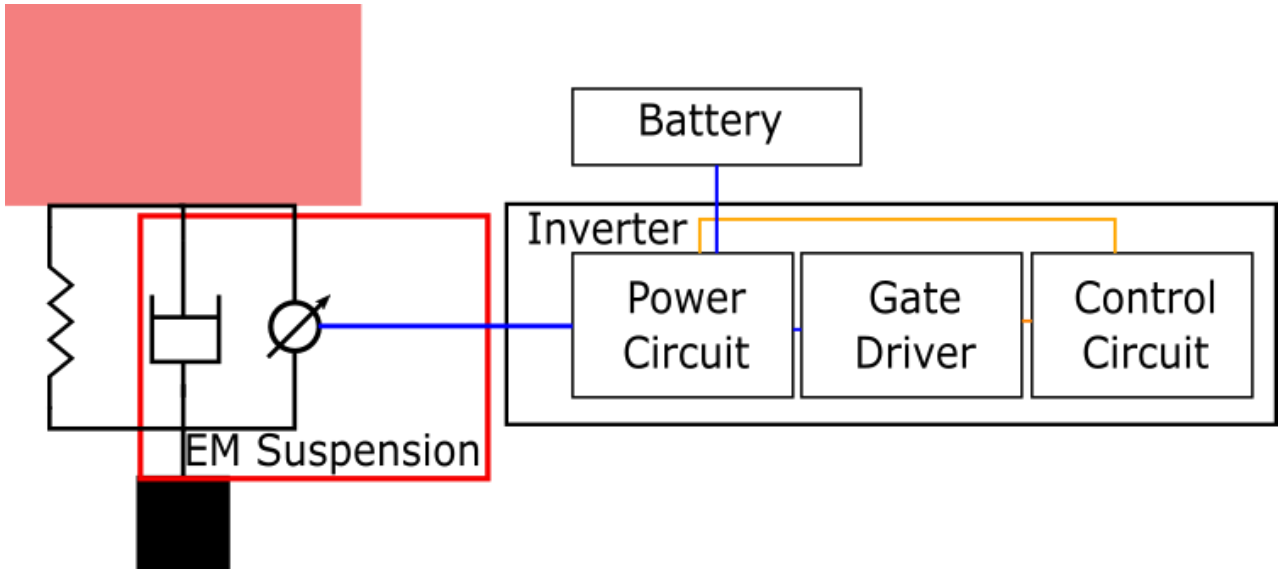
Unsprung Mass

Example of a very bad road

Road Class D → ISO 8608

Problem with Electromagnetic Suspension

Sprung Mass



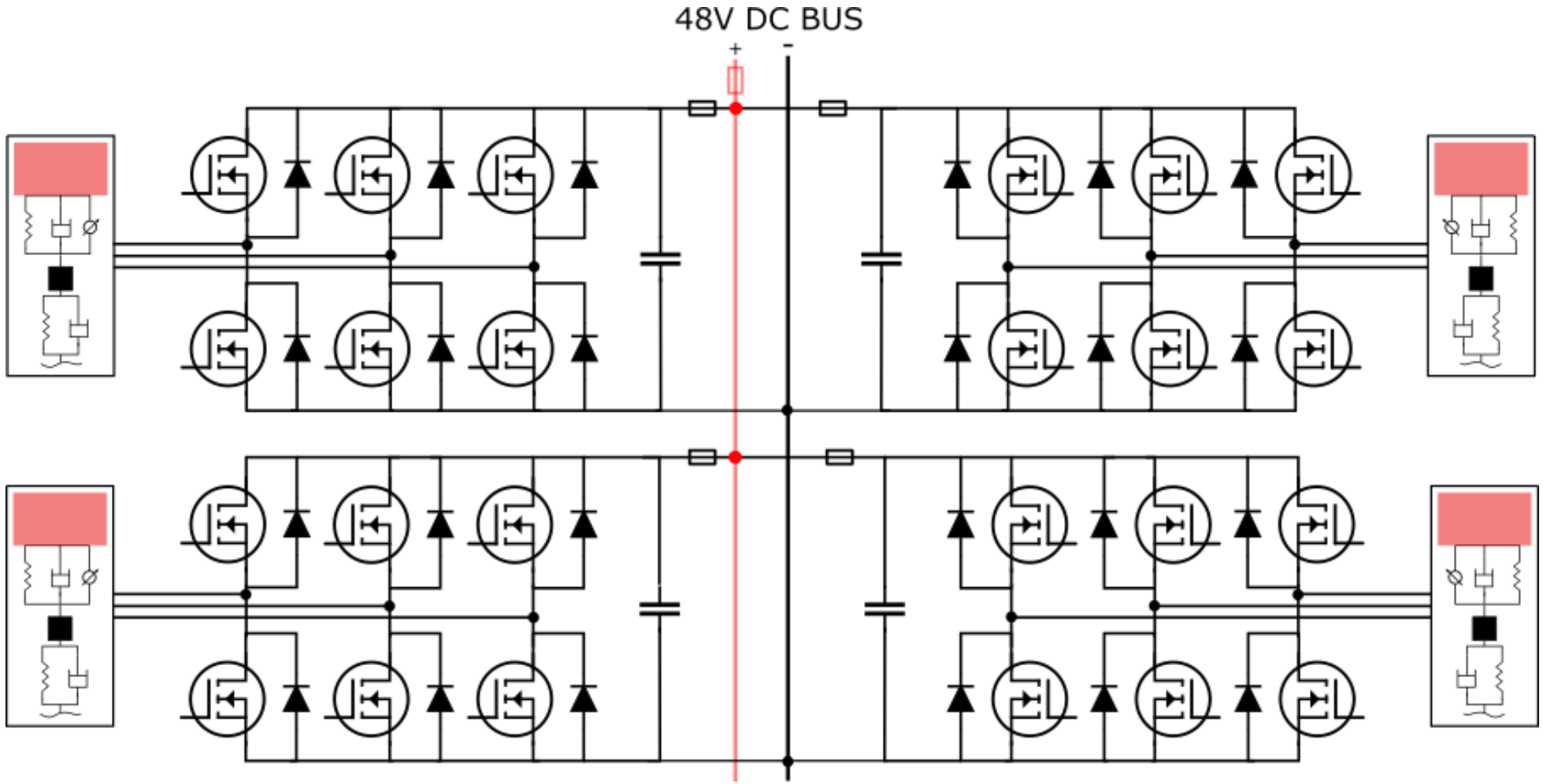
Unsprung Mass

Quarter Car with Electromagnetic Suspension

- Additional Complexity
- Additional Electric Power Consumption
- Increase the system failure probability

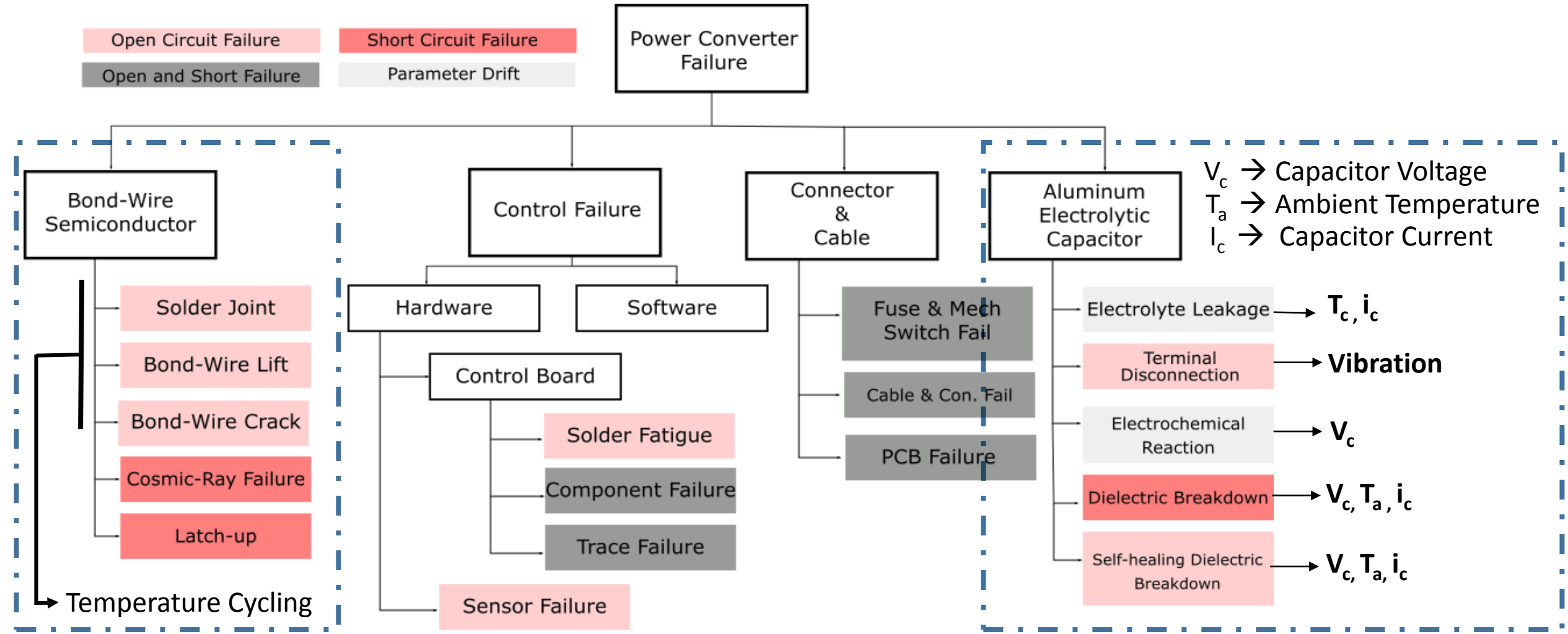
Fail-operational is required !

Electromagnetic Suspension System

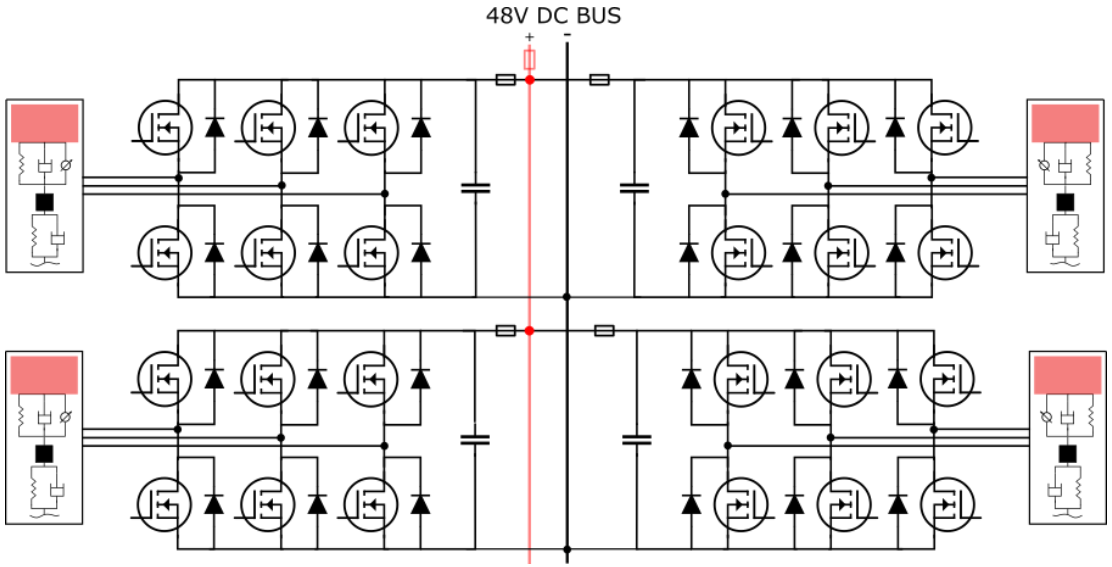


Full-Car Model with four Electromagnetic Suspension

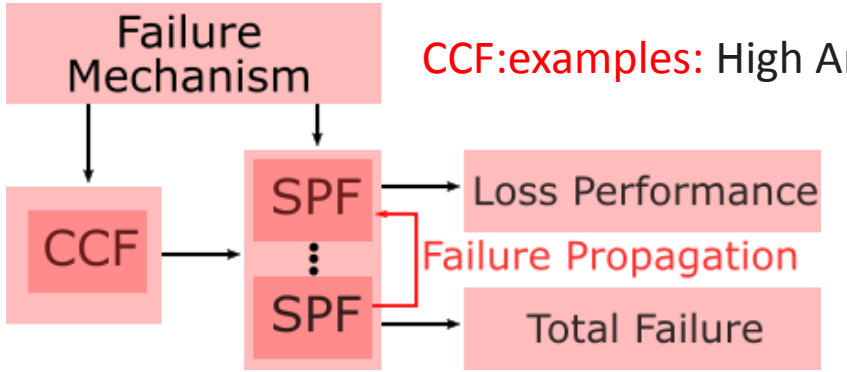
Power Electronics Failure Tree



System Failure Analysis



4 Two level three phase, 4 fast fuses, 4 EM suspension, 48 VDC Bus

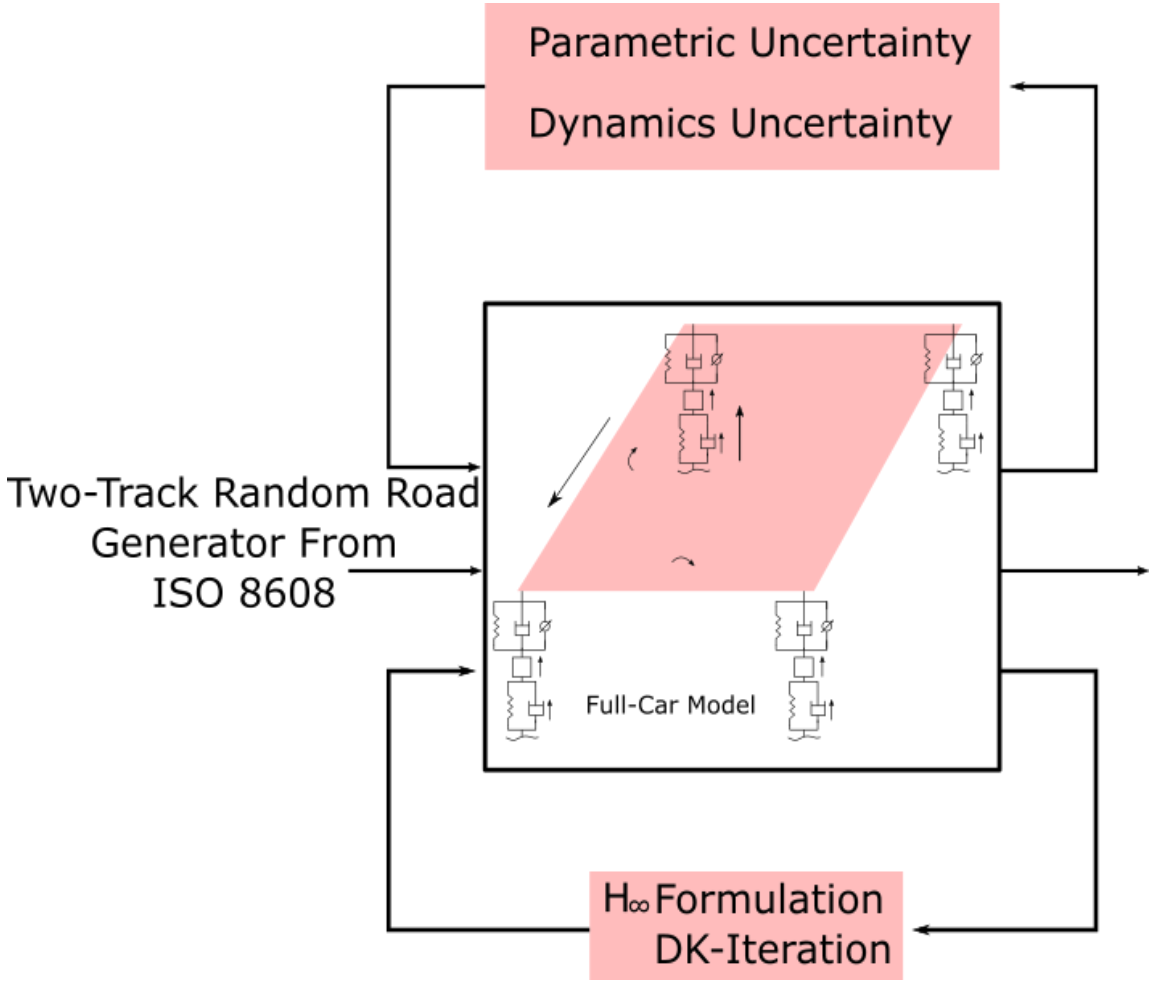


CCF:examples: High Ambient Temperature

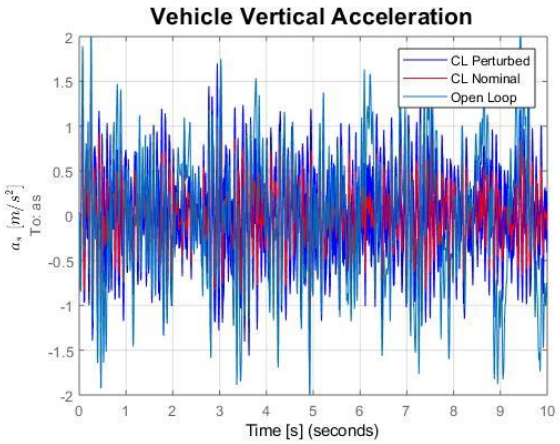
Grouping From Failure Mechanism

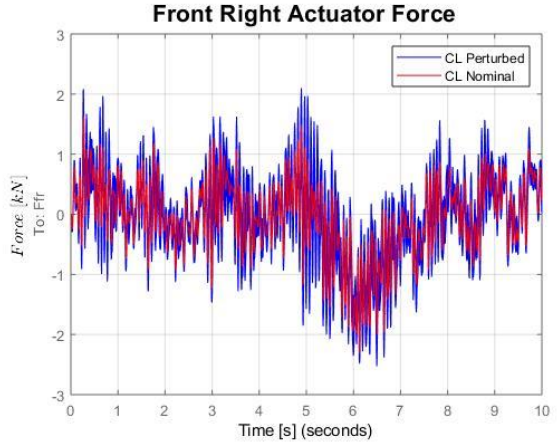
Group	Single-Point Failure (SPF)
Output Port (Electromagnetic Suspension)	Open Circuit
	Conductor-Conductor Short
	Conductor-Ground Short
	Suspension Parameter Drift
Power Semiconductor	Open Circuit
	Short Circuit
Gate Driver and Sensors	Open Circuit from the converter
	Sensor Parameter Drift and Open
Capacitor	Open Circuit
	Short Circuit
	Parameter Drift
Input Port	Open Circuit
	Short Circuit

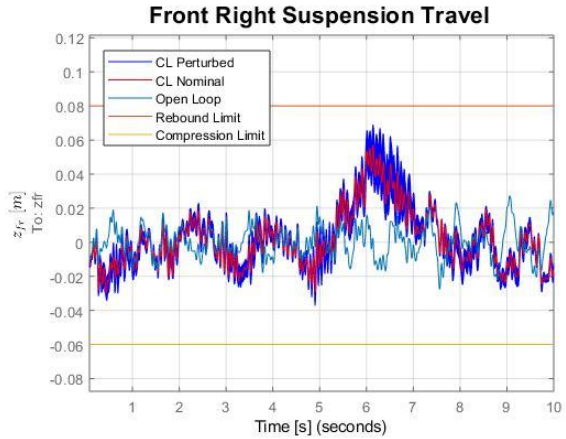
Robust Control Formulation



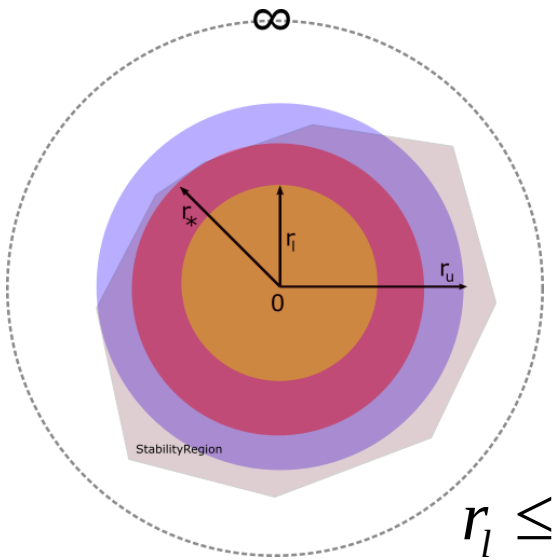
24 parameter Monte-Carlo variation of car dynamics, Class C, 50 km/h



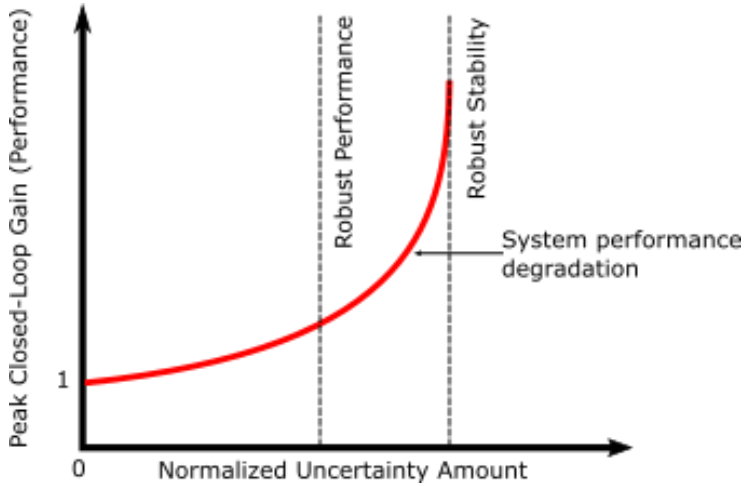




Robust Stability and Performance



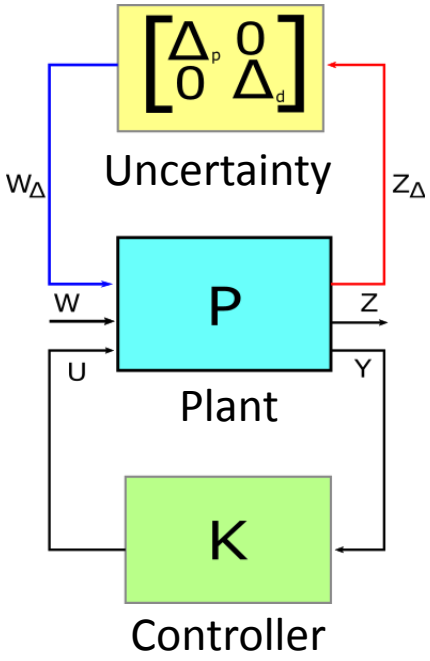
$$r_l \le r_* < r_u$$

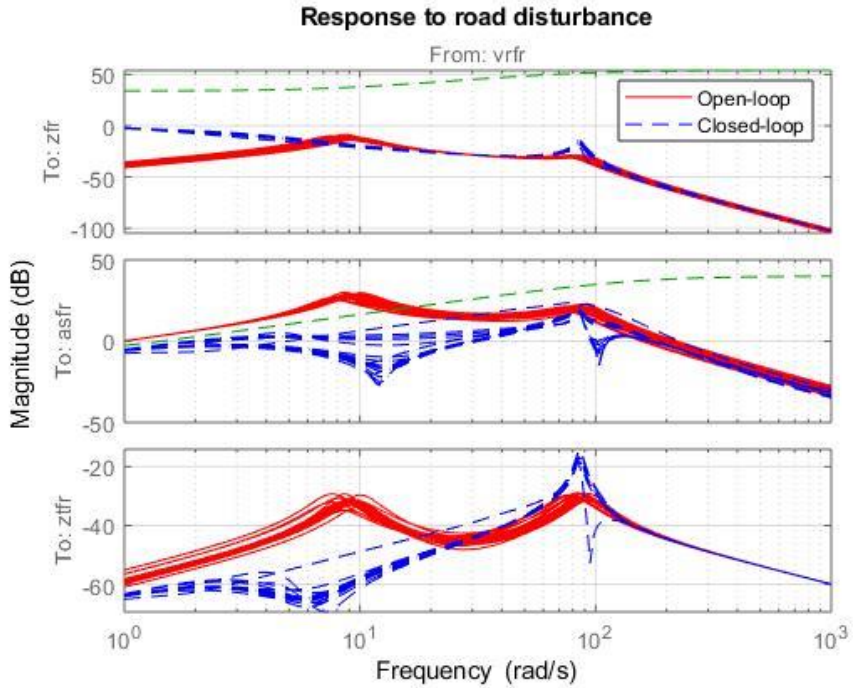


For Robust Performance:

- Nominal Stability
- Nominal Performance
- Robust Stability

$$\left\|\Delta * P * K\right\|_\infty \le 1 \quad \left\|\Delta\right\|_\infty \le 1$$





$r_{pl} = 1.0496$ $r_{sl} = 1.1543$

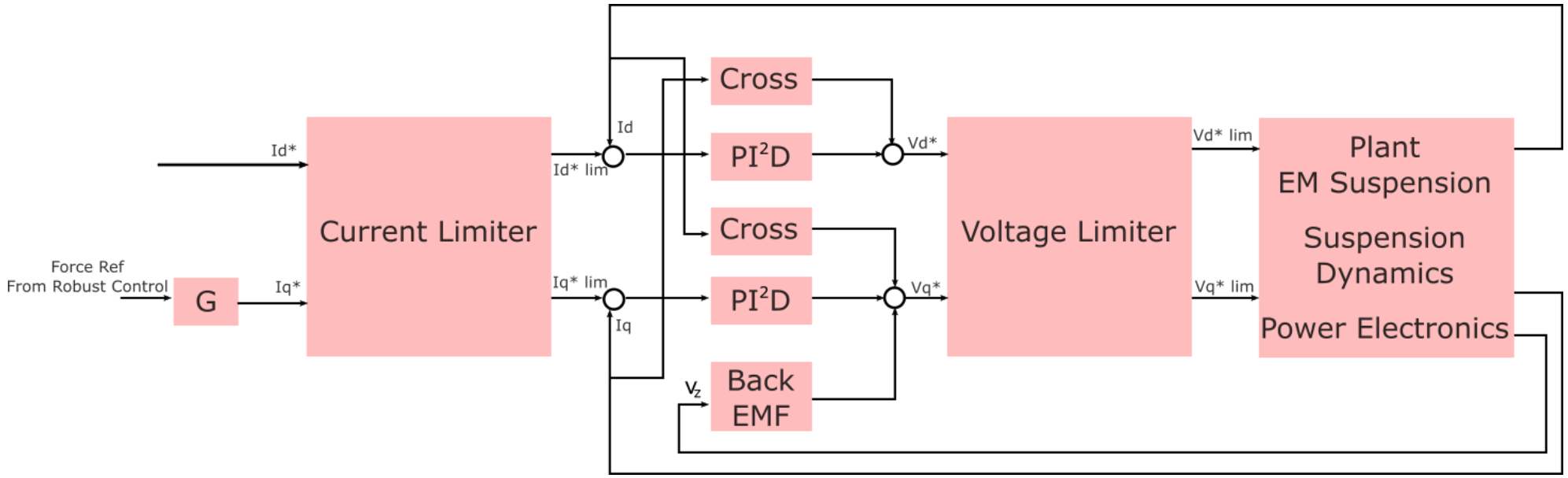
$r_{pu} = 1.0535$ $r_{su} = 1.1566$

- To keep the performance,

We can increase the uncertainty set up to 5 %

- For the system stability, we should not increase the uncertainty set more than 15%

Power Electronics Control



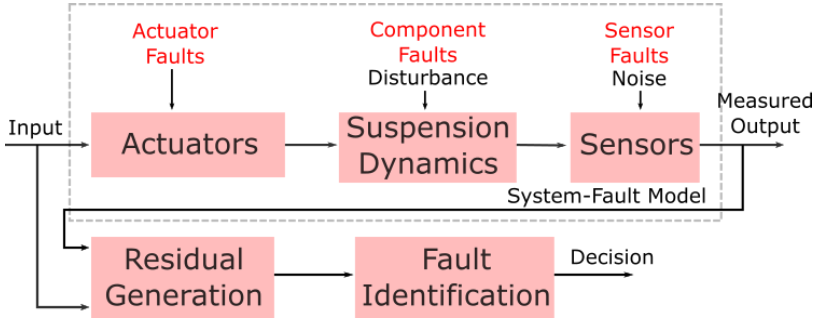
Proportional-Double Lag-Lead Controller → Represent the Power Electronics and EM Suspension as the 3rd order filter

Current Limiter → $\sqrt{I_d^2 + I_q^2} = I_s$ →Power Electronics Limitation

Voltage Limiter → $\sqrt{V_d^2 + V_q^2} = \frac{V_{dc}}{\sqrt{3}}$ →DC Bus Limitation and SVM limitation

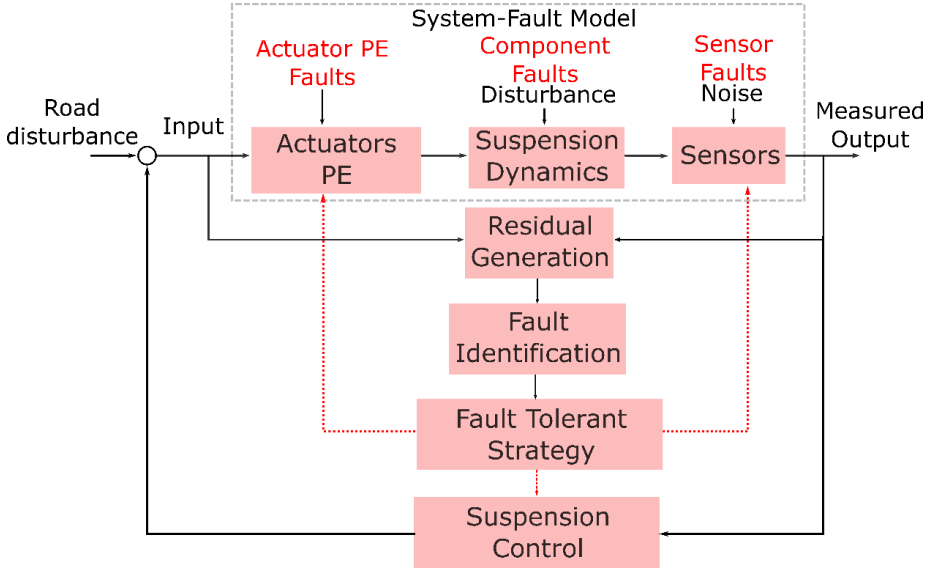
Assume → quasi-halbach array (Ld=Lq)

Fault Detection and Identification – Fault Tolerant



Main Objectives

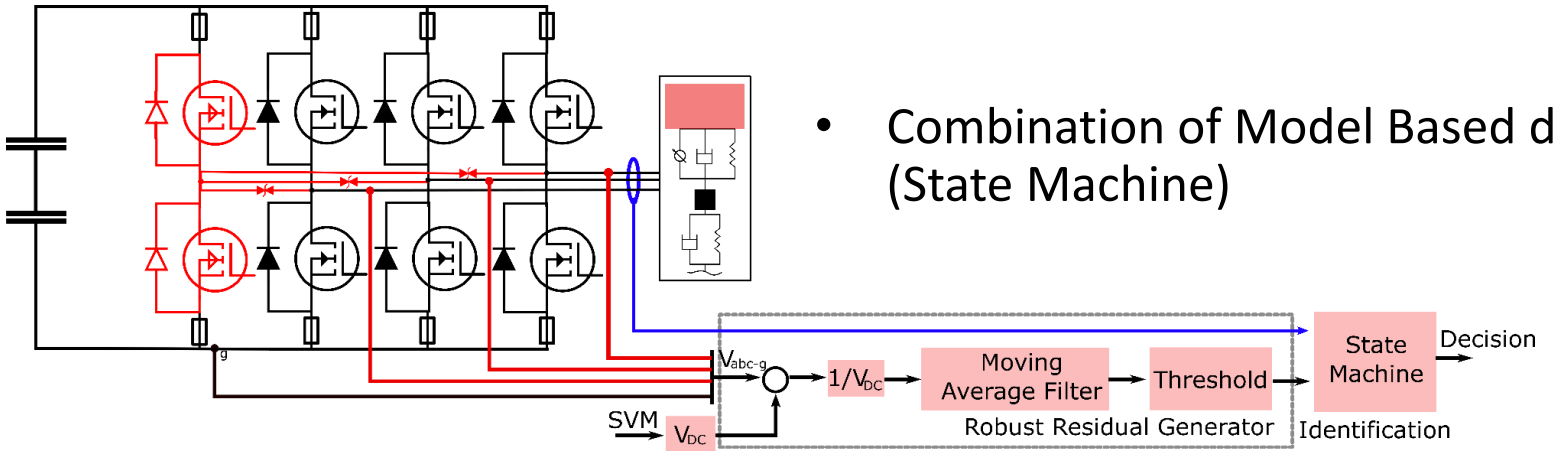
Fast detection based on the **Model-based approach**



Main Objectives

Realize a **partial performance** of comfort **safety** as the main goals

Fault Detection and Identification



- Combination of Model Based detector with Truth Table (State Machine)

Truth Table

Case	D1	D2	D3	D4	D5
> K_{th}	F	-	T	T	-
< -K_{th}	F	T	-	-	T
2nd Flag	-	F	F	T	T

- K_{th} is the Threshold limit in the positive and negative side
- 2nd Flag is the flag when the d(t)-d(t-1) is larger than threshold

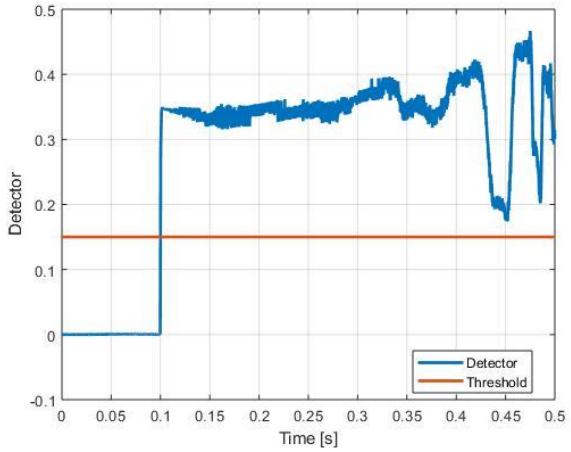
Legend
D1 → Normal
D2 → open M+
D3 → open M-
D4 → short M+
D5 → short M-

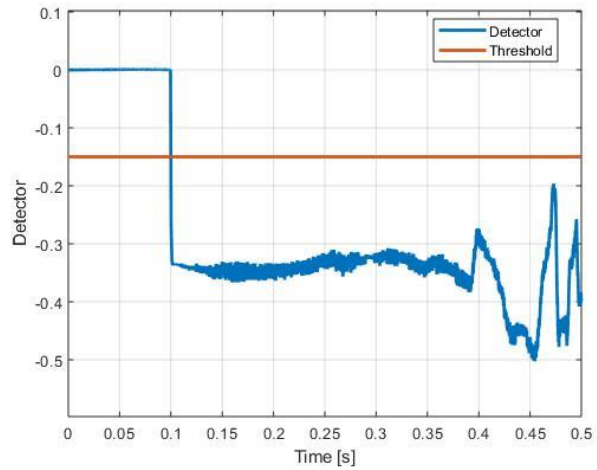
Fault Detector Performance

M+

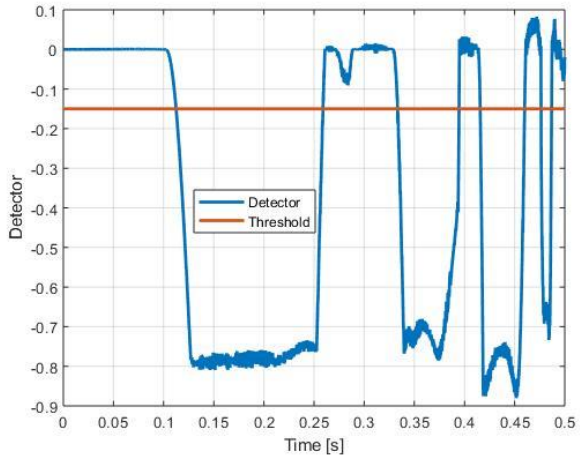
M-

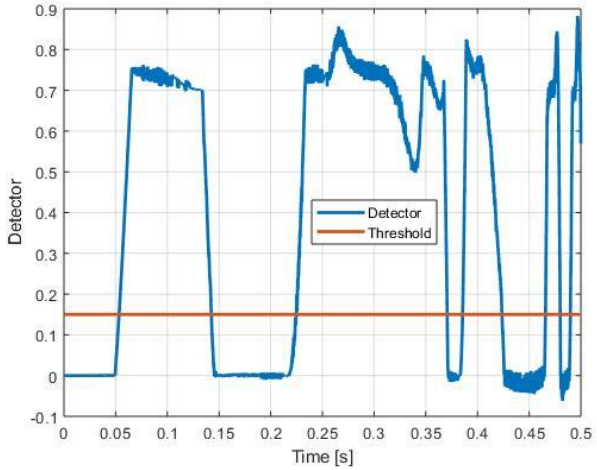
Short Circuit



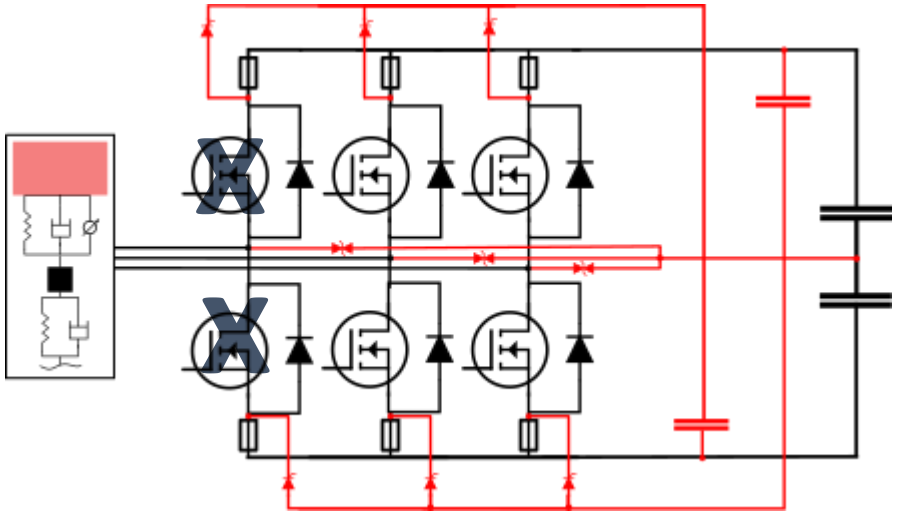


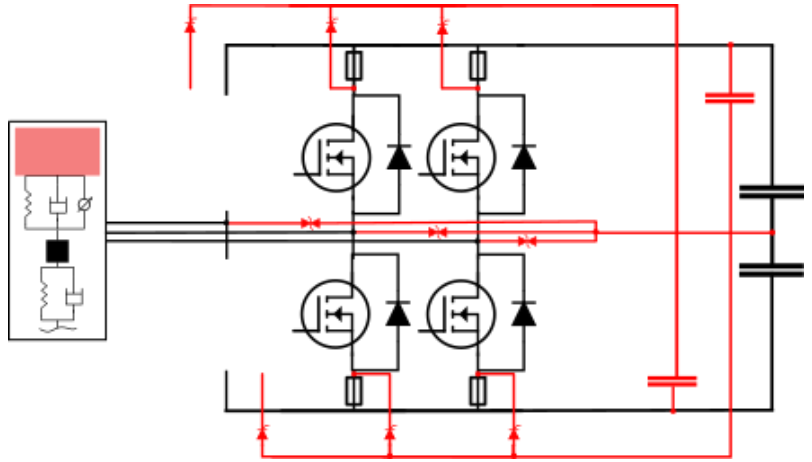
Open Circuit

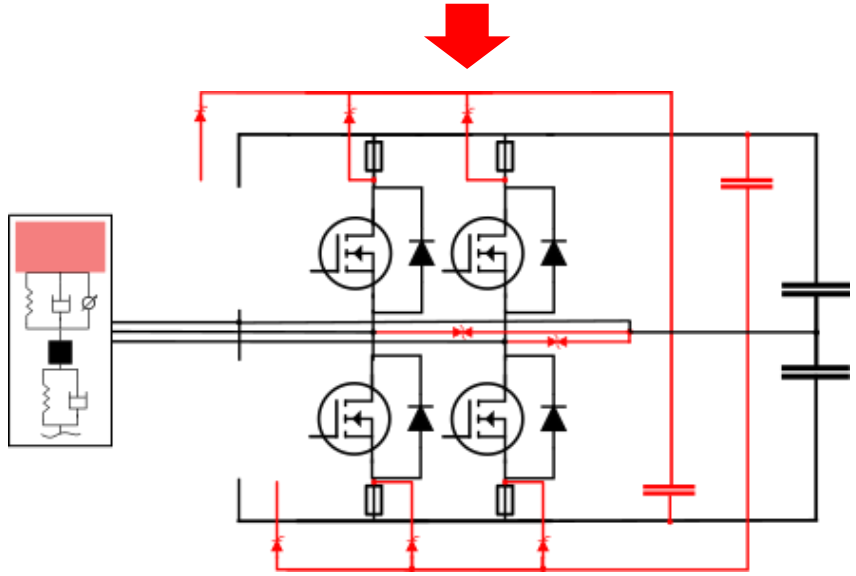




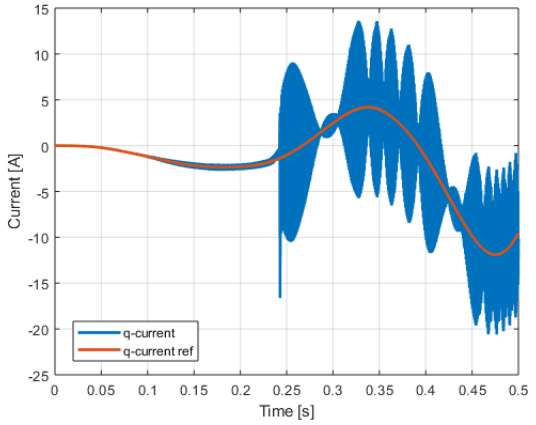
Power Converter Reconfiguration



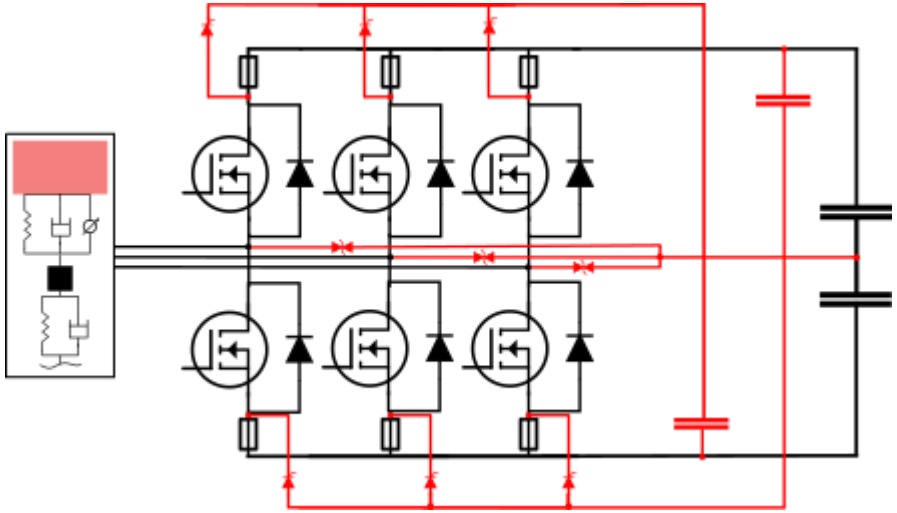


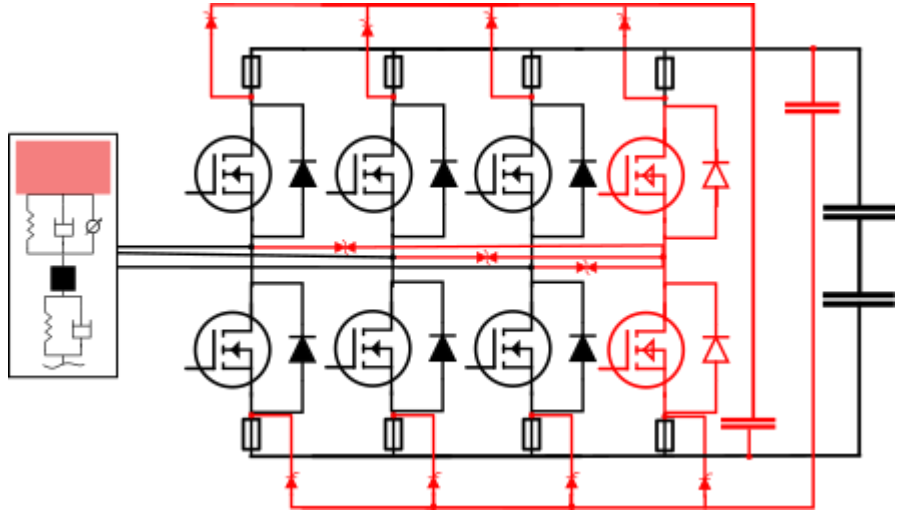


Q-Axis Reference and Actual Current

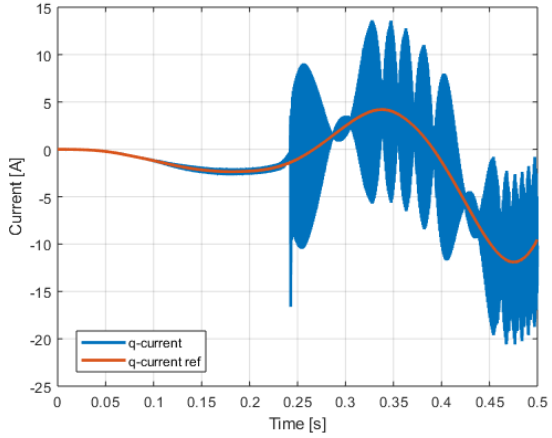


Power Converter Reconfiguration

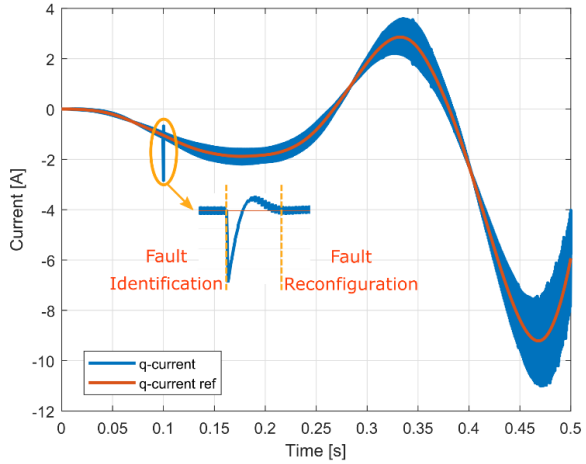




- Split Capacitor for compensating phase loss
- Same Controller, SVM reconfiguration



- 4th leg as Redundancy
- Same Controller



Conclusion

- Electromagnetic Active Suspension can replace the Passive Suspension for increasing safety and system comfort.
- Due to additional complexity, fault-tolerant operation is needed
- The main cause of failure is bond-wire semiconductor and aluminum electrolyte capacitor
- Model-Based Fault Detection and Identification can quickly detect and isolate the fault in the system

Future Step to Investigate

- Reconfiguration of 4 suspension corner control during fault

Contactgegevens

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