ESTECO
INTERNATIONAL
USERS' MEETING

um
2026

Sensitivity Analysis of High-Frequency System-Level Model of Electric Drivetrain for Accurate Common Mode Voltage and Bearing Current Prediction

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PhD Researcher

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Post-Doc Researcher

GHENT UNIVERSITY

ESTECO
INTERNATIONAL
USERS' MEETING

Agenda

Overview of Ghent University

Motivation

Overview of an Electric Drivetrain and Bearing Current

High-Frequency Modelling of Electric Drivetrain

Sensitivity Analysis of Electric Drivetrain

Conclusions

Demo

GHENT
UNIVERSITY

GHENT UNIVERSITY

- → Top 100 university
- → Since 1817
- → 11 faculties

BELGIUM

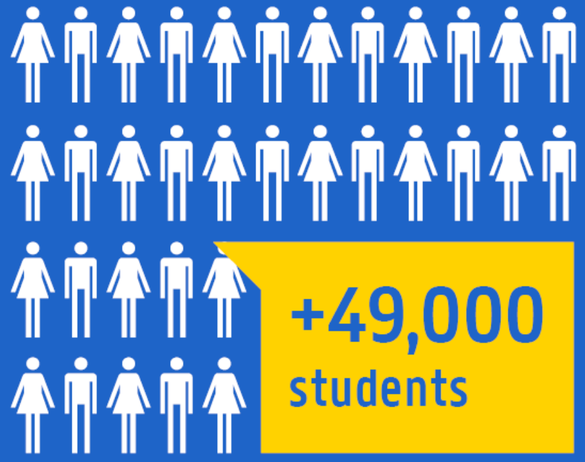
SOUTH KOREA

GHENT UNIVERSITY
GLOBAL CAMPUS

The 1st European university in Korea.

+200 programmes

64 English-taught master's programmes



2,000
Ghent University students abroad

6,000
Foreign students at Ghent University
(including exchange students)

DARE TO THINK

Our credo: critical and independent minds.

PLURALISM & PARTICIPATION

Open to everyone irrespective of ideological, political, cultural or social background.

SUSTAINABILITY

For a future that is ecologically, socially and economically sustainable, within a local global context.

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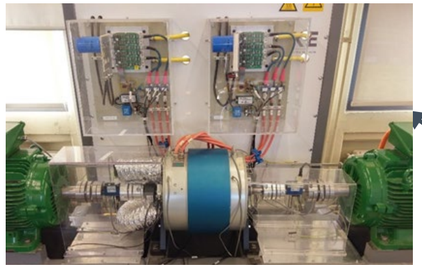
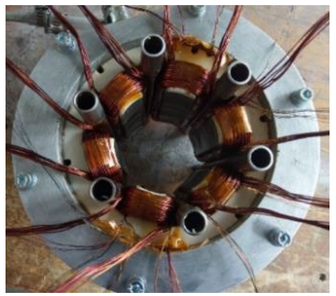
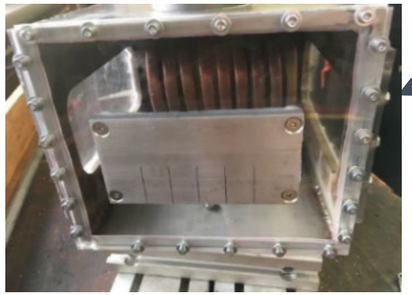
Ghent University Research in Motion Products





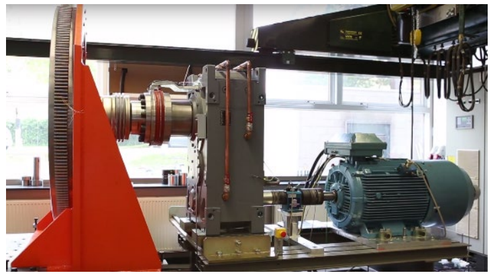


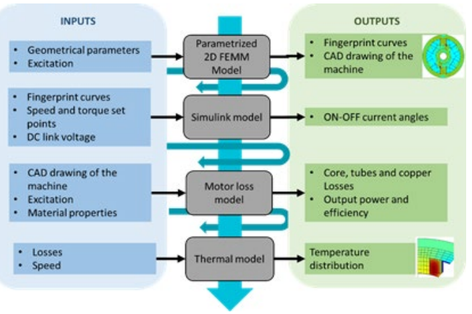
Electromechanical (novel) actuators: design + control

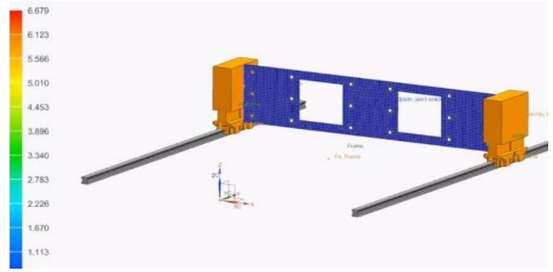
Multiphysical modelling, testing & validation of drive trains & their components

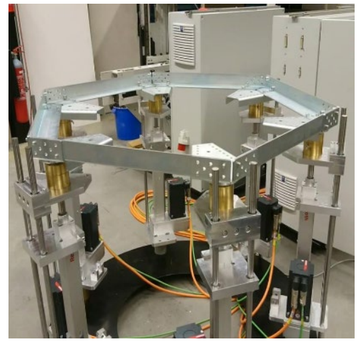
Cooling & Lubrication Thermal & energy management

Multiple-coordinated motion system design









FLANDERS MAKE
DRIVING INNOVATION IN MANUFACTURING

core lab MIRO

Flanders Make is the strategic research center for the manufacturing industry.

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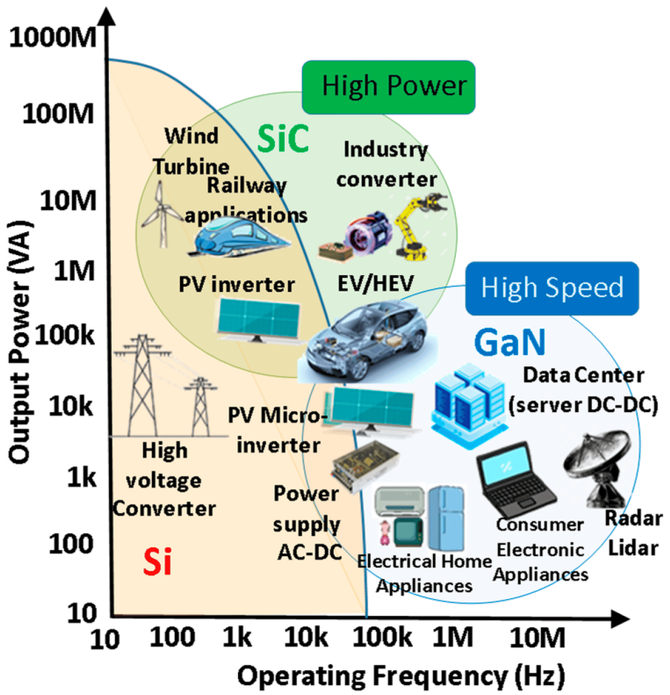
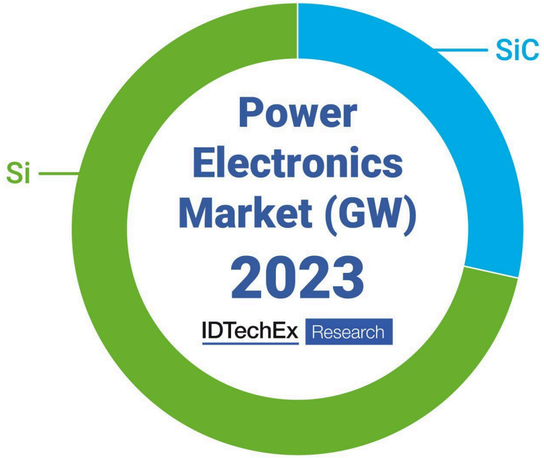
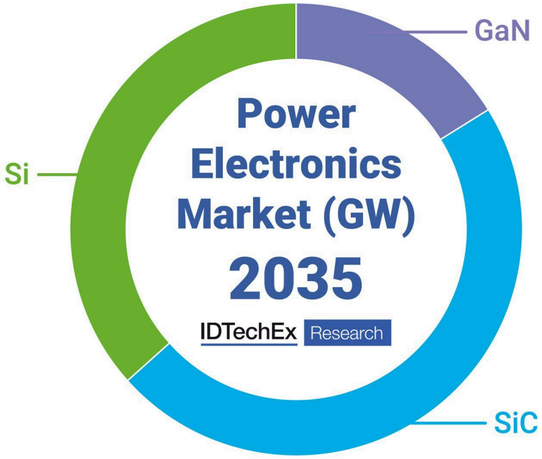
Motivation



Gallium Nitride Power Devices in Power Electronics Applications: State of Art and Perspectives





Power Electronics for Electric Vehicles 2025-2035: Technologies, Markets, and Forecasts

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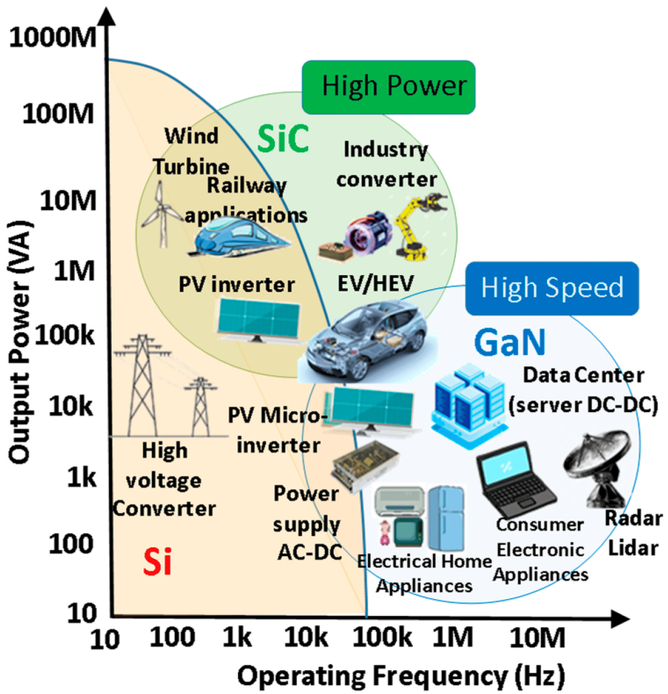
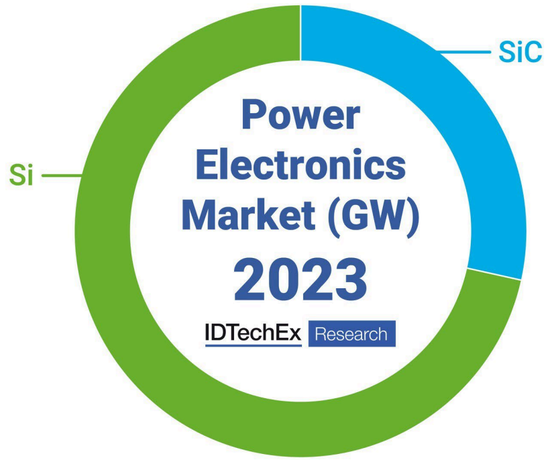
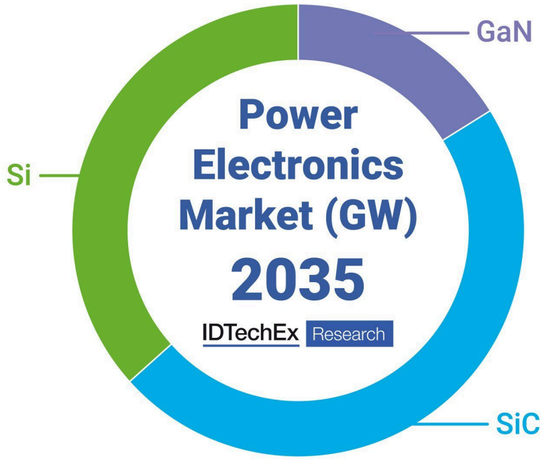
Motivation

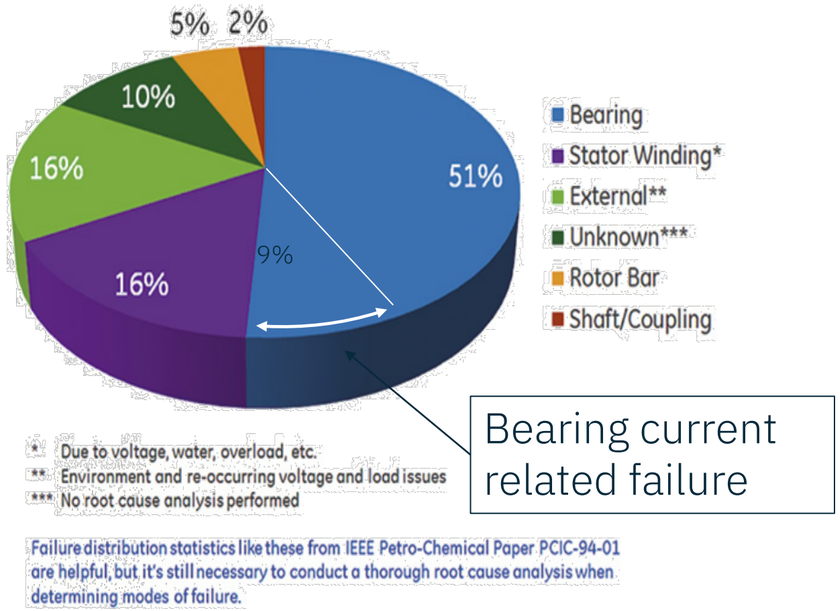


Gallium Nitride Power Devices in Power Electronics Applications: State of Art and Perspectives





Power Electronics for Electric Vehicles 2025-2035: Technologies, Markets, and Forecasts

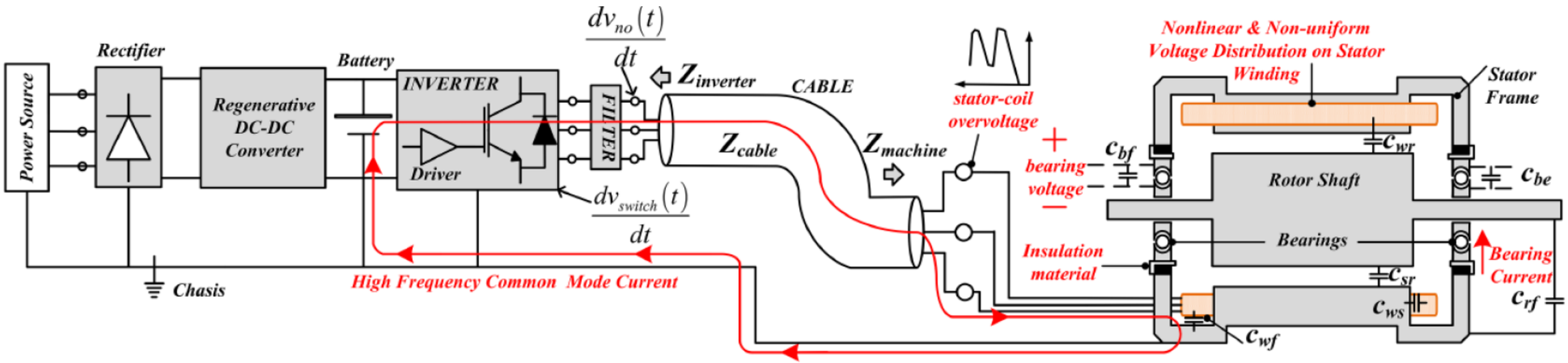


Bearing current related failure

Trend towards increased **DC link voltage** and **wide bandgap SiC and GaN** transistors with high dV/dt and high switching frequency

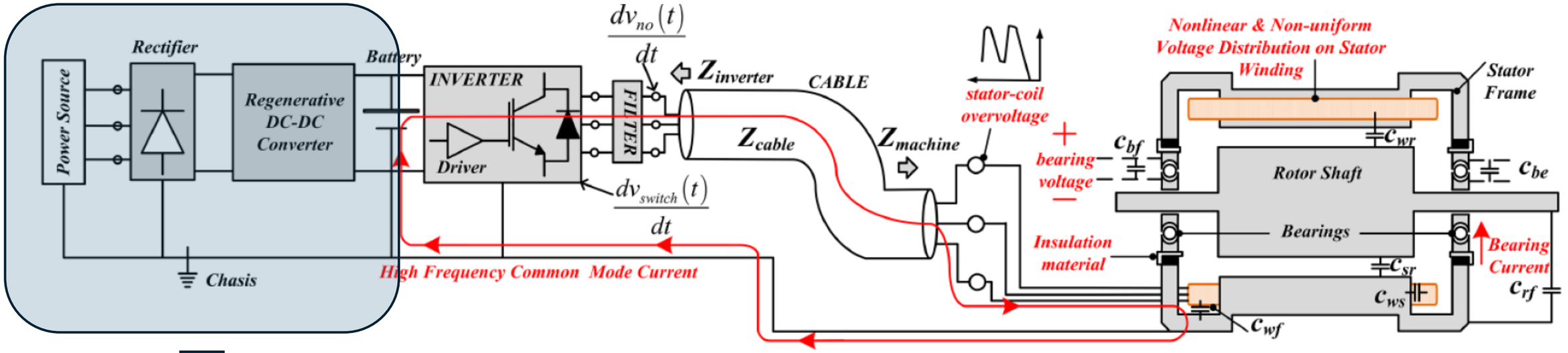
➢ increased risk on bearing damage

Overview of Electric Drivetrain and Bearing Currents



M. Asefi, J. Nazarzadeh, “Survey on high-frequency models of PWM electric drives for shaft voltage and bearing current analysis,” *IET Electr. Syst. in Transport.,* Vol. 7, No. 3, pp. 179-189, 2017.

Overview of Electric Drivetrain and Bearing Currents



Grid/battery

M. Asefi, J. Nazarzadeh, “Survey on high-frequency models of PWM electric drives for shaft voltage and bearing current analysis,” *IET Electr. Syst. in Transport.,* Vol. 7, No. 3, pp. 179-189, 2017.

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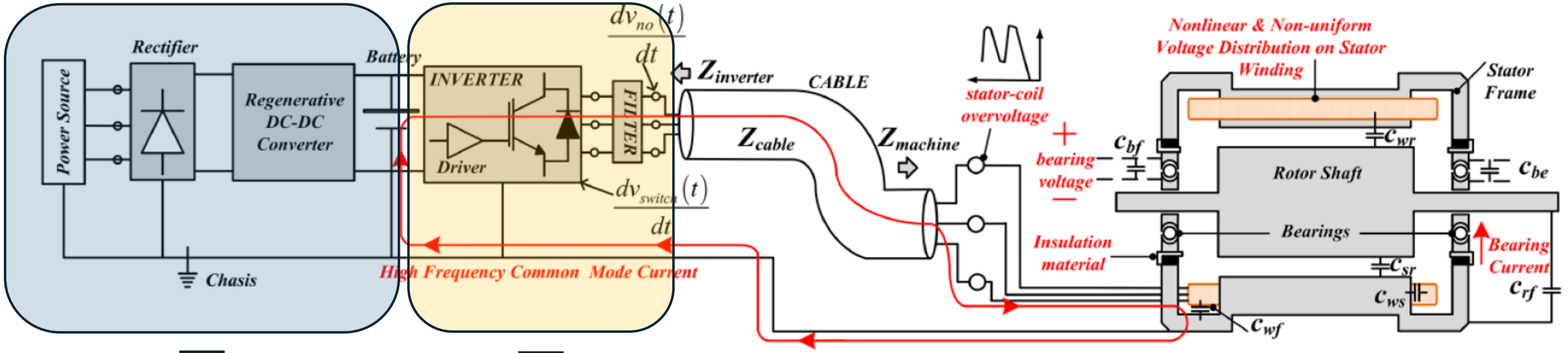

Grid/battery

Power Electronics

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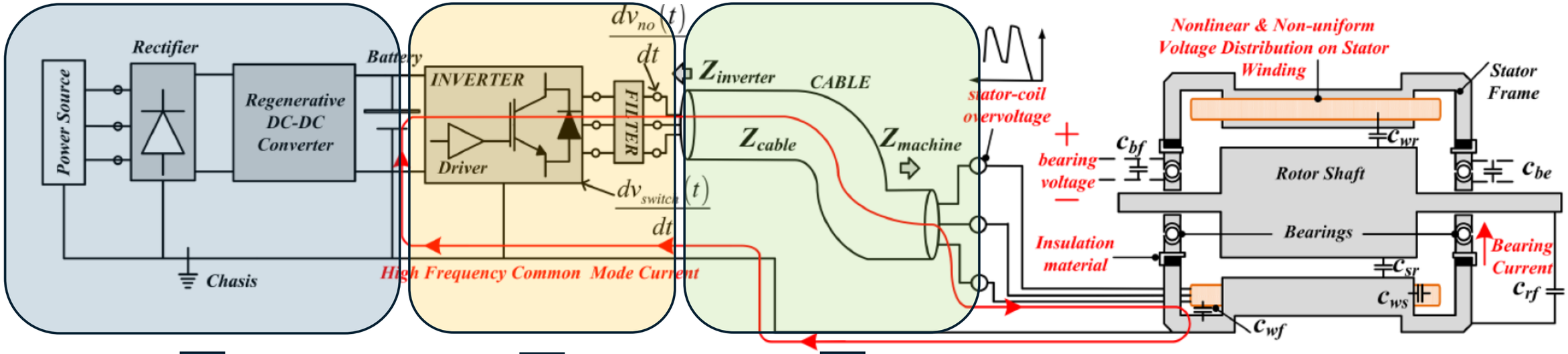


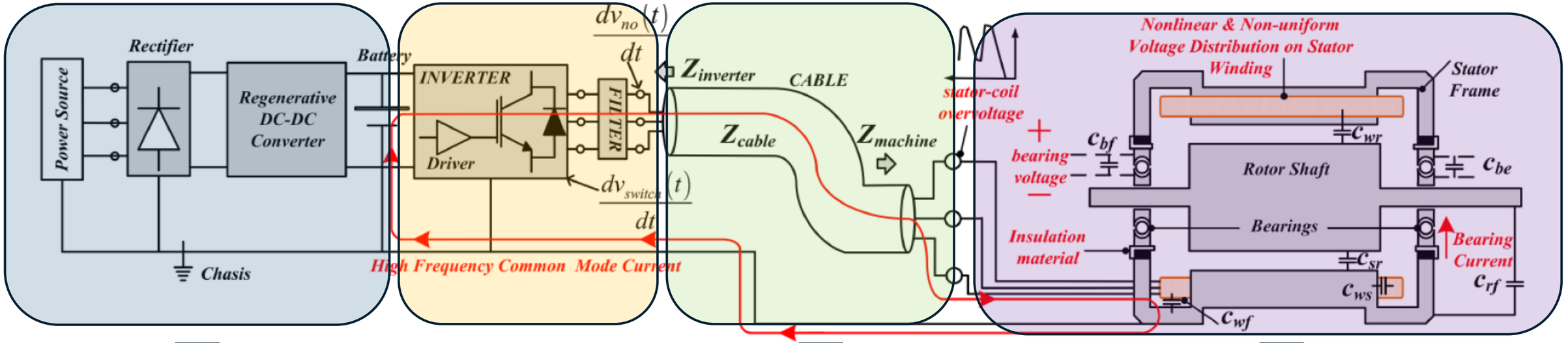
Grid/battery

Power Electronics

Cable

M. Asefi, J. Nazarzadeh, “Survey on high-frequency models of PWM electric drives for shaft voltage and bearing current analysis,” *IET Electr. Syst. in Transport.,* Vol. 7, No. 3, pp. 179-189, 2017.

Overview of Electric Drivetrain and Bearing Currents



Grid/battery

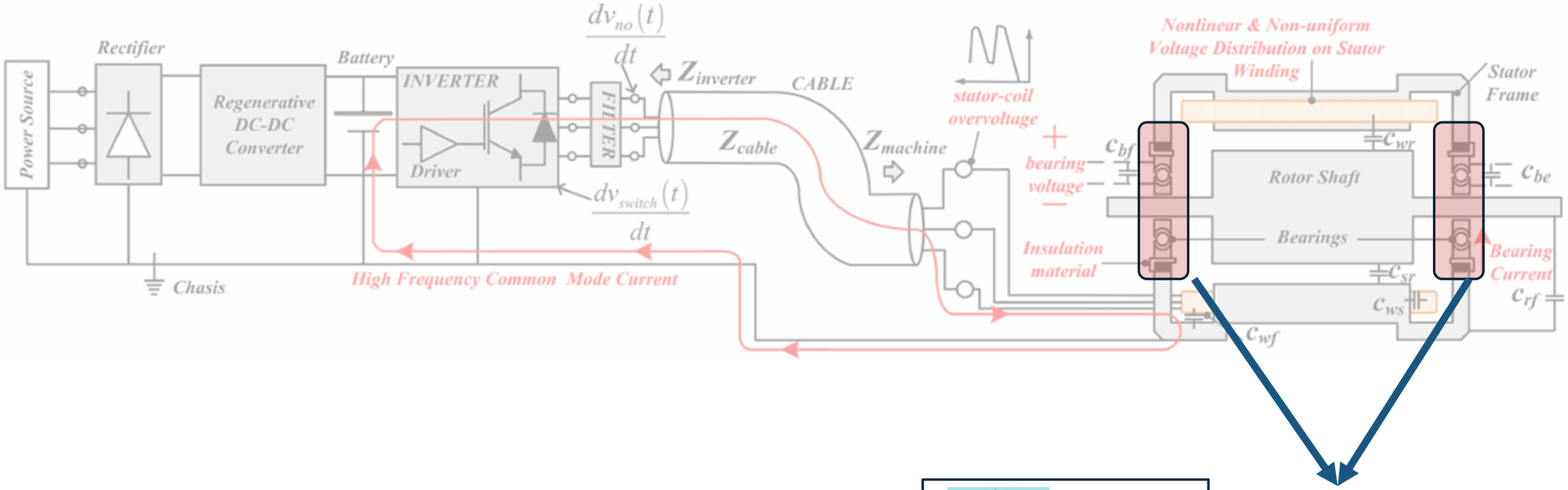
Power Electronics

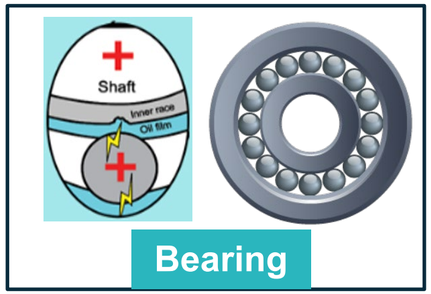
Cable

Electric Motor

M. Asefi, J. Nazarzadeh, “Survey on high-frequency models of PWM electric drives for shaft voltage and bearing current analysis,” *IET Electr. Syst. in Transport.,* Vol. 7, No. 3, pp. 179-189, 2017.

Overview of Electric Drivetrain and Bearing Currents

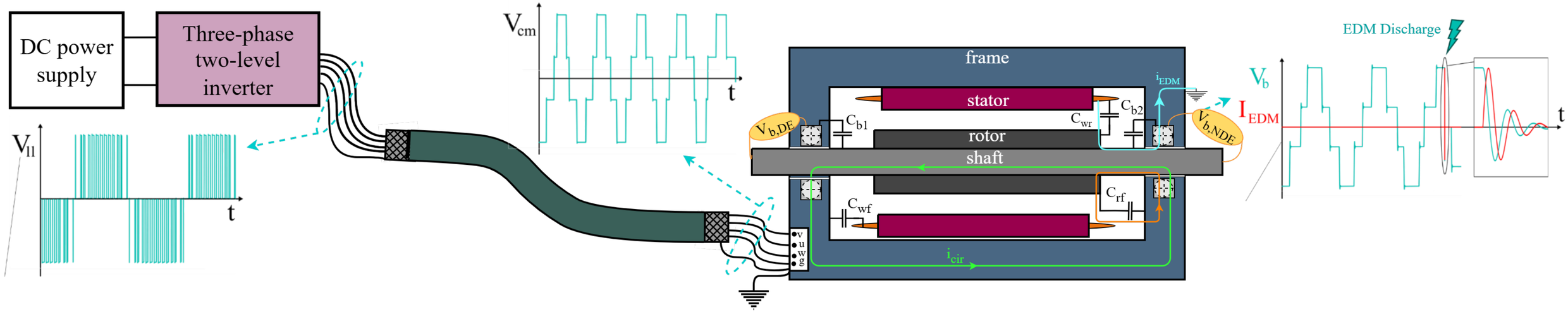




Bearings

M. Asefi, J. Nazarzadeh, “Survey on high-frequency models of PWM electric drives for shaft voltage and bearing current analysis,” *IET Electr. Syst. in Transport.,* Vol. 7, No. 3, pp. 179-189, 2017.

High-Frequency Modeling of Electric Drivetrain



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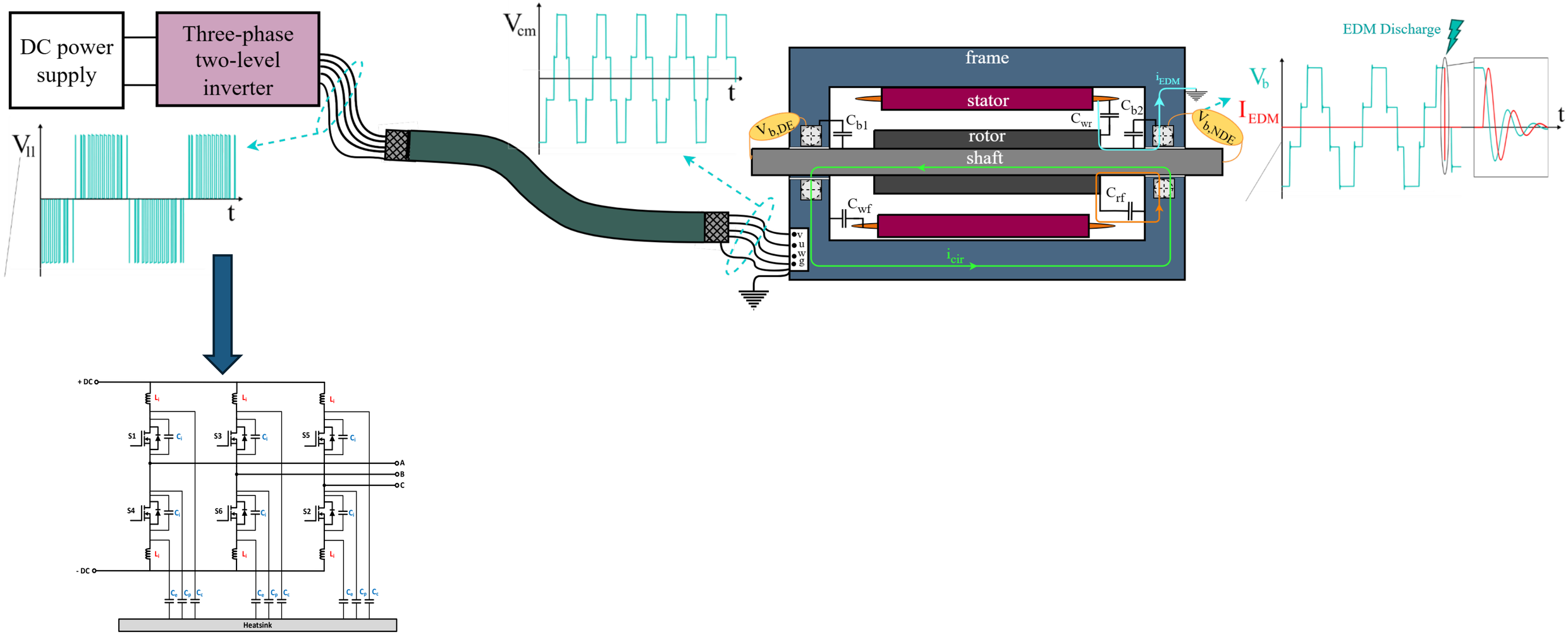

Power Electronics

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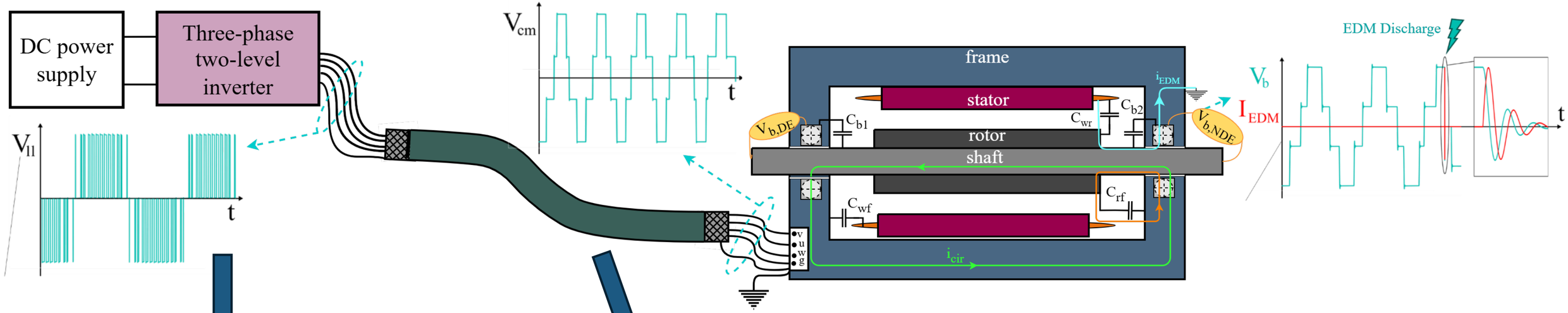
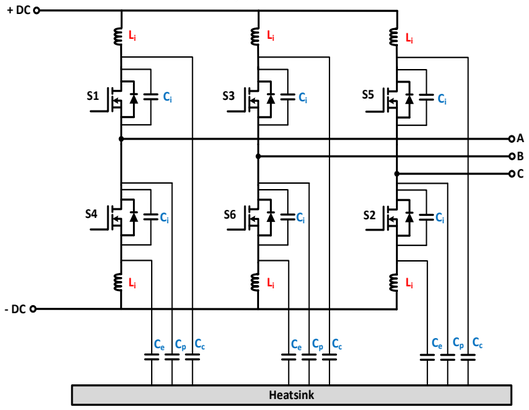
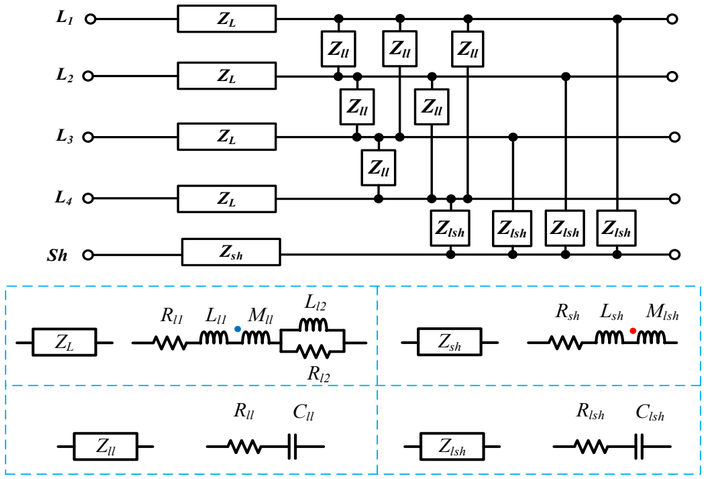
High-Frequency Modeling of Electric Drivetrain



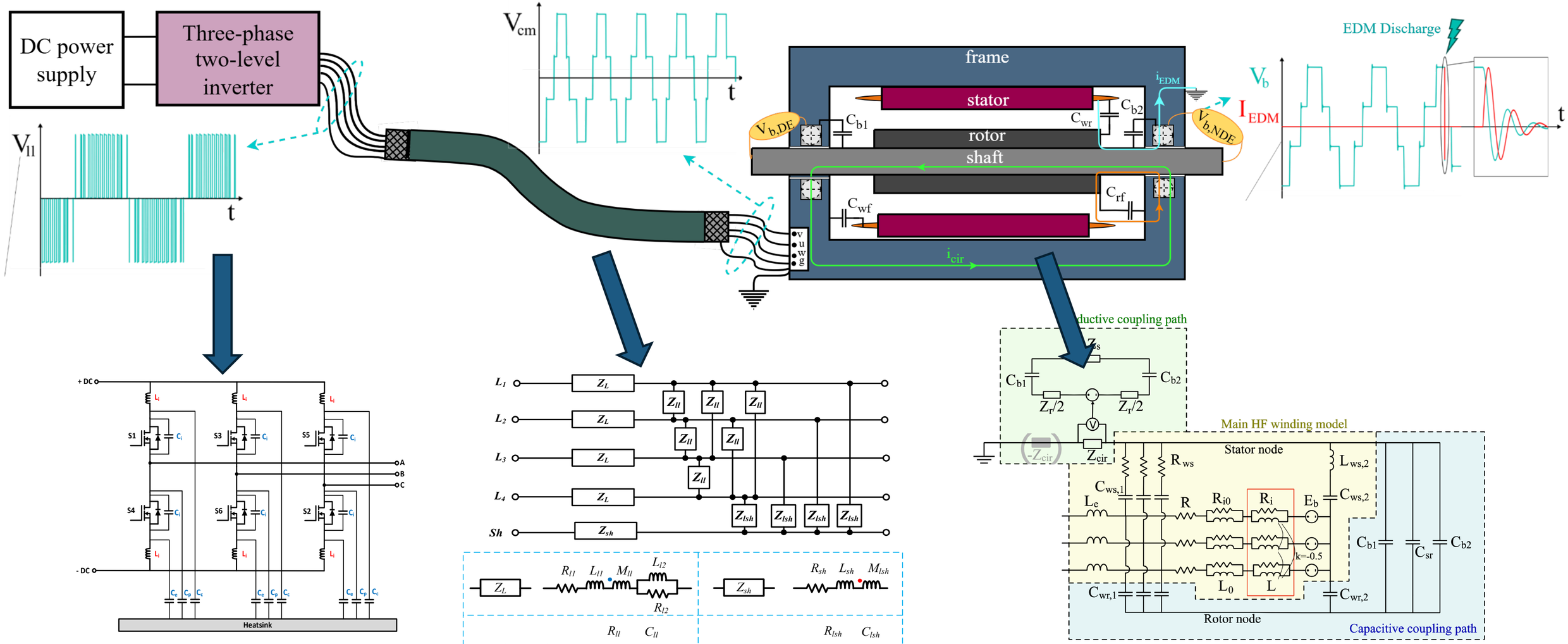


Power Electronics



Cable

High-Frequency Modeling of Electric Drivetrain

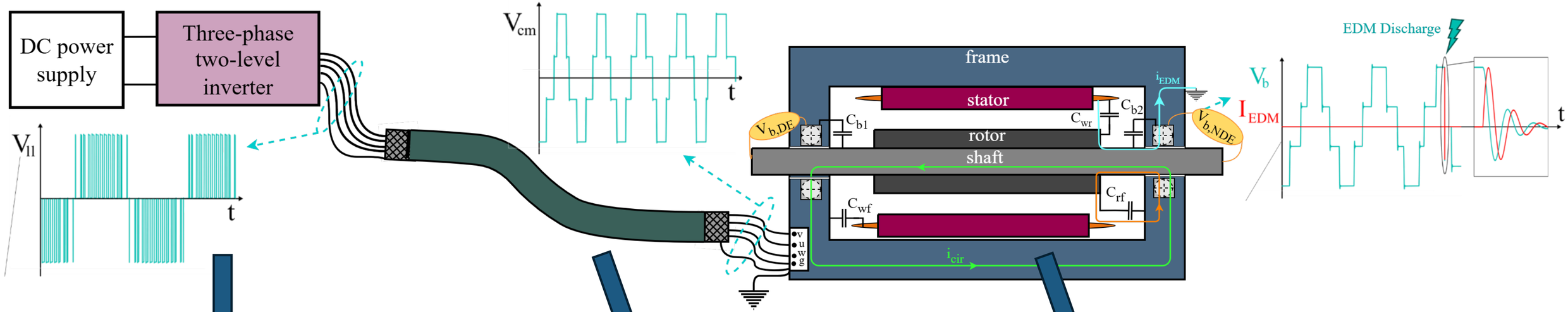


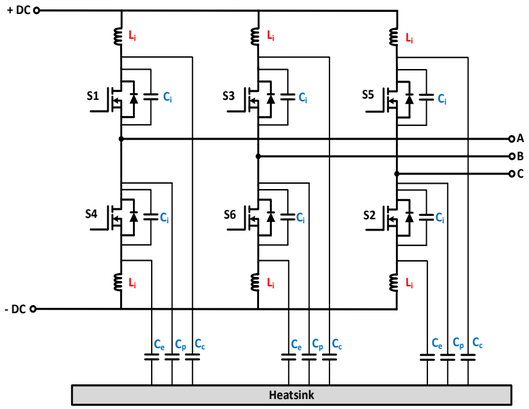
Power Electronics

Cable

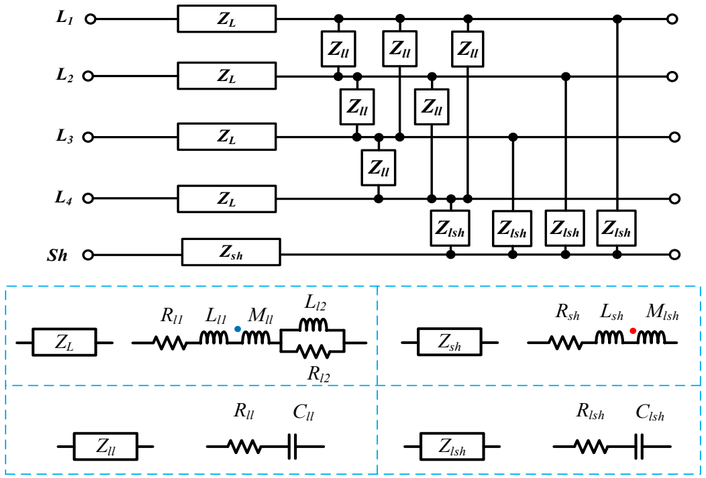
Electric motor

High-Frequency Modeling of Electric Drivetrain





Power Electronics



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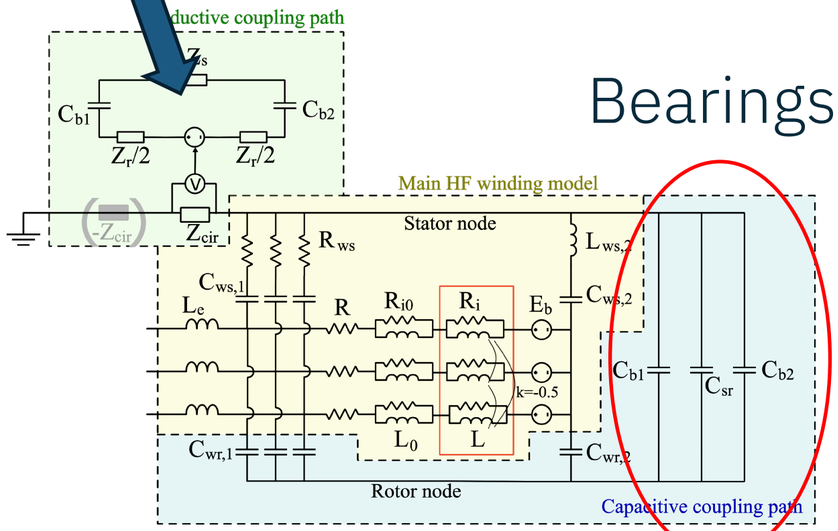

Bearings

Electric motor

Sensitivity Analysis of Electric Drivetrain

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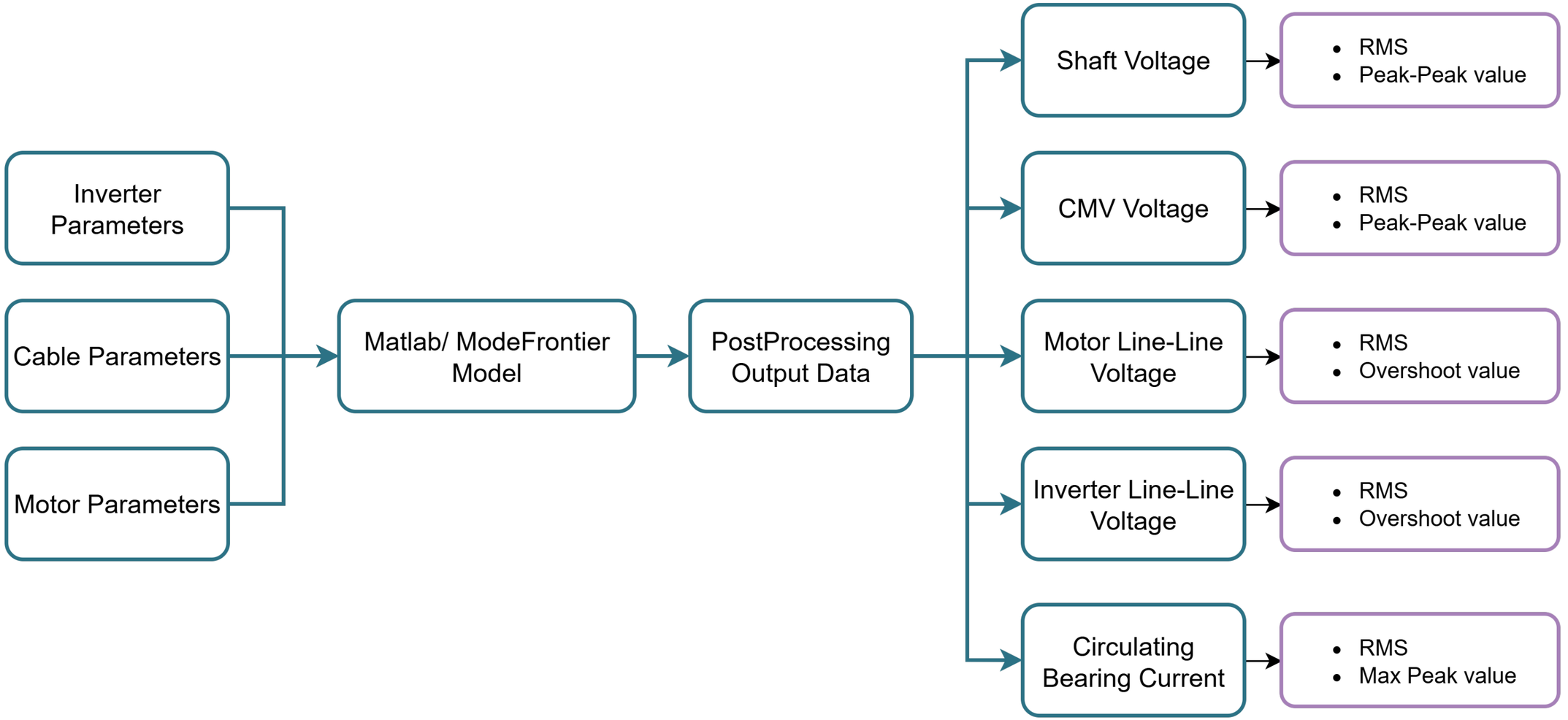
Sensitivity Analysis of Electric Drivetrain



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Sensitivity Analysis of Electric Drivetrain

Inverter Parameters

Cable Parameters

Motor Parameters

Matlab/ ModeFrontier Model

PostProcessing Output Data

- Shaft Voltage
  - RMS
  - Peak-Peak value
- CMV Voltage
  - RMS
  - Peak-Peak value
- Motor Line-Line Voltage
  - RMS
  - Overshoot value
- Inverter Line-Line Voltage
  - RMS
  - Overshoot value
- Circulating Bearing Current
  - RMS
  - Max Peak value

Impedance analyser (Hioki RLC IM3536)
Magnitude and phase angle, Frequency sweep (4 Hz – 10 MHz)

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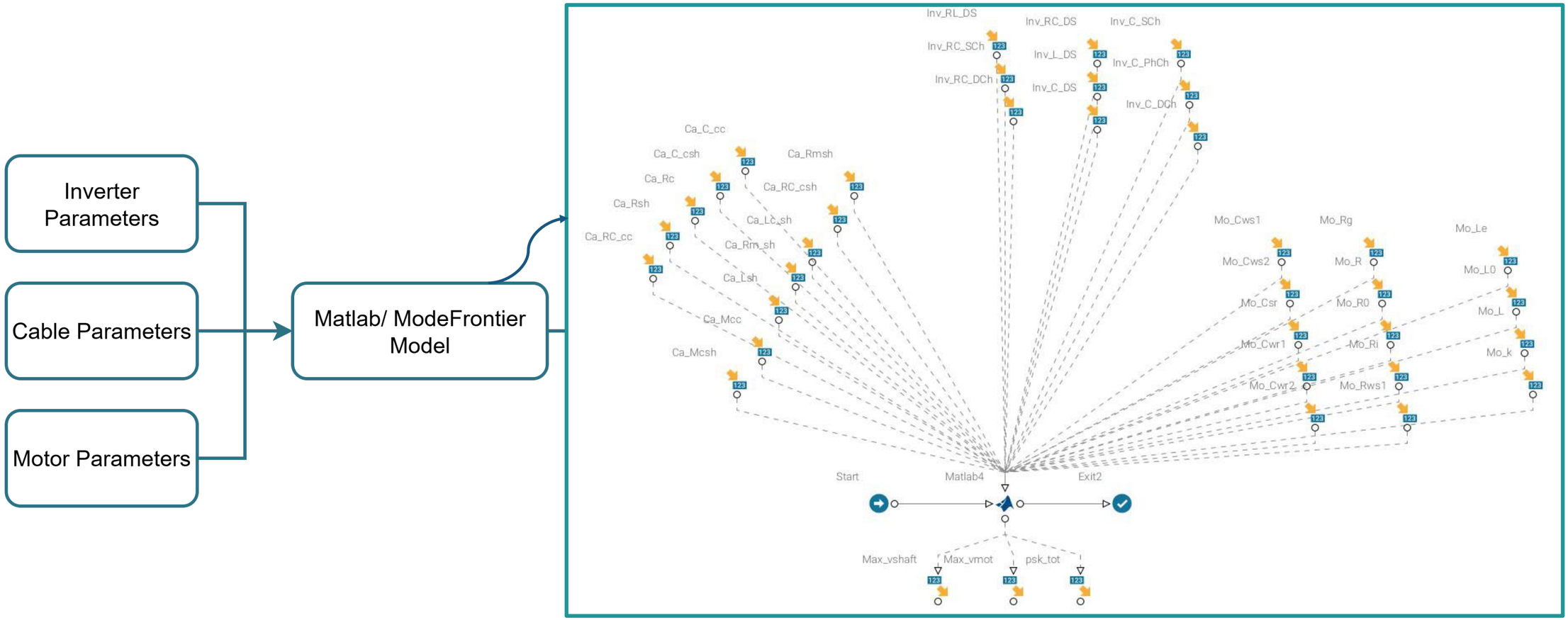
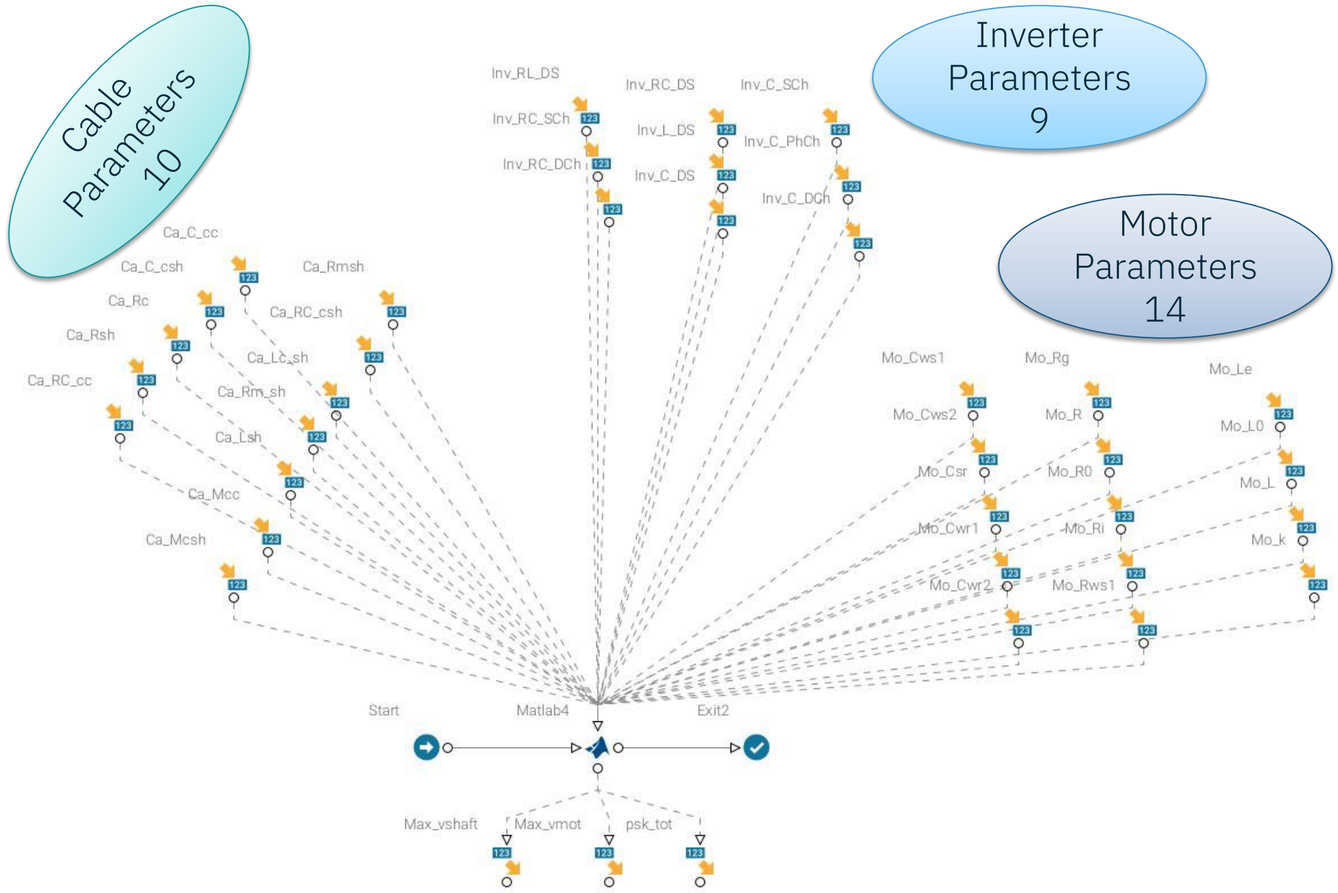
Sensitivity Analysis Using modeFrontier



Sensitivity Analysis Methodology:

- A sensitivity analysis was performed to identify the dominant parameters influencing the system-level model response.
- The complete model contains 33 parameters distributed across the inverter, motor, and cable subsystems.

- To isolate the contribution of each subsystem, the analysis was conducted three separate times:
  - Inverter study: inverter parameters varied while motor and cable parameters were fixed at measured values.
  - Motor study: motor parameters varied while inverter and cable parameters were fixed.
  - Cable study: cable parameters varied while inverter and motor parameters were fixed.

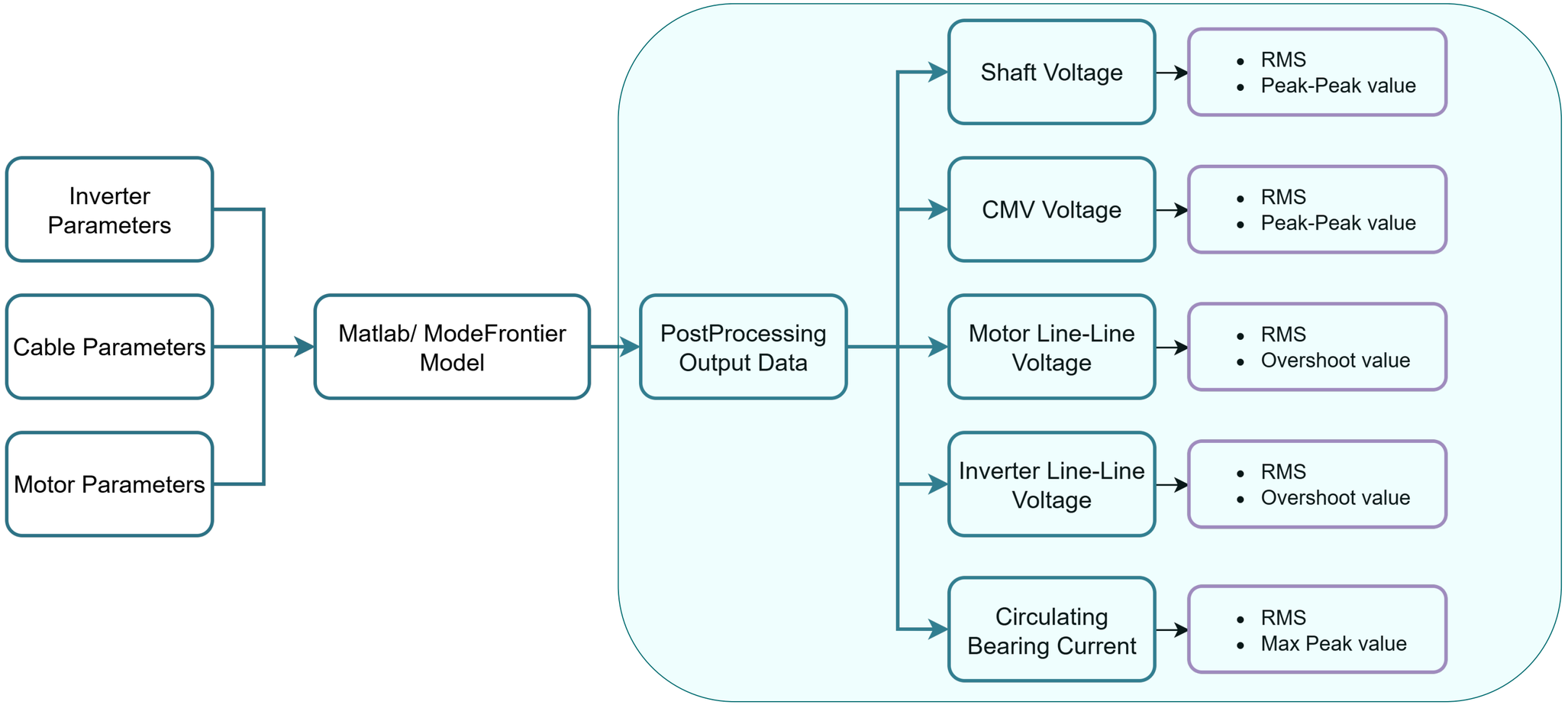


Sensitivity Analysis Methodology:

- For each study, a Design of Experiments (DOE) consisting of **2000 samples** was generated using Uniform Latin Hypercube (ULH) sampling.

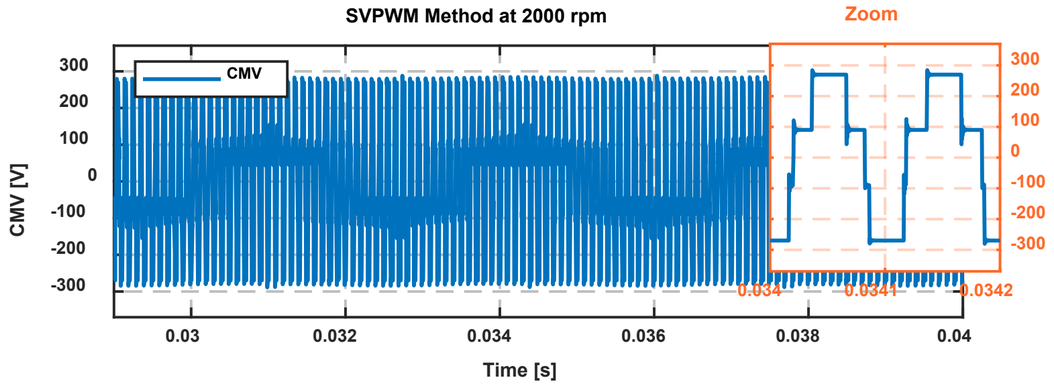
- Parameters were randomly varied within **±20% of their nominal values** while ensuring a uniform coverage of the design space and minimizing correlations between variables.

Post-Processing and Sensitivity Model Development

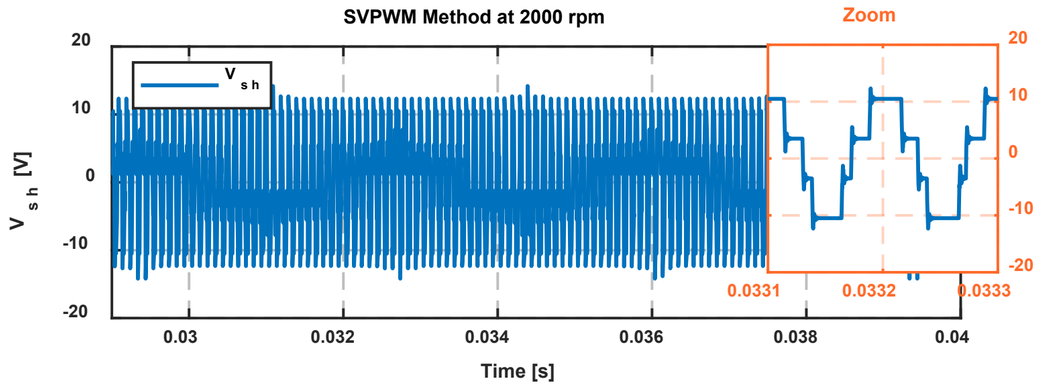


Results from HF Model for Each DOE:

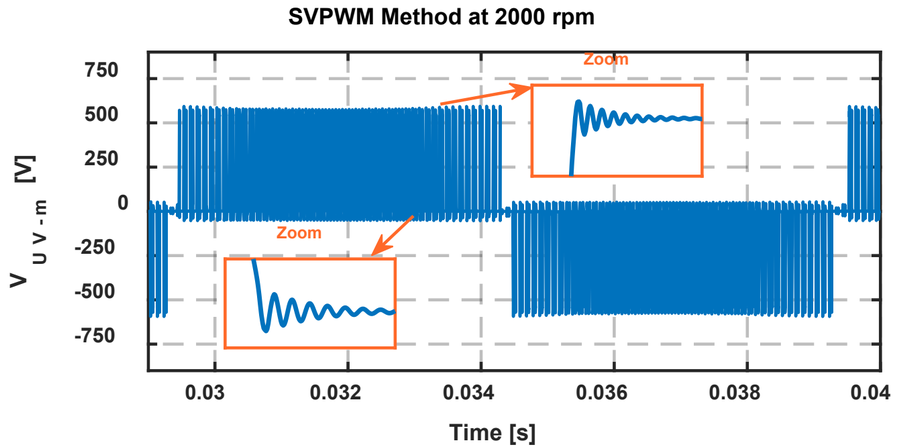
Common mode voltage



Shaft voltage



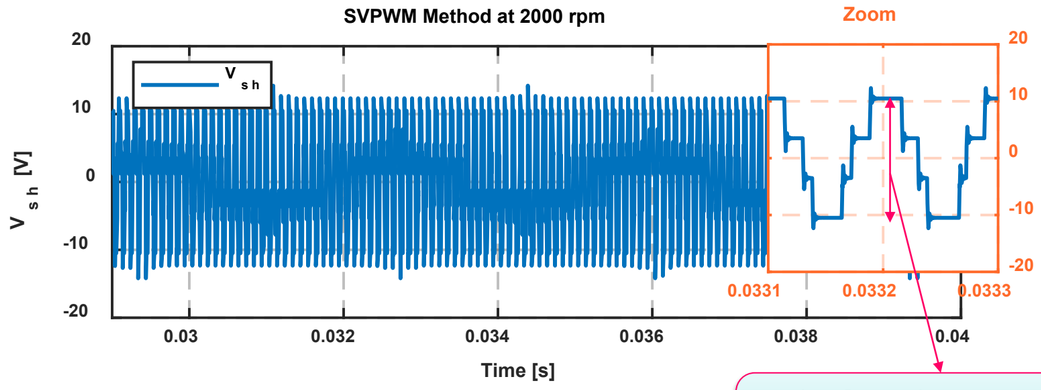
Motor line voltage



Post-Processing and Sensitivity Model Development

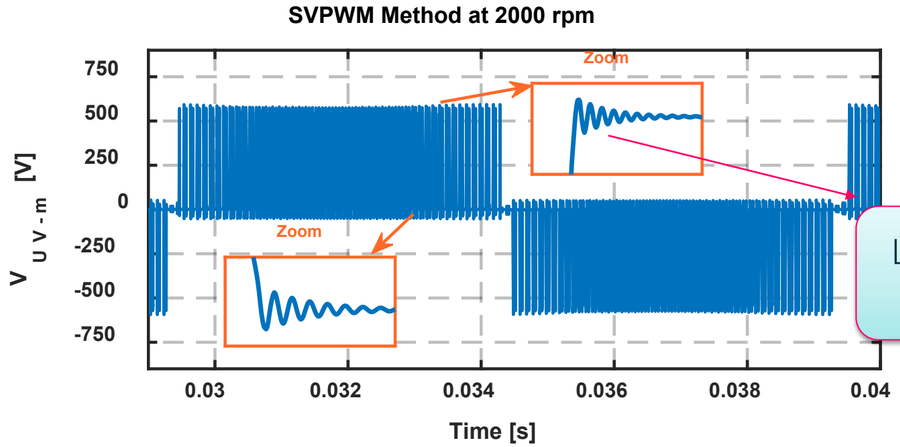
- A post-processing routine was developed to automatically extract the key output metrics from each DOE design
- The extracted outputs were returned to modeFRONTIER together with the corresponding input parameters.
- A Smoothing Spline ANOVA (SS-ANOVA) response surface model was trained for each output variable.
- SS-ANOVA was selected because it handles nonlinear relationships between inputs and outputs.
- The trained models were subsequently used to generate sensitivity charts and rank the influence of the design parameters.
- The predictive accuracy of all trained models was high, with $R^2 > 90\%$ for all output metrics.

Shaft voltage



Shaft Voltage Peak-Peak Value

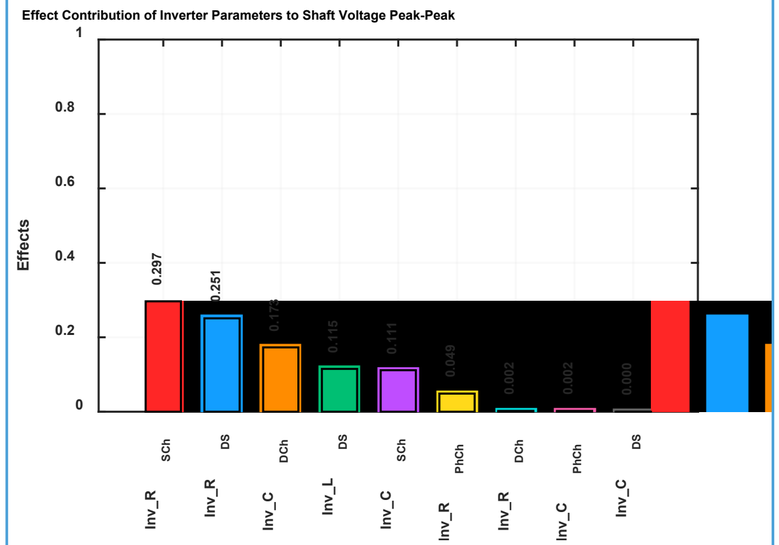
Motor line voltage



Line Voltage Overshoot

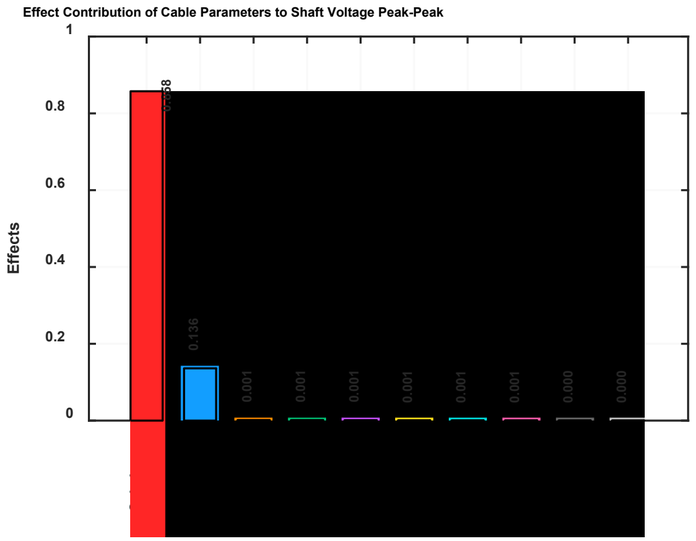
SENSITIVITY ANALYSIS OF SYSTEM PARAMETERS ON SHAFT VOLTAGE PEAK-PEAK VALUE:

Inverter



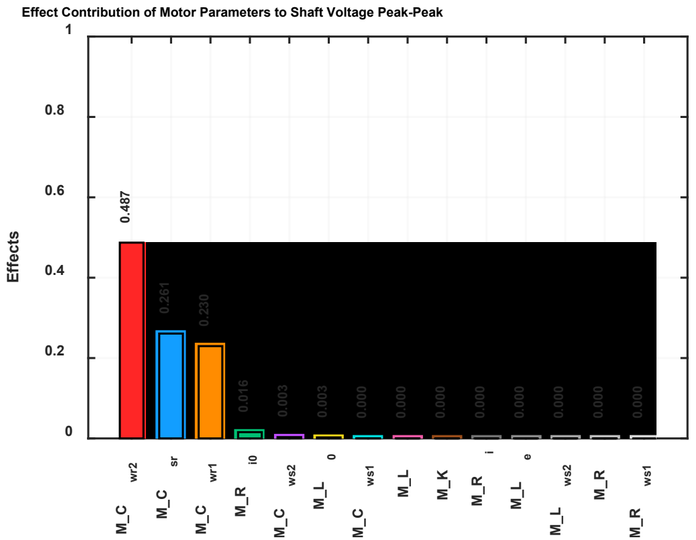
- Resistance from source to chassis
- Resistance from drain to source
- Resistance from drain to chassis
- Inductance from drain to source

Cable



- Inductance of conductor
- Shieled inductance

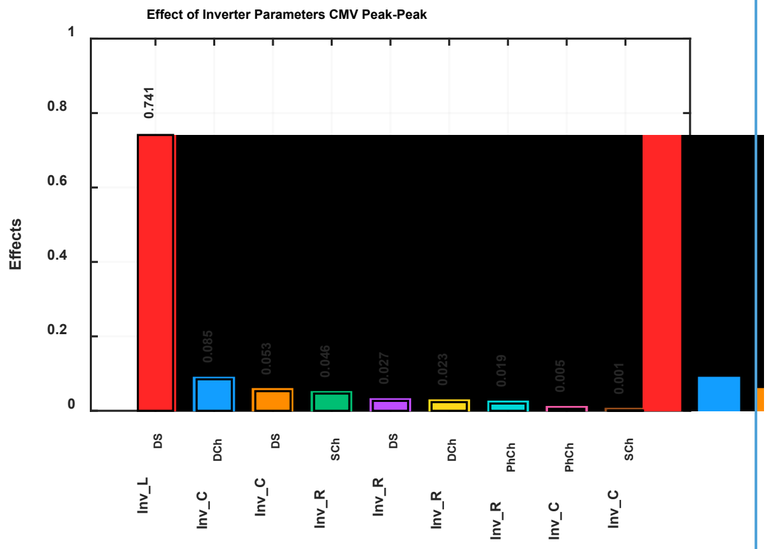
Motor



- Winding to rotor capacitances
- Stator to rotor capacitance

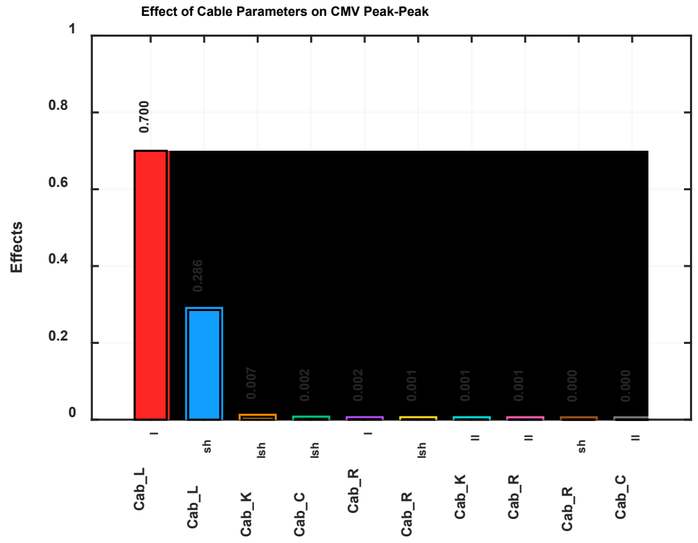
SENSITIVITY ANALYSIS OF SYSTEM PARAMETERS ON CMV PEAK-PEAK VALUE:

Inverter



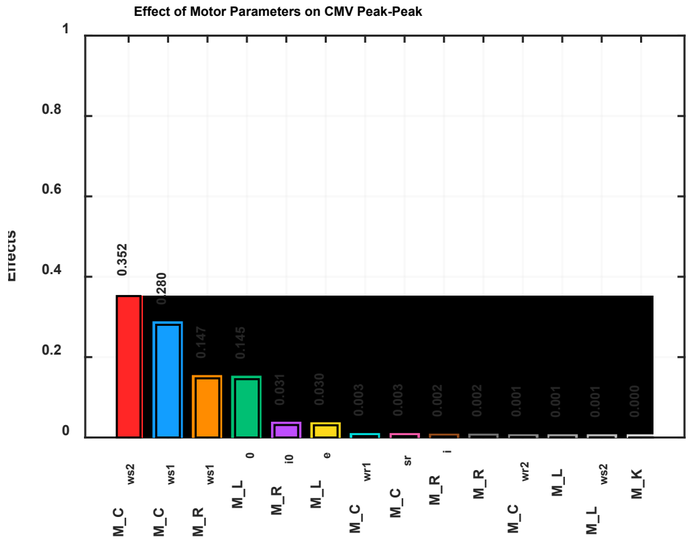
- Semiconductor switch parasitic inductance

Cable



- Inductance of conductor
- Shieled inductance

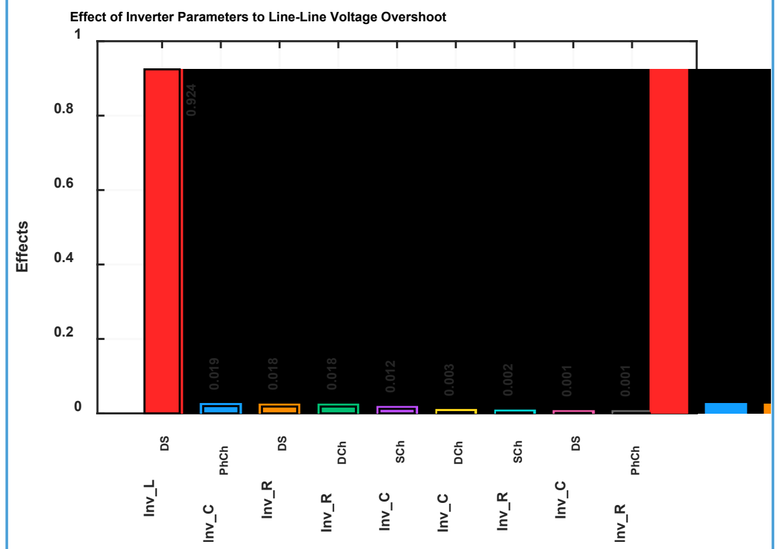
Motor



- Winding to stator capacitances.
- Winding to stator resistance

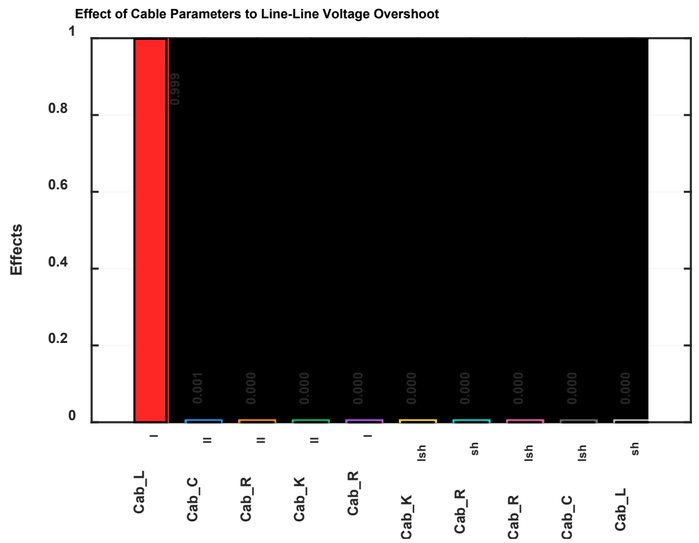
SENSITIVITY ANALYSIS OF SYSTEM PARAMETERS ON MOTOR LINE-LINE VOLTAGE:

Inverter



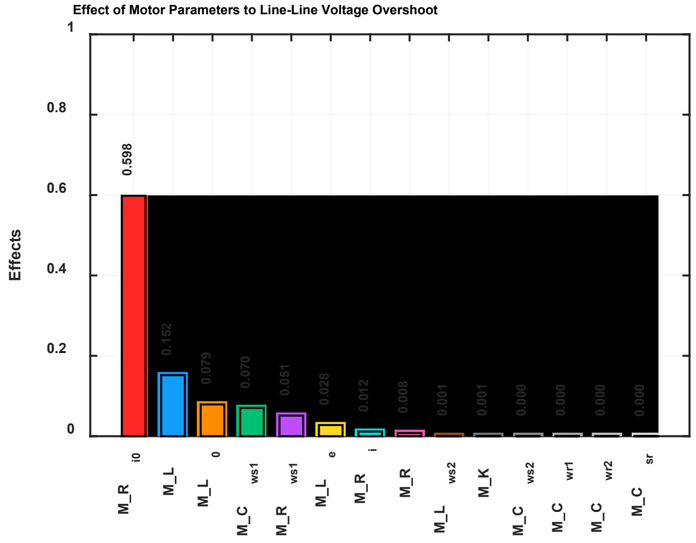
- Inductance from drain to source
- Parasitic capacitance from phase to chassis
- Parasitic resistance from drain to source

Cable



- Inductance of conductor
- Capacitance from line-line

Motor



- Corresponding iron loss resistance.
- Winding inductance
- Coupled inductance

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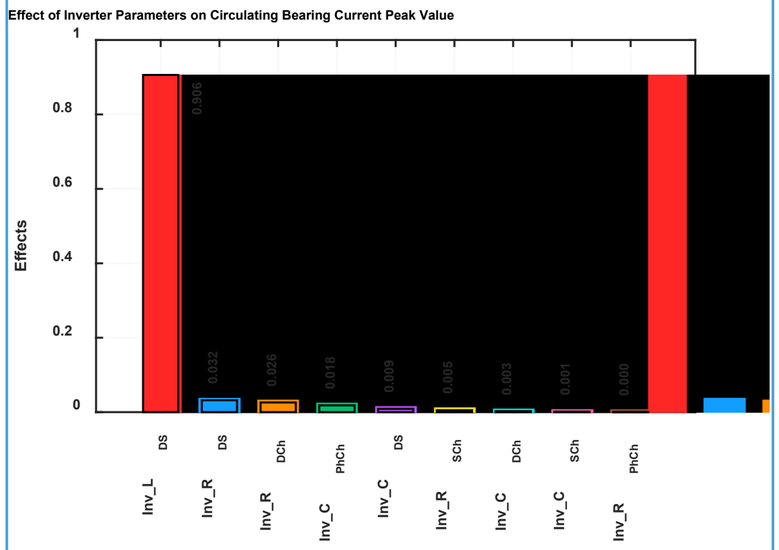
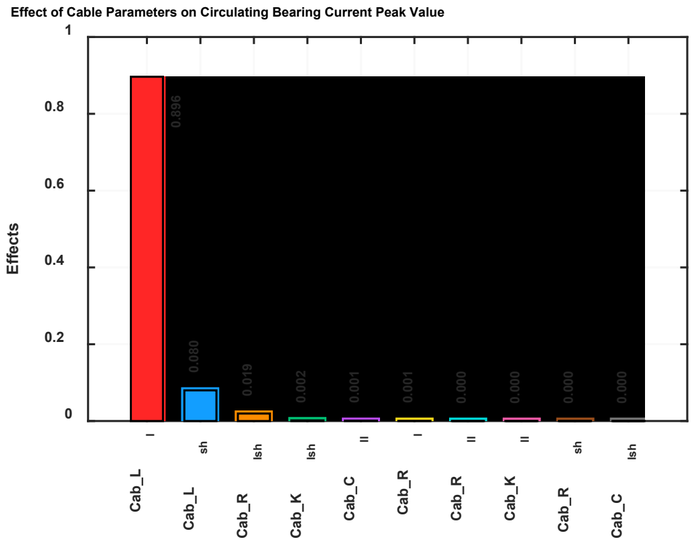
SENSITIVITY ANALYSIS OF SYSTEM PARAMETERS ON CIRCULATING BEARING CURRENT PEAK VALUE:

Inverter



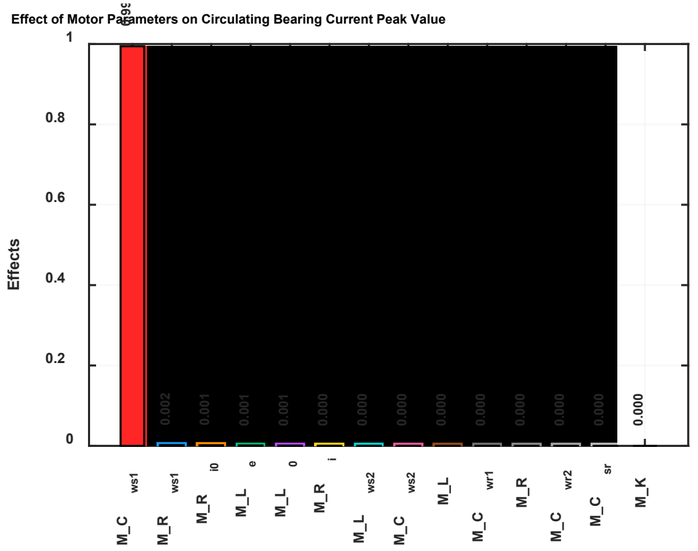
- Semiconductor switch parasitic inductance

Cable



- Inductance of conductor
- Shieled inductance

Motor



- Winding to stator capacitance

Conclusions

- The results show that the drivetrain high-frequency behavior is mainly dominated by:
  - **From the inverter side**, the most influential parameters are the semiconductor switch parasitic inductance.
  - **From the cable side**, the dominant factors are mainly: conductor inductance and shield inductance.
  - **From the motor side**, the dominant factors are mainly: Winding to stator capacitances and the inductance experienced by high-frequency components that capacitively bridge the winding inductance through Cws,1 and Cws,2.
- The analysis demonstrates that only a limited subset of parameters strongly affects CMV, shaft voltage, voltage overshoot, and bearing currents.
- Therefore, accurate prediction of high-frequency phenomena can be achieved by prioritizing the identification and modeling of these dominant parasitic parameters.

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Assessment tool for bearing current mitigation strategies

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Thank you

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