6TH INTERNATIONAL WORKSHOP ON GRID SIMULATOR TESTING OF WIND TURBINE POWER TRAINS AND OTHER RENEWABLE TECHNOLOGIES

IREQ PHIL Simulator Project Update: Power Amplifier Design

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HYDRO-QUEBEC RESEARCH INSTITUTE (IREQ), CANADA

Outline

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Objective

Lead the energy transition at Hydro-Québec by developing a hybrid (virtual and real) T&D laboratory to study and integrate :

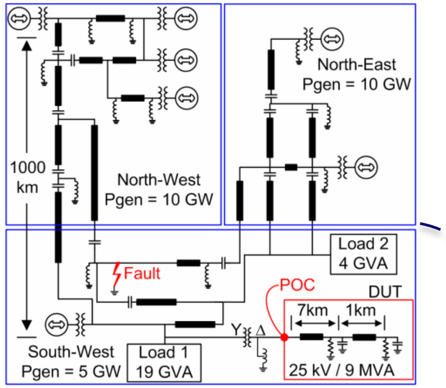
- Distributed Energy Resources
- Smart grids
- Microgrids

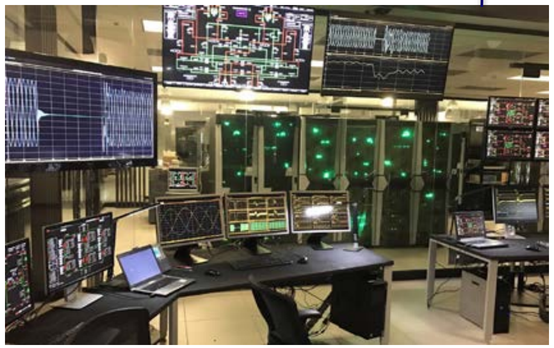
Challenge

Design a 7.5-MW power amplifier to connect, in EMT closed-loop, a real distribution network (25 kV) to a simulated transmission system

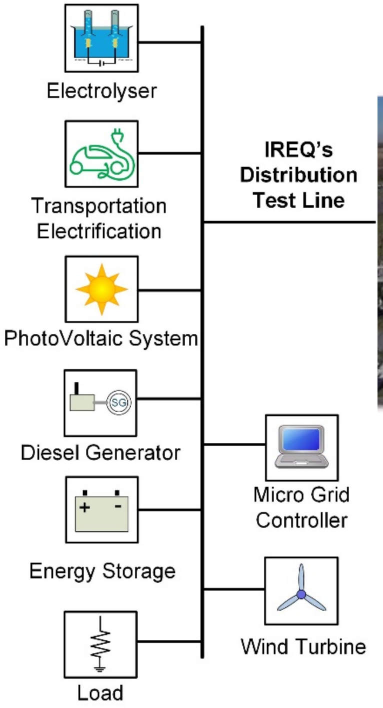
PHIL Simulator (SimP) at a glance

Network simulation in Hypersim



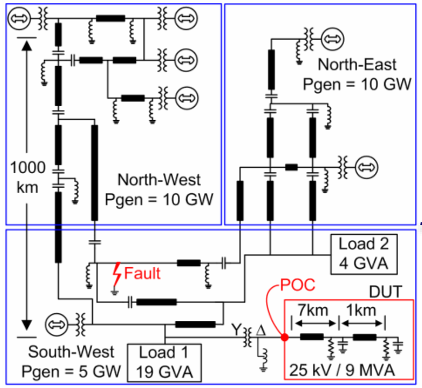


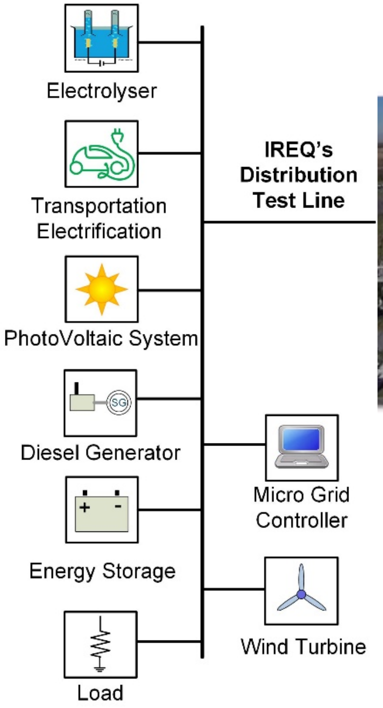
Distribution test line 25 kV



PHIL Simulator (SimP) at a glance

Network simulation
in Hypersim

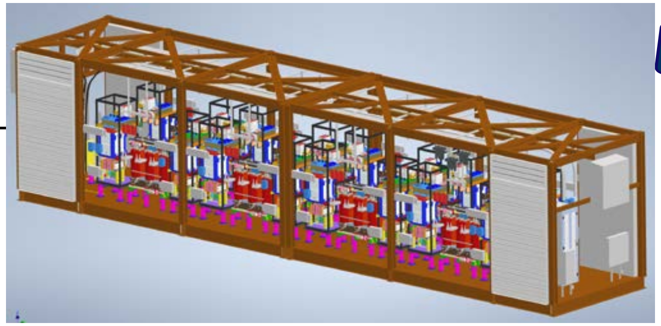




Distribution test line
25 kV

I

Amplifier
7.5 MVA @ 25 kV



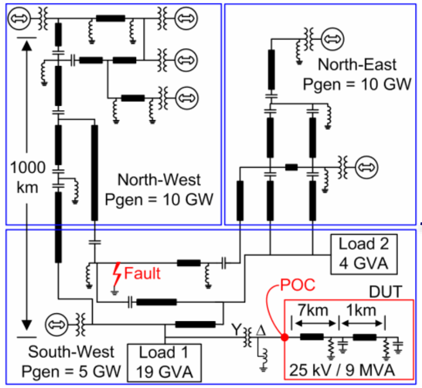
V

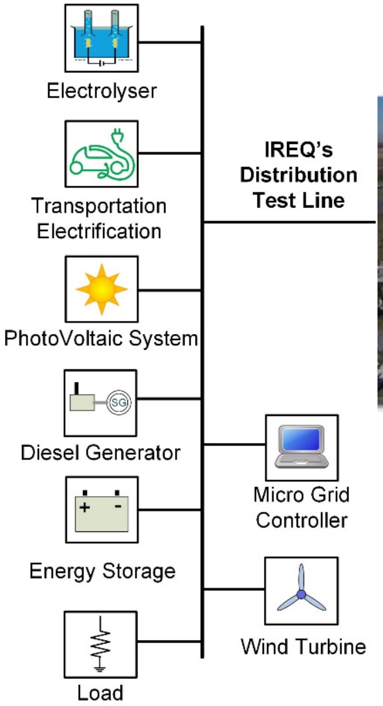
Closed
Loop

I

PHIL Simulator (SimP) at a glance

Network simulation
in Hypersim





Distribution test line
25 kV

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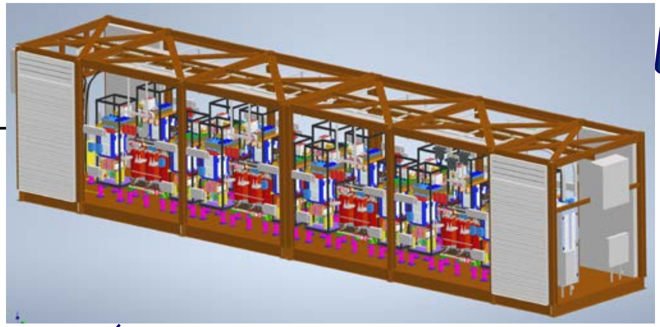


V

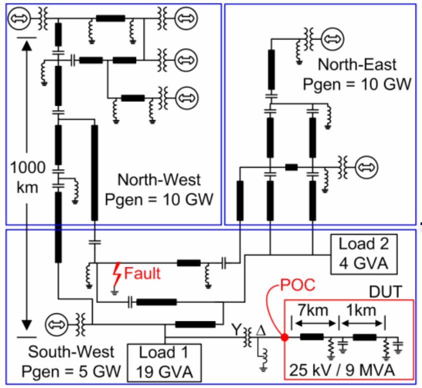
Closed
Loop

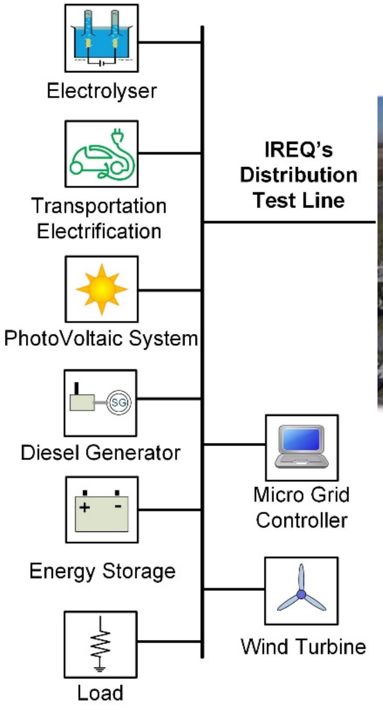
I

- Designed specifically for PHIL
- Multicell
- Without output transformer
- Movable

PHIL Simulator (SimP) at a glance

Network simulation
in Hypersim





Distribution test line
25 kV

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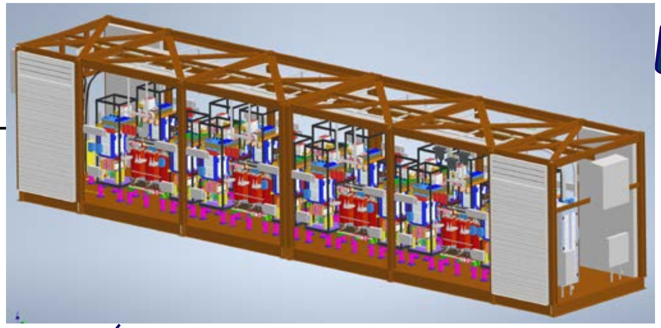
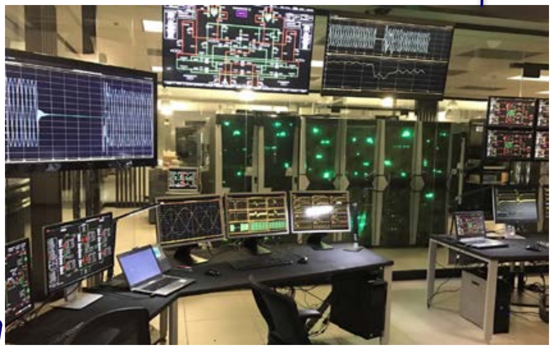


V

Closed
Loop

I

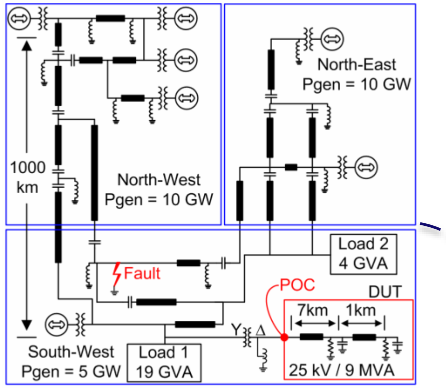


- Designed specifically for PHIL
- Multicell
- Without output transformer
- Movable

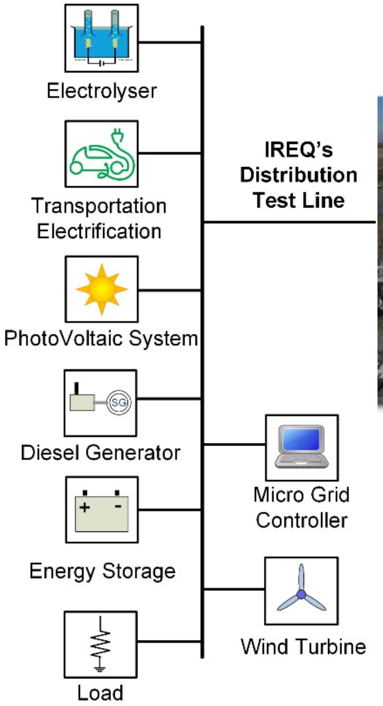
- Design of a general closed-loop interface
- Designed specifically for PHIL
- Embedded in Hypersim

PHIL Simulator (SimP) at a glance

Network simulation
in Hypersim



SimP
In-house global design of the PHIL infrastructure



Distribution test line
25 kV

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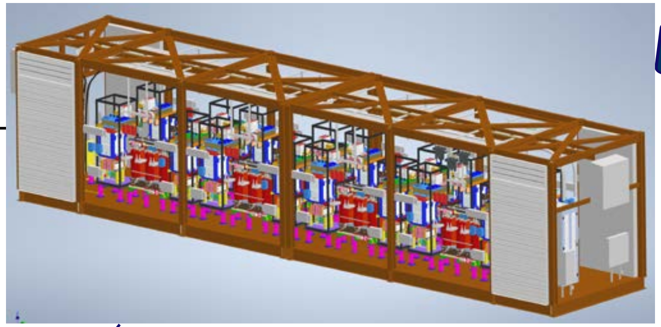
Amplifier
7.5 MVA @ 25 kV



V

Closed
Loop

I

- Designed specifically for PHIL
- Multicell
- Without output transformer
- Movable

- Design of a general closed-loop interface
- Designed specifically for PHIL
- Embedded in Hypersim

Project milestones

Design of the power amplifier (PA) topology

Cascaded H-Bridge

Transformerless

High bandwidth

25 kV, 7.5 MVA

☑

Development of the reduced-scale version of the PA

Cascaded H-Bridge

Transformerless

High bandwidth

208 V, 3 kVA

☑

Design of a general closed-loop interface

Stable

Precise

High bandwidth

☑

Making a single full-scale Cell

Complete cell (transfo, Active-Front-End, H-Bride)

2 kV, 167 kW

Overload capability of H-Bride: 10x nominal current

☑

Project milestones

Design of the power amplifier (PA) topology

Cascaded H-Bridge

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High bandwidth

25 kV, 7.5 MVA

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208 V, 3 kVA

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Stable

Precise

High bandwidth

Making a single full-scale Cell

Complete cell (transfo, Active-Front-End, H-Bride)

2 kV, 167 kW

Overload capability of H-Bride: 10x nominal current

Complete the PA

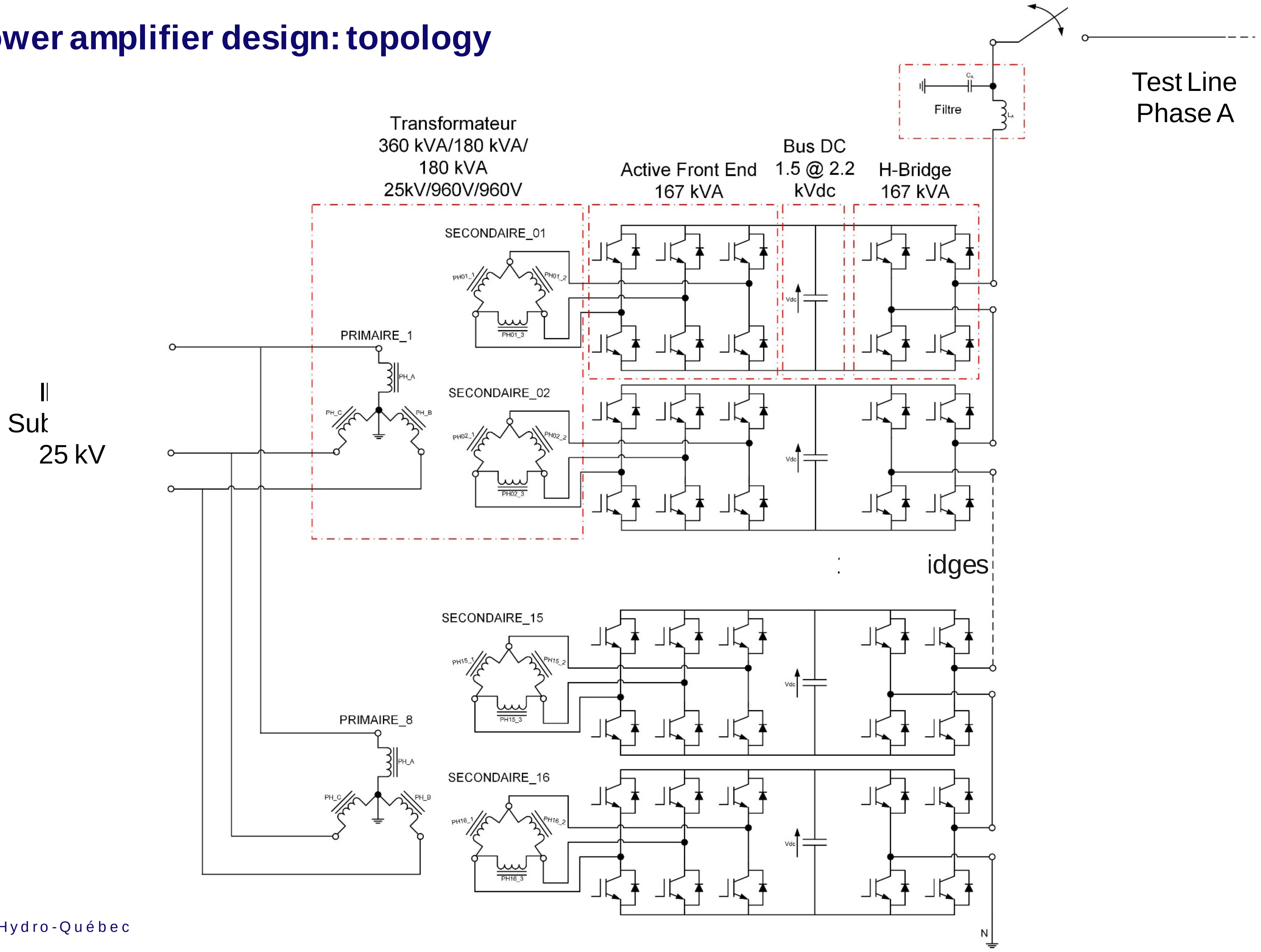
3-phase

1.5 PU overvoltage capability

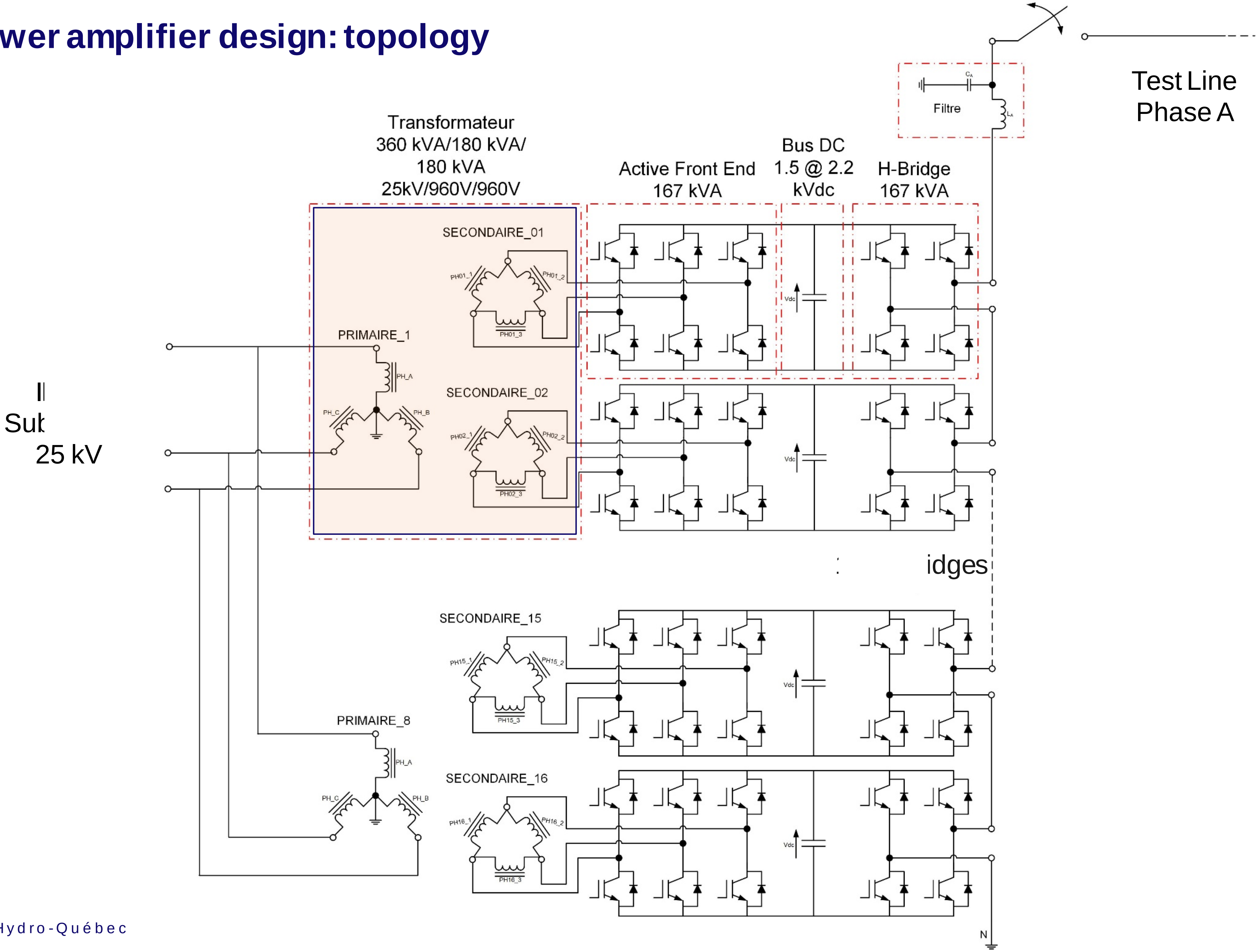
10 PU overcurrent capability

DC to 1 kHz in closed-loop

Power amplifier design: topology

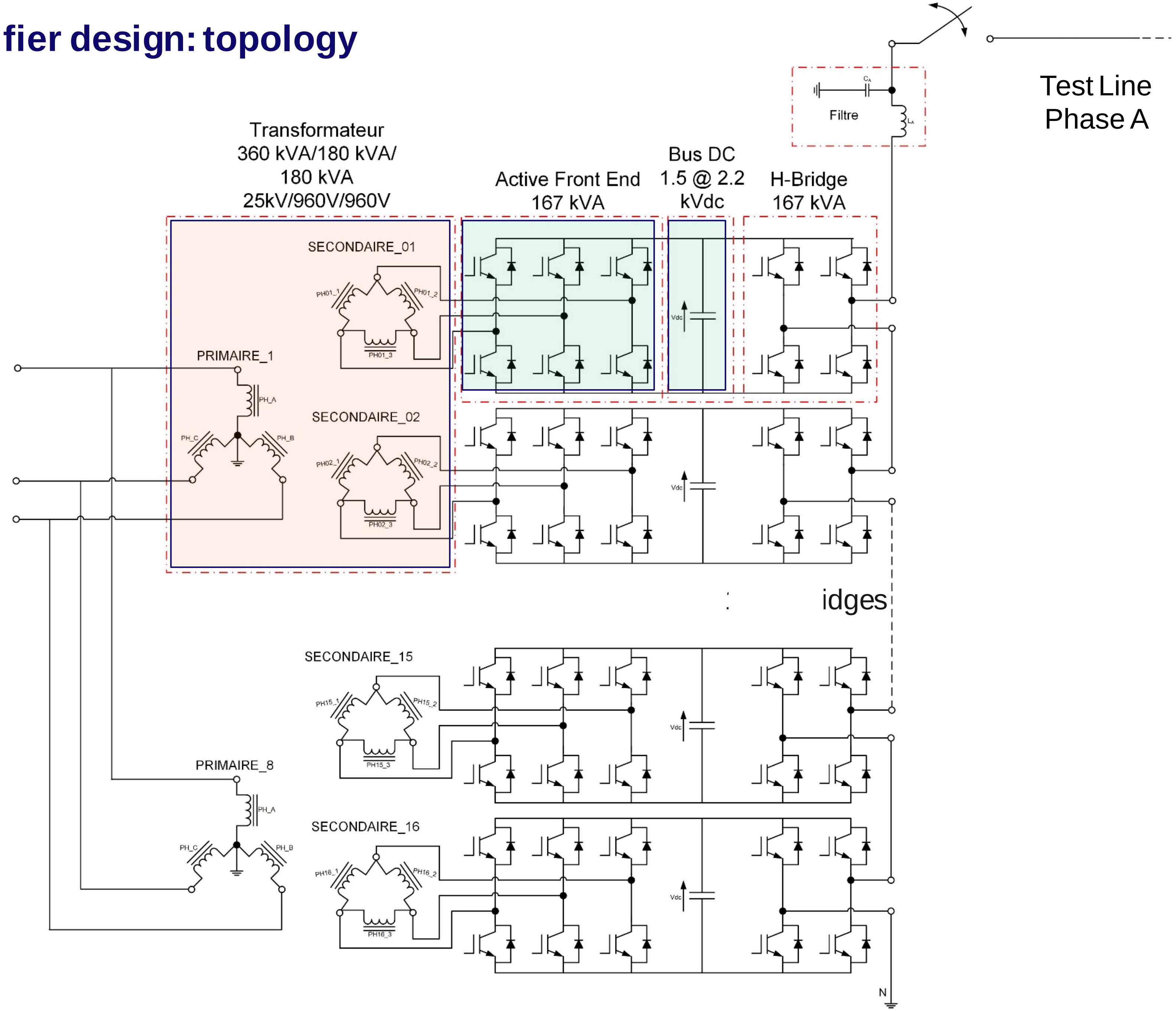


Power amplifier design: topology

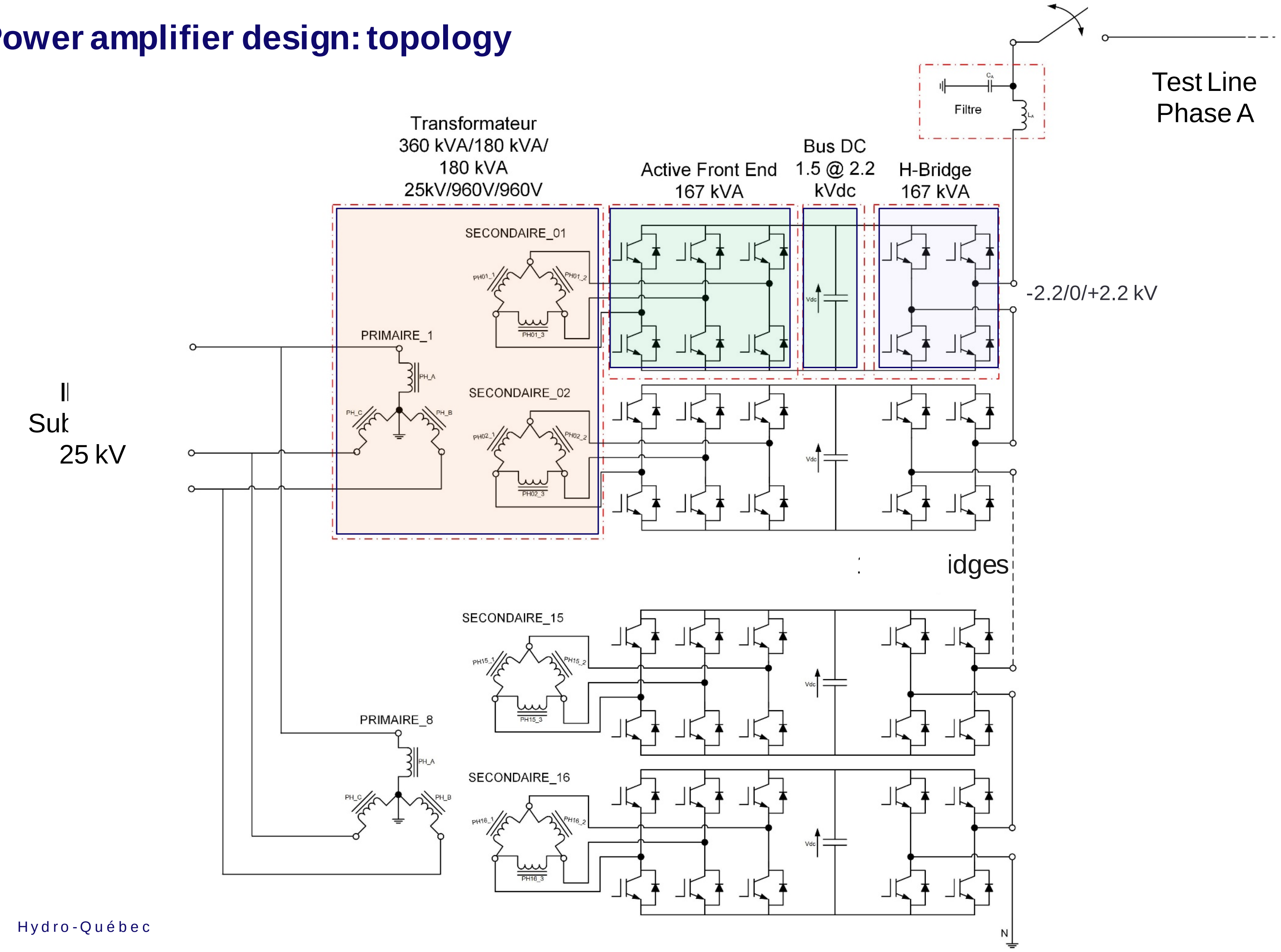


Power amplifier design: topology

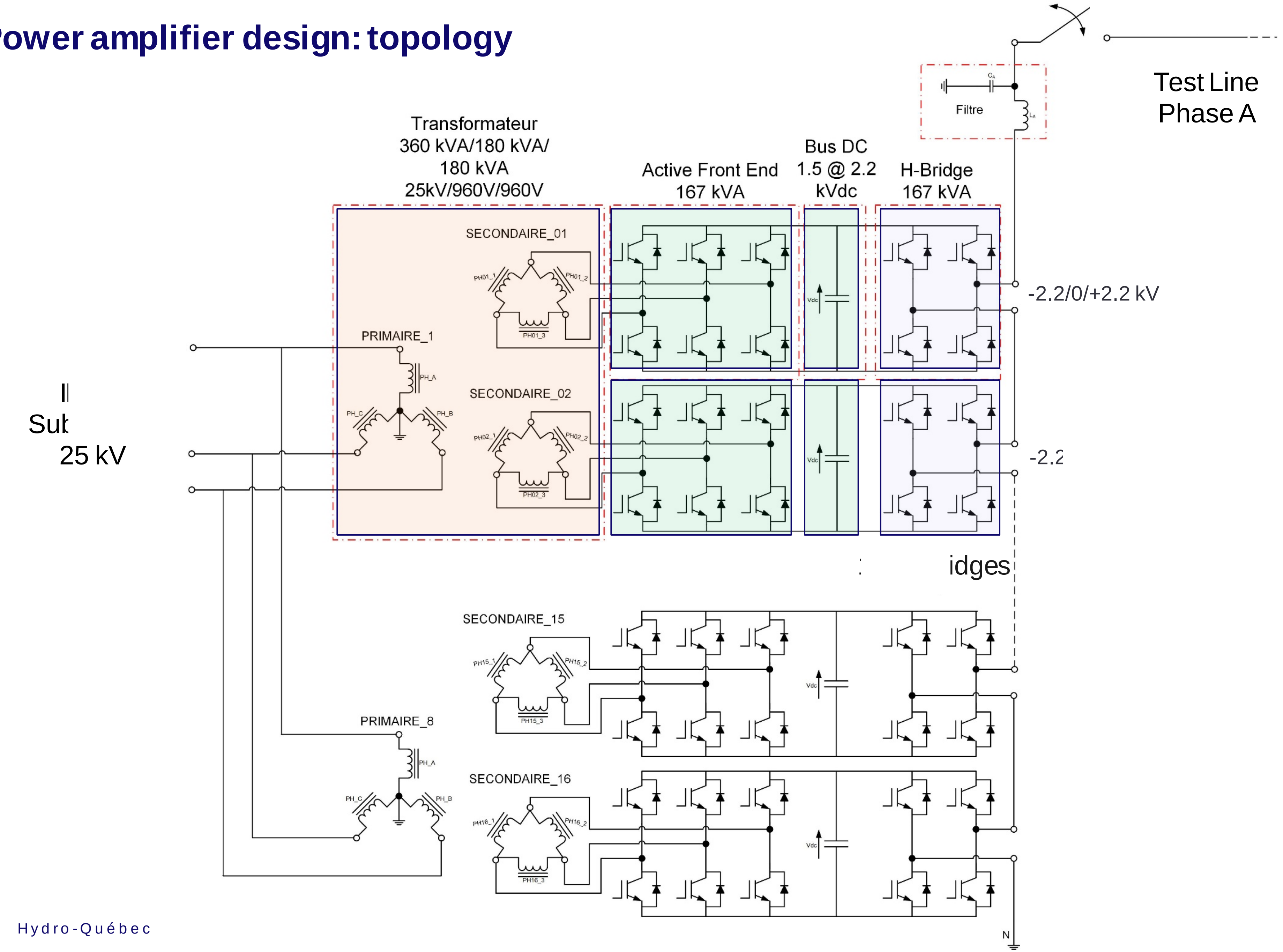
Sub
25 kV



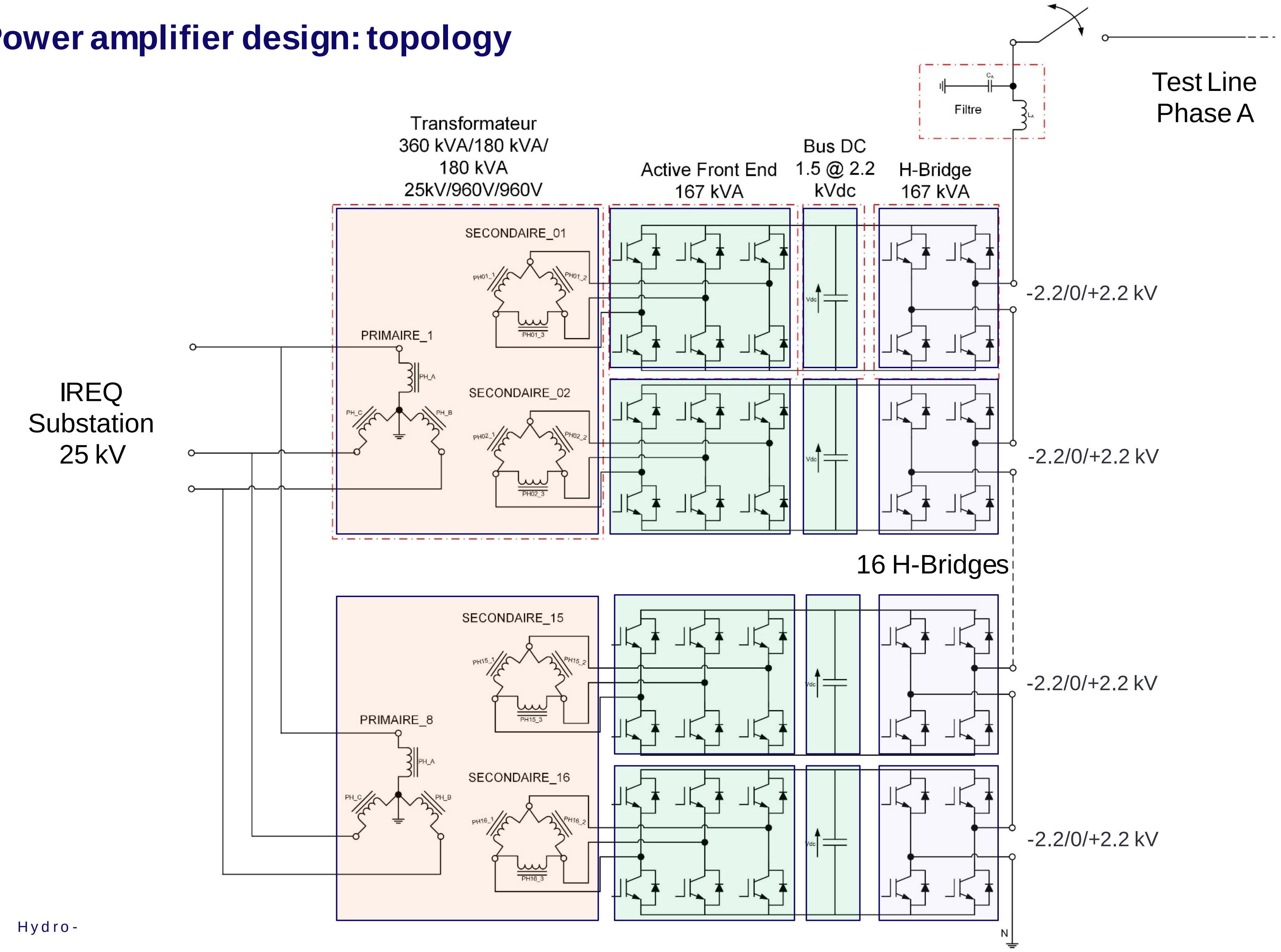
Power amplifier design: topology



Power amplifier design: topology

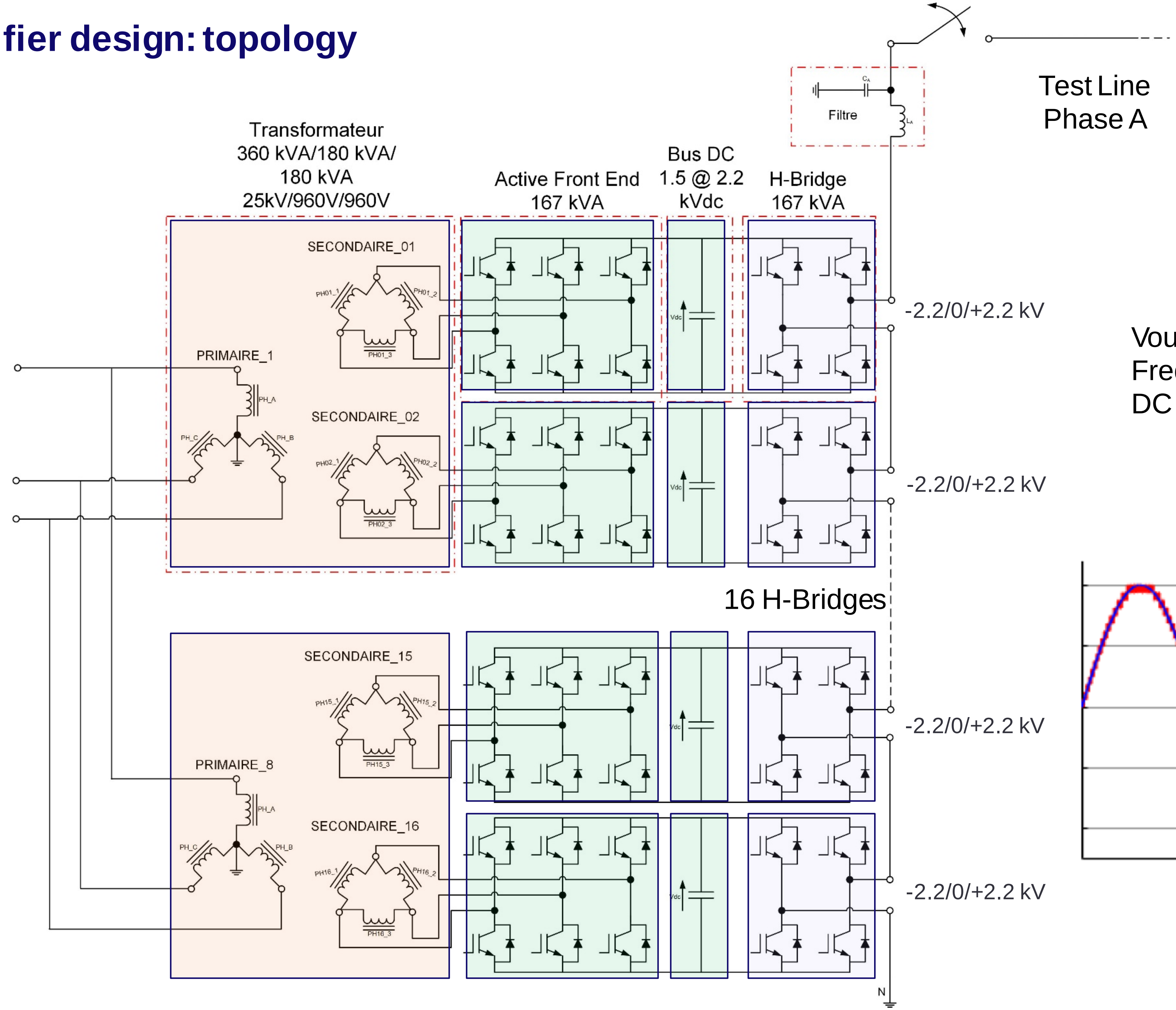


Power amplifier design: topology

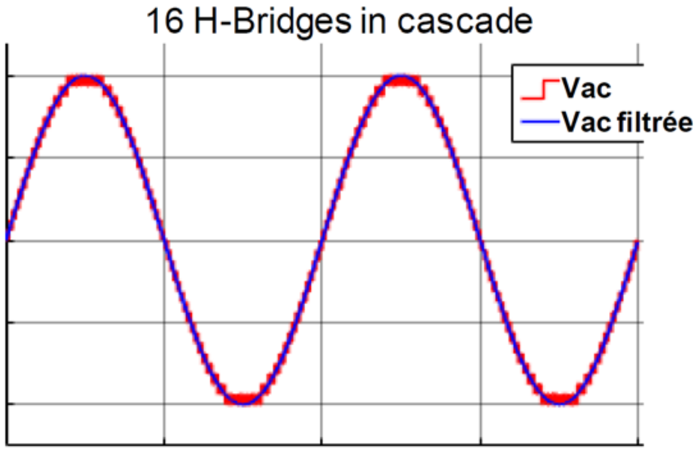


Power amplifier design: topology

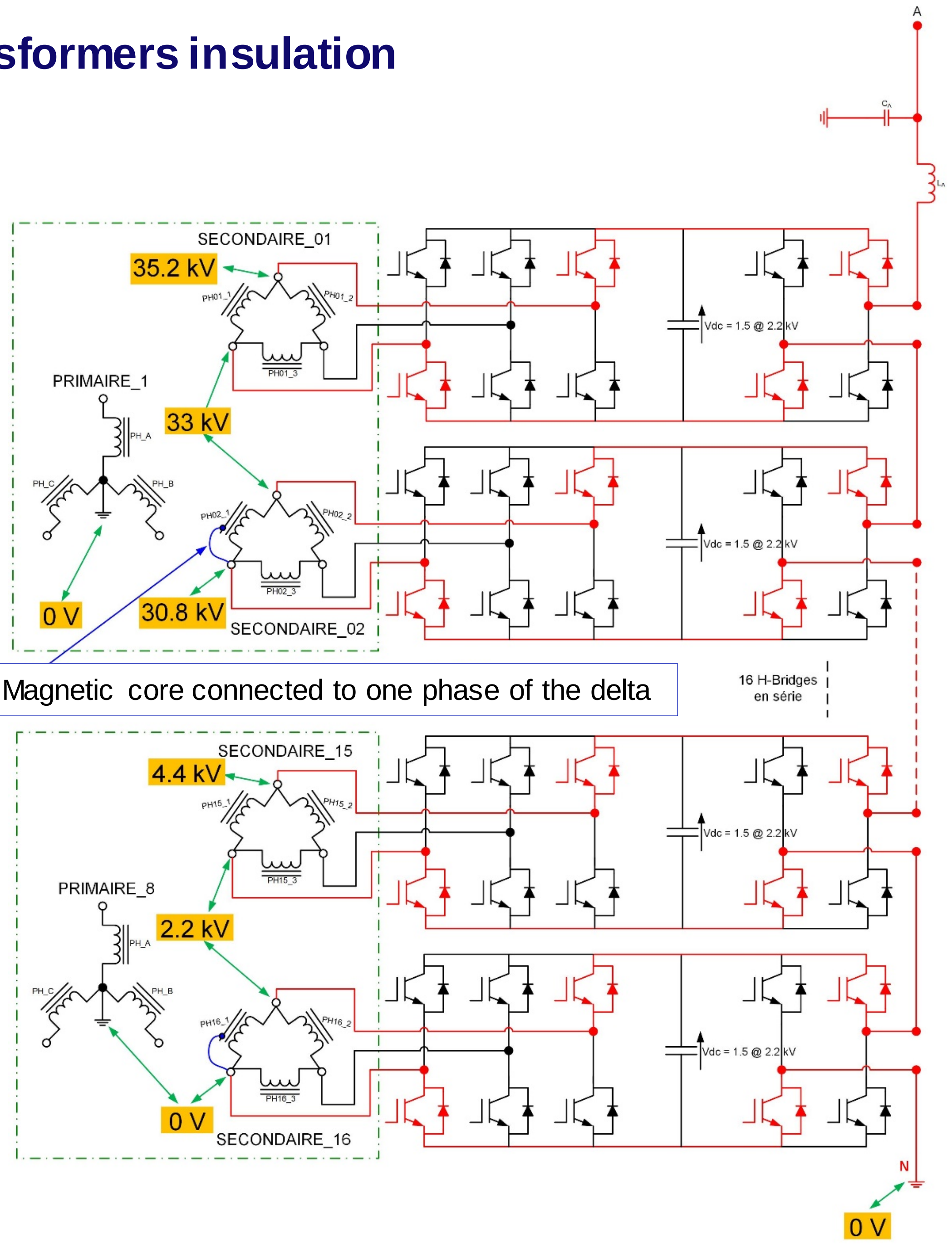
IREQ
Substation
25 kV



Vout : 0 to 35.2 kV peak
Freq: DC to 7 kHz open loop
DC to 1 kHz closed-loop

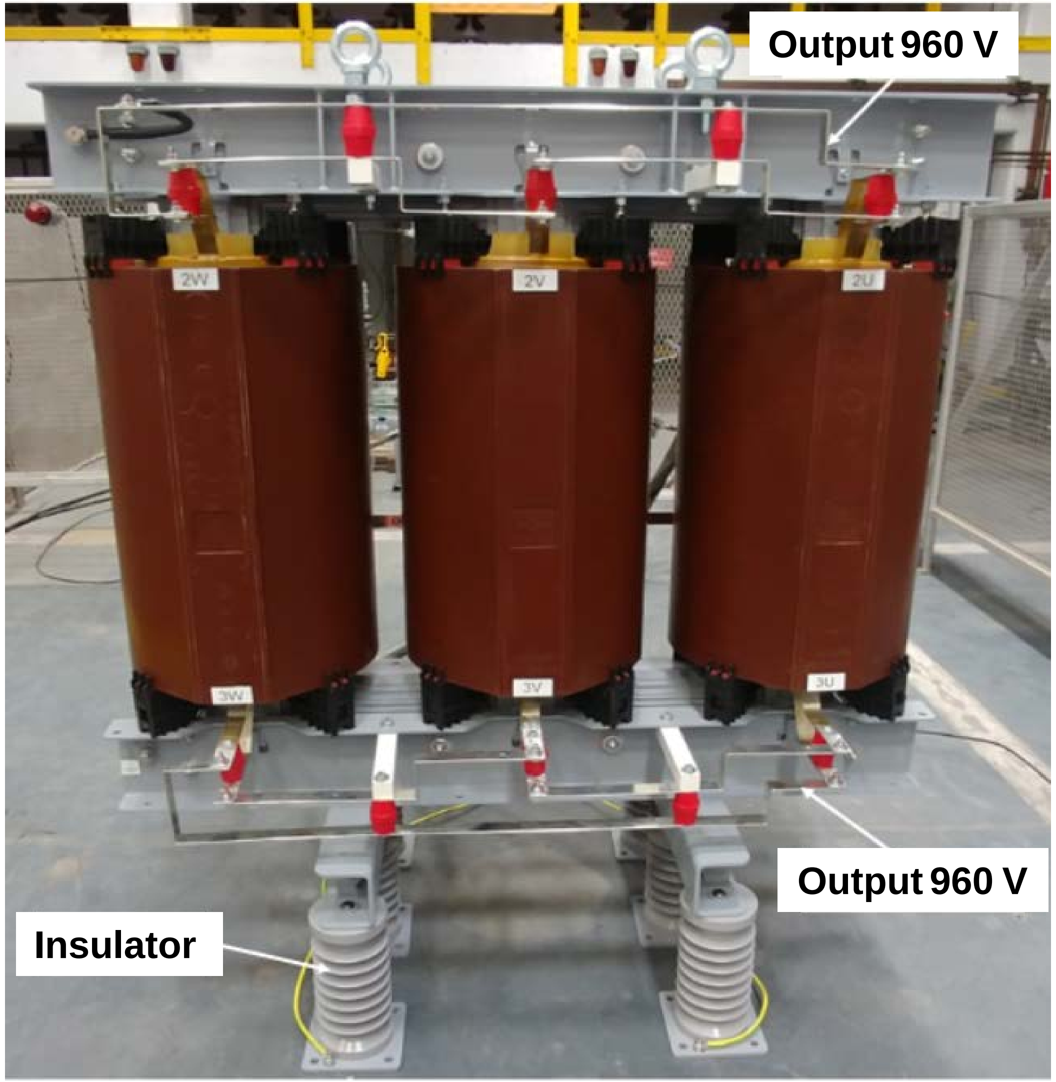


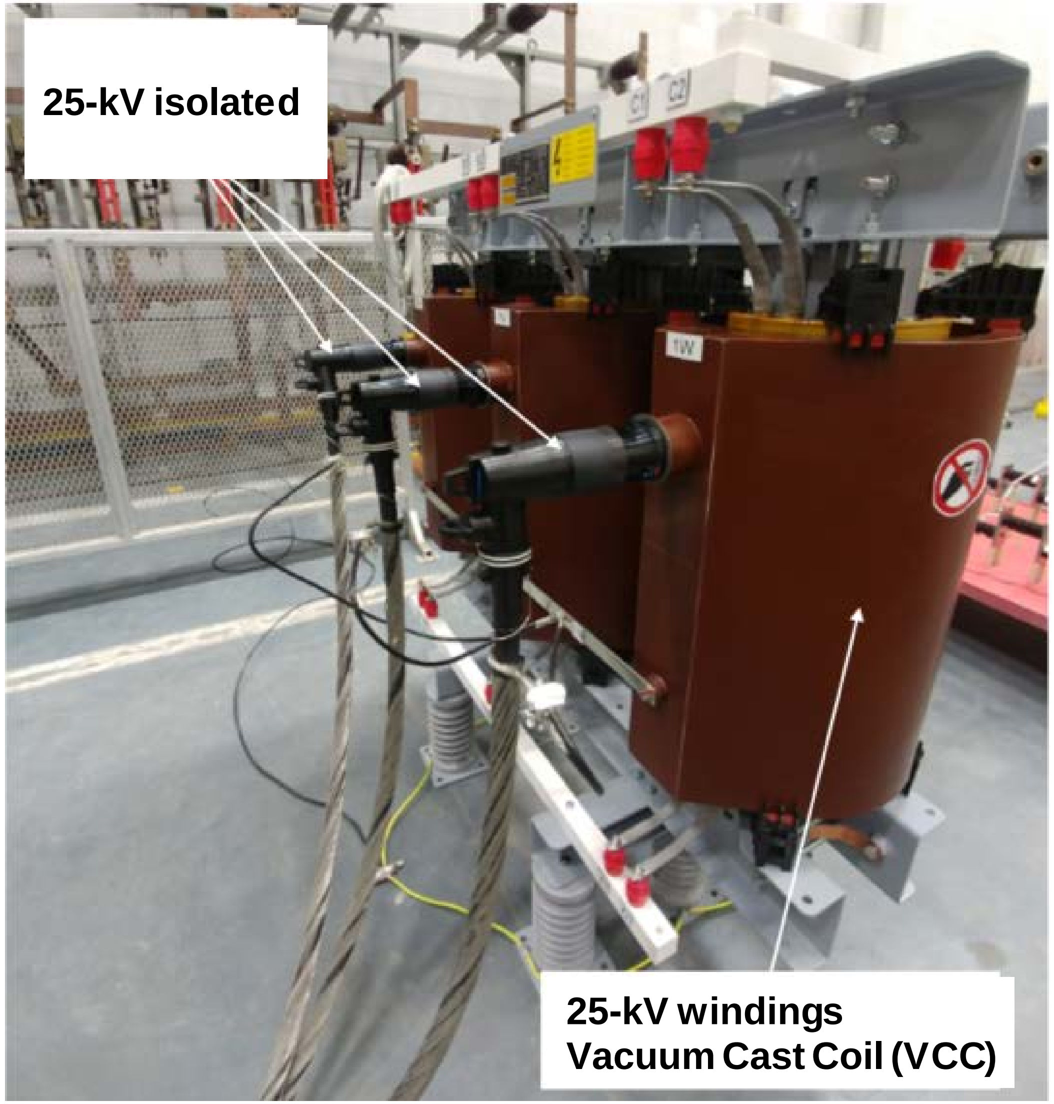
Power amplifier design: transformers insulation



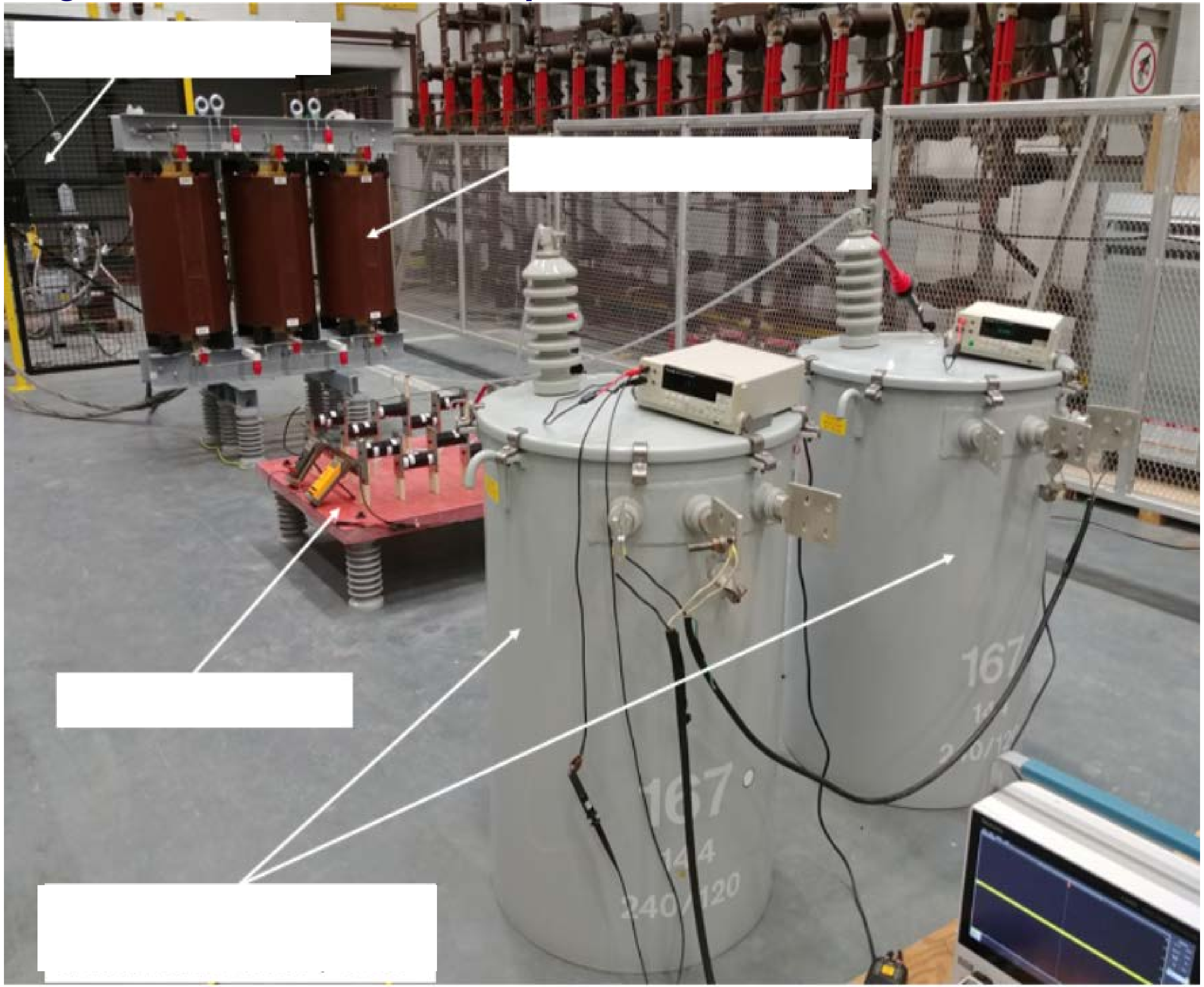
Magnetic core connected to one phase of the delta

Power amplifier design: transformer 372 kVA 25 kV/960V/960V

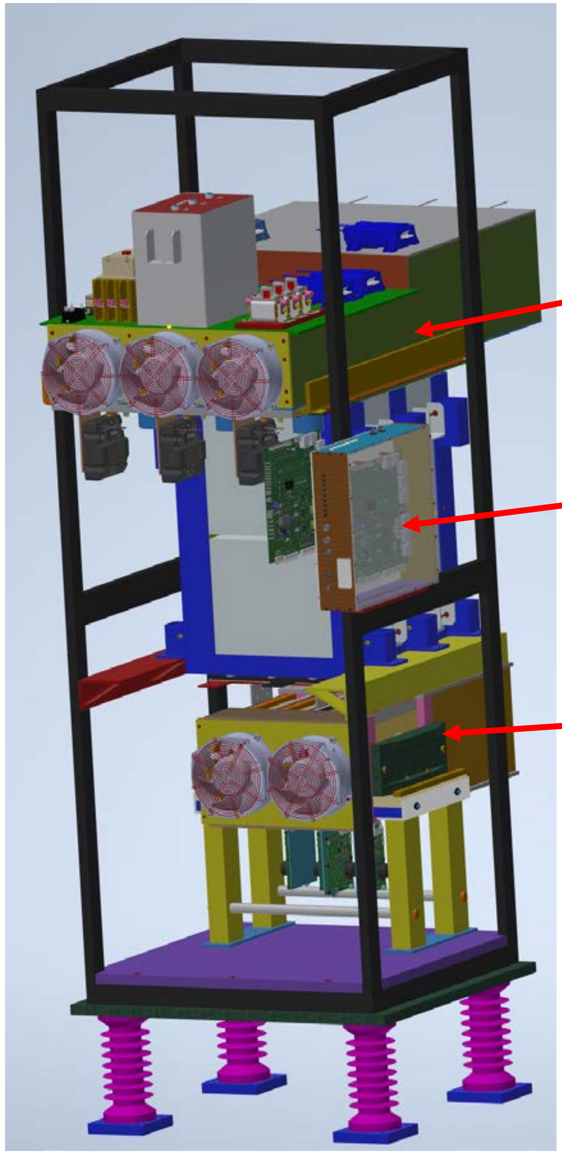




Power amplifier design: transformers test setup



Power amplifier design: rack and converters



Front view

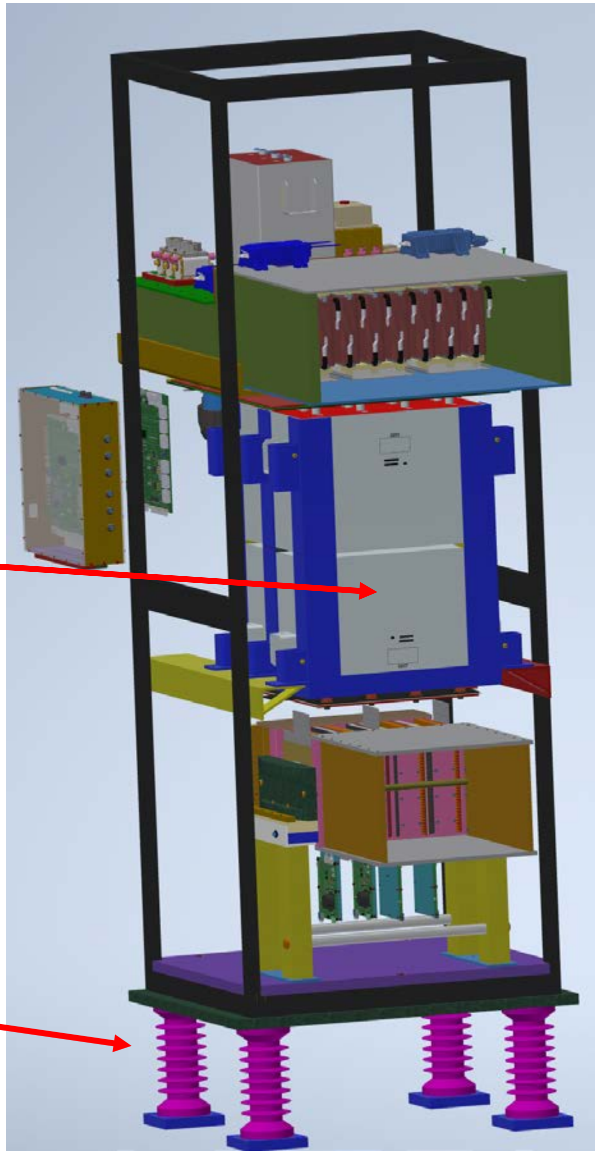
Active Front End (AFE) with filter & meters

Control

DC Bus Capacitors

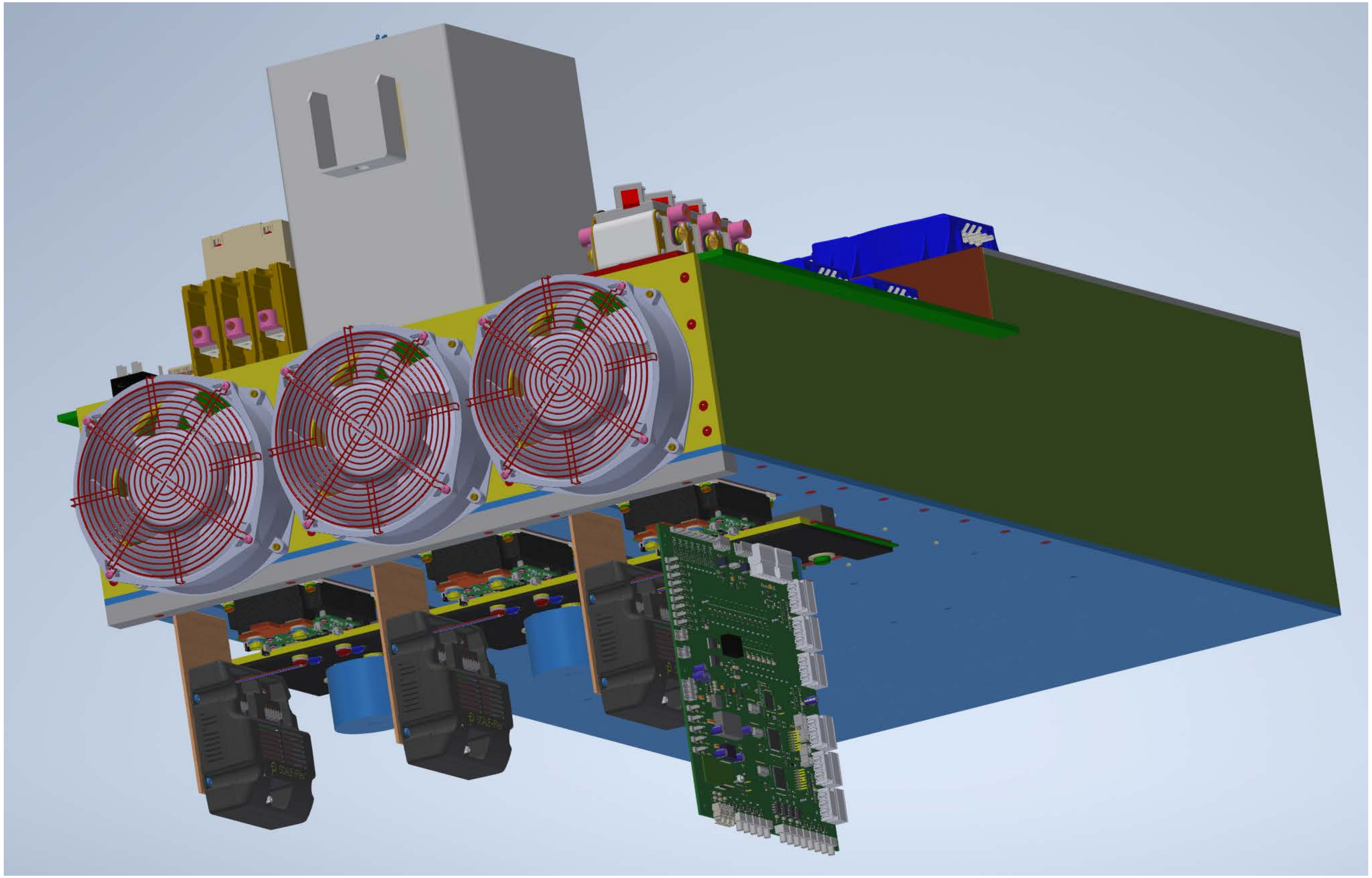
H-Bridge

Insulators

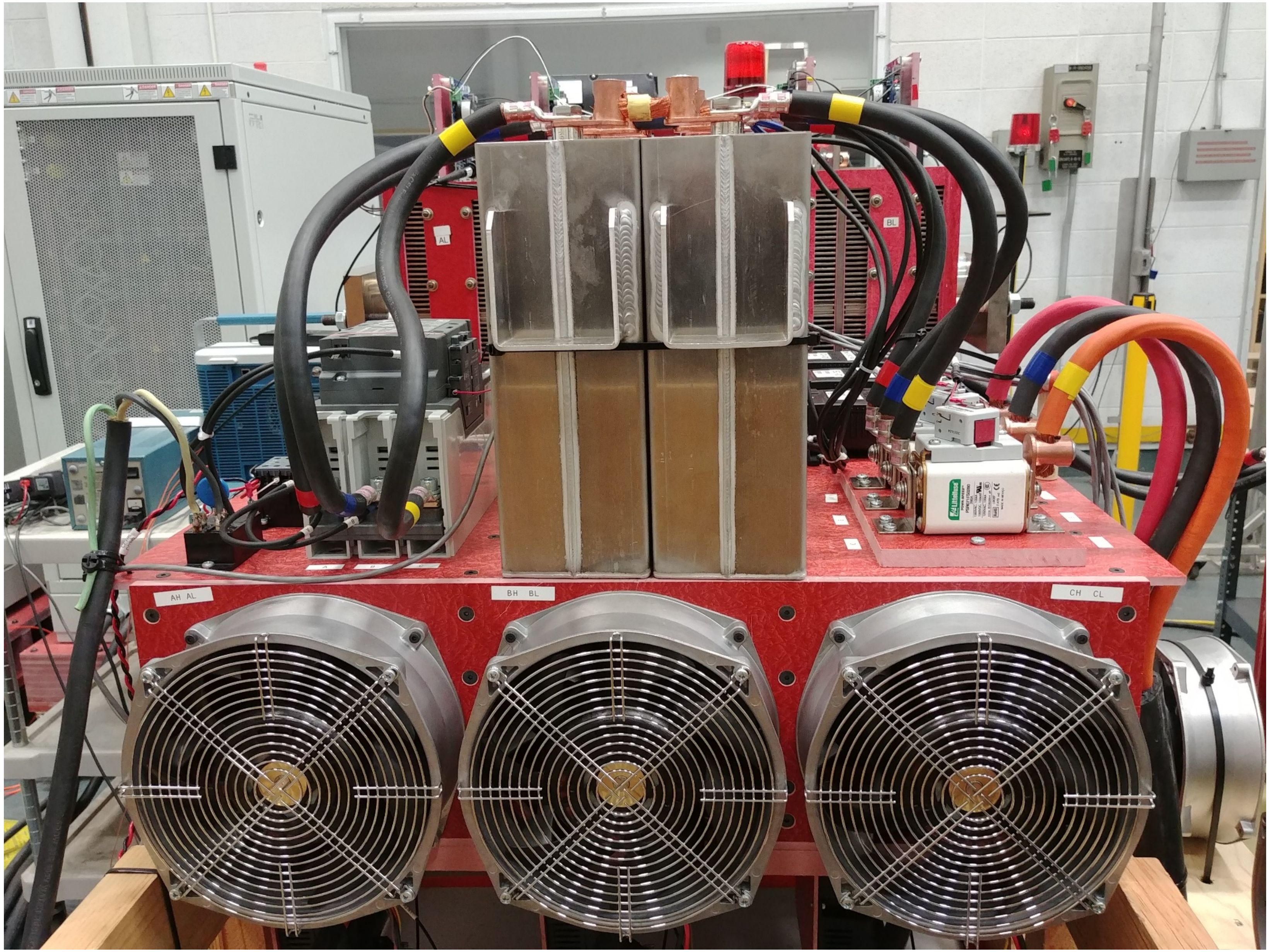


Rear view

Power amplifier design: AFE

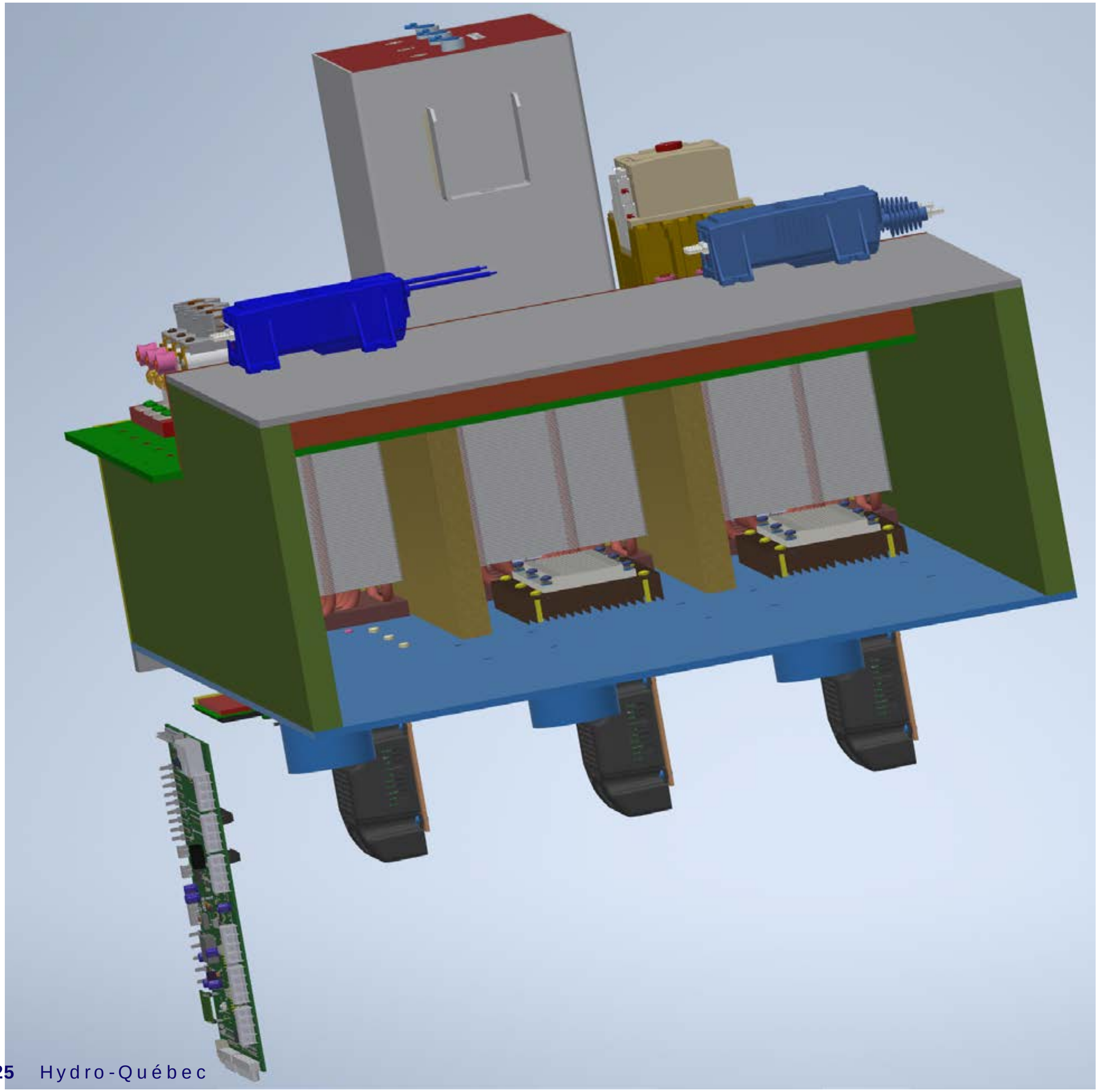


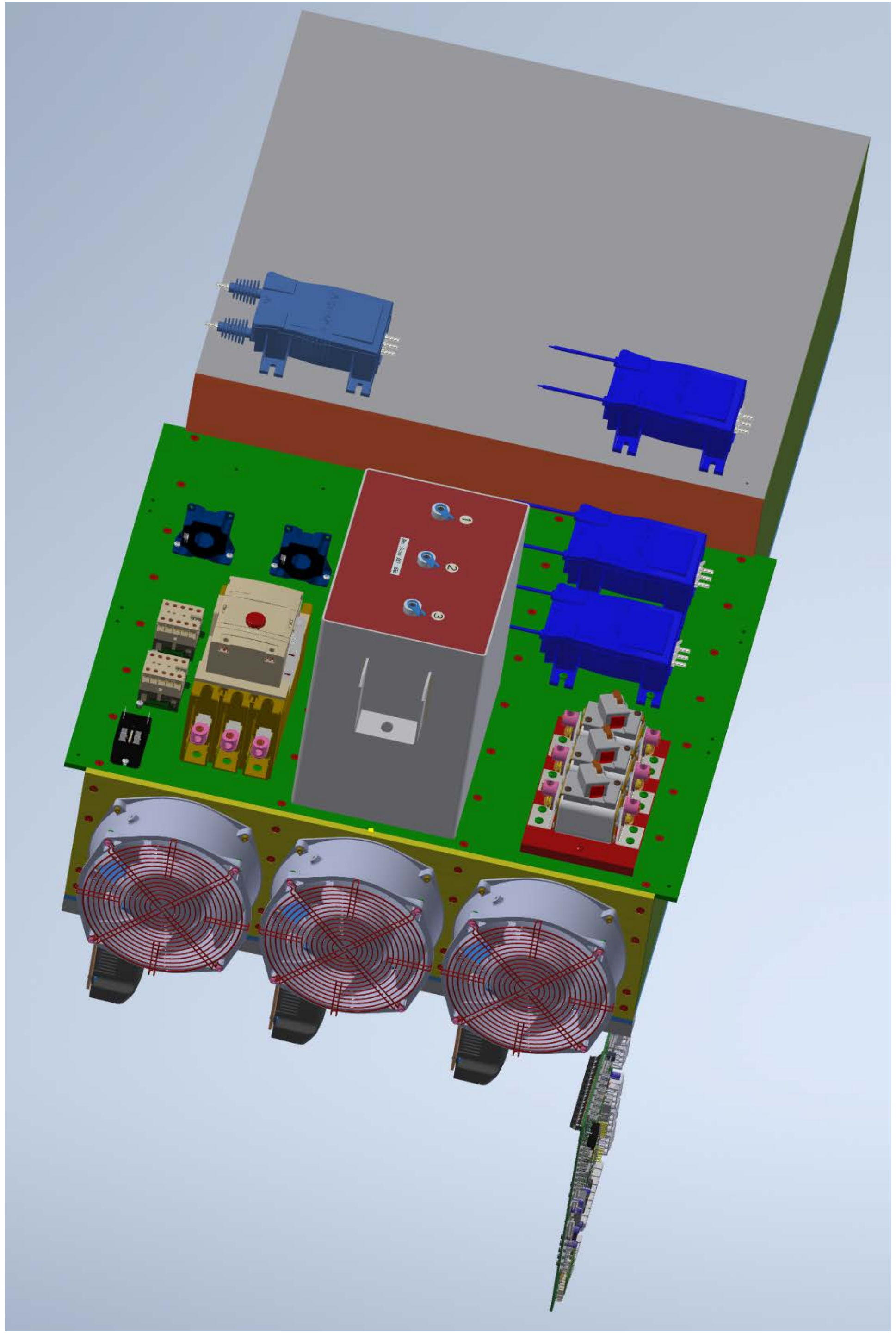
Power amplifier design: AFE



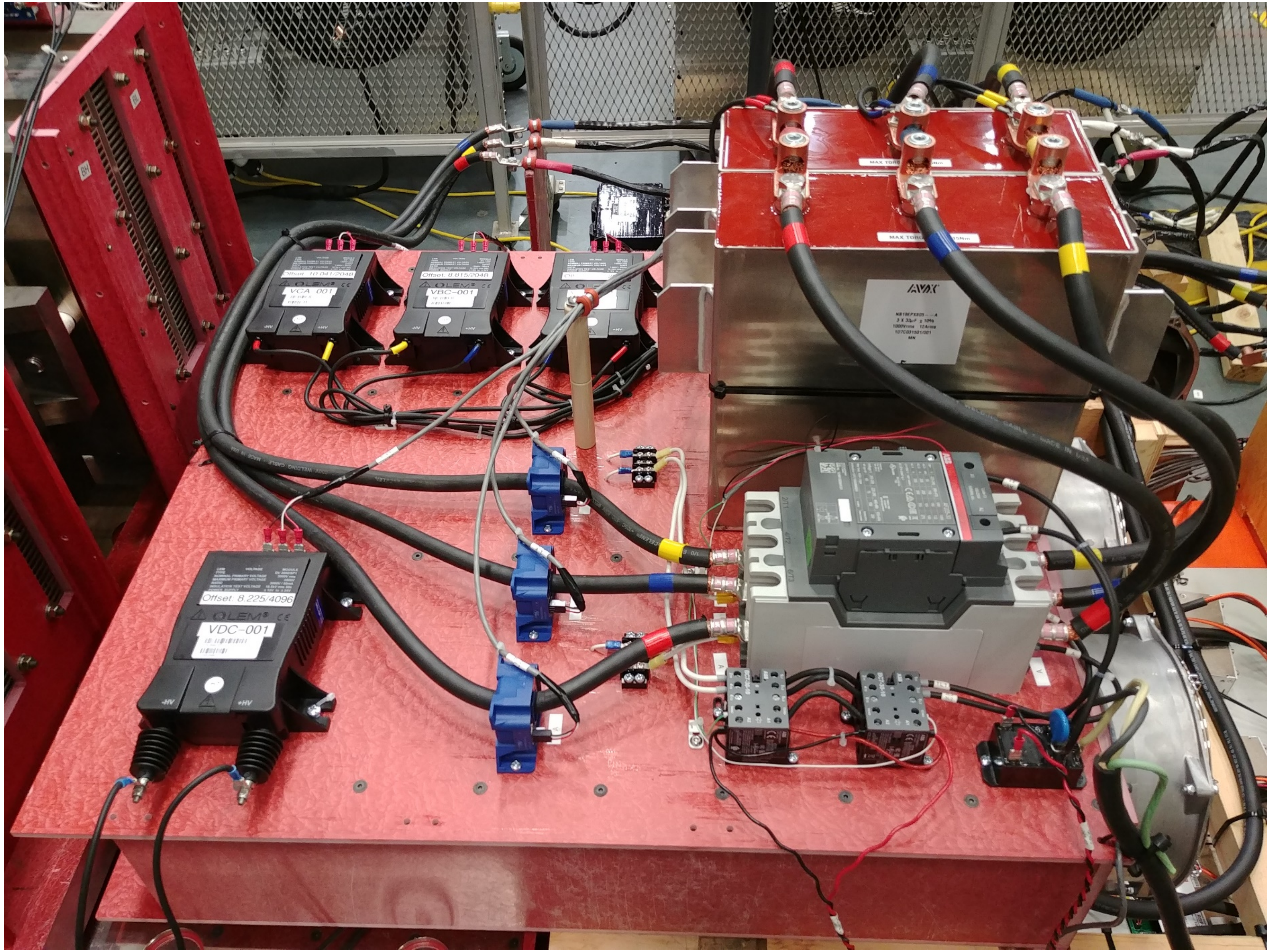
Power amplifier design: AFE control design and validation

Power amplifier design: AFE





Power amplifier design: AFE



Power amplifier design: AFE IGBT & heat sink

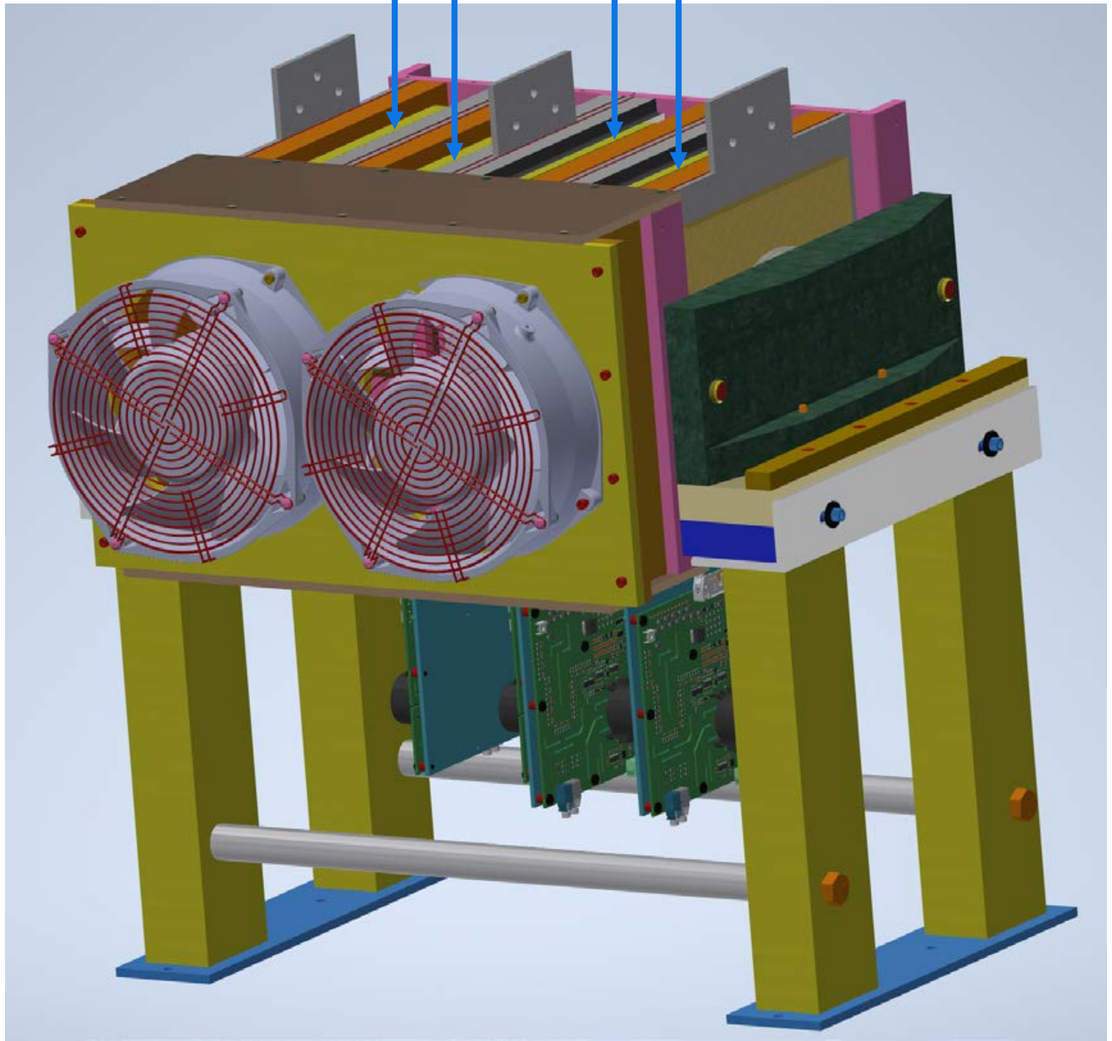
IGBT (LinPak phase leg 3300 V)

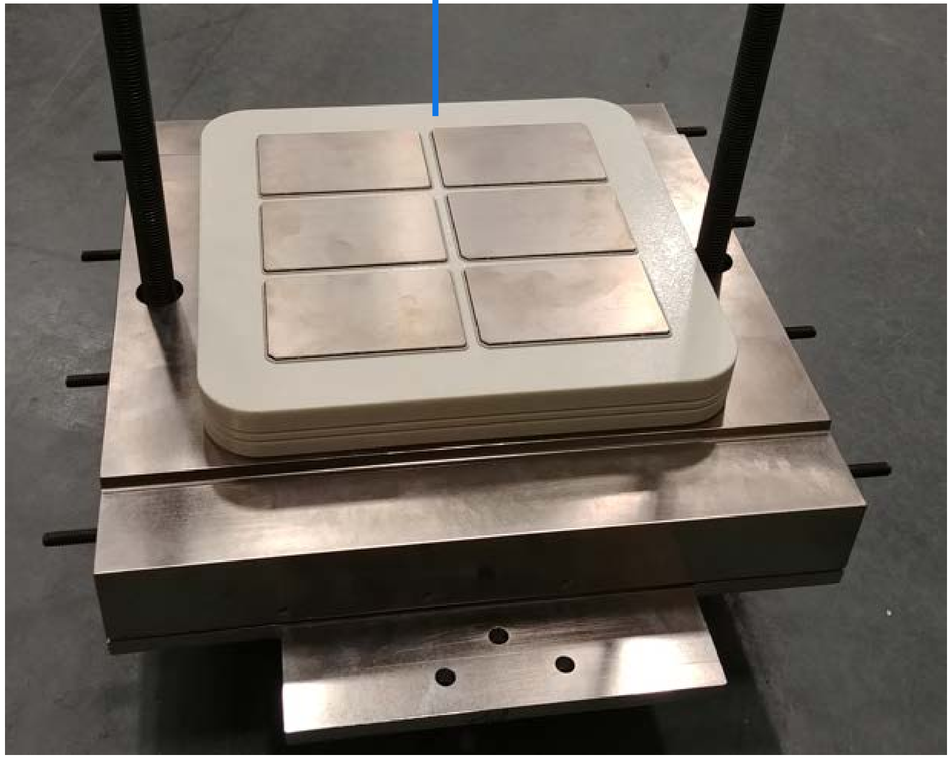
ipe)

Power amplifier design: H-Bridge & IGBT Presspack

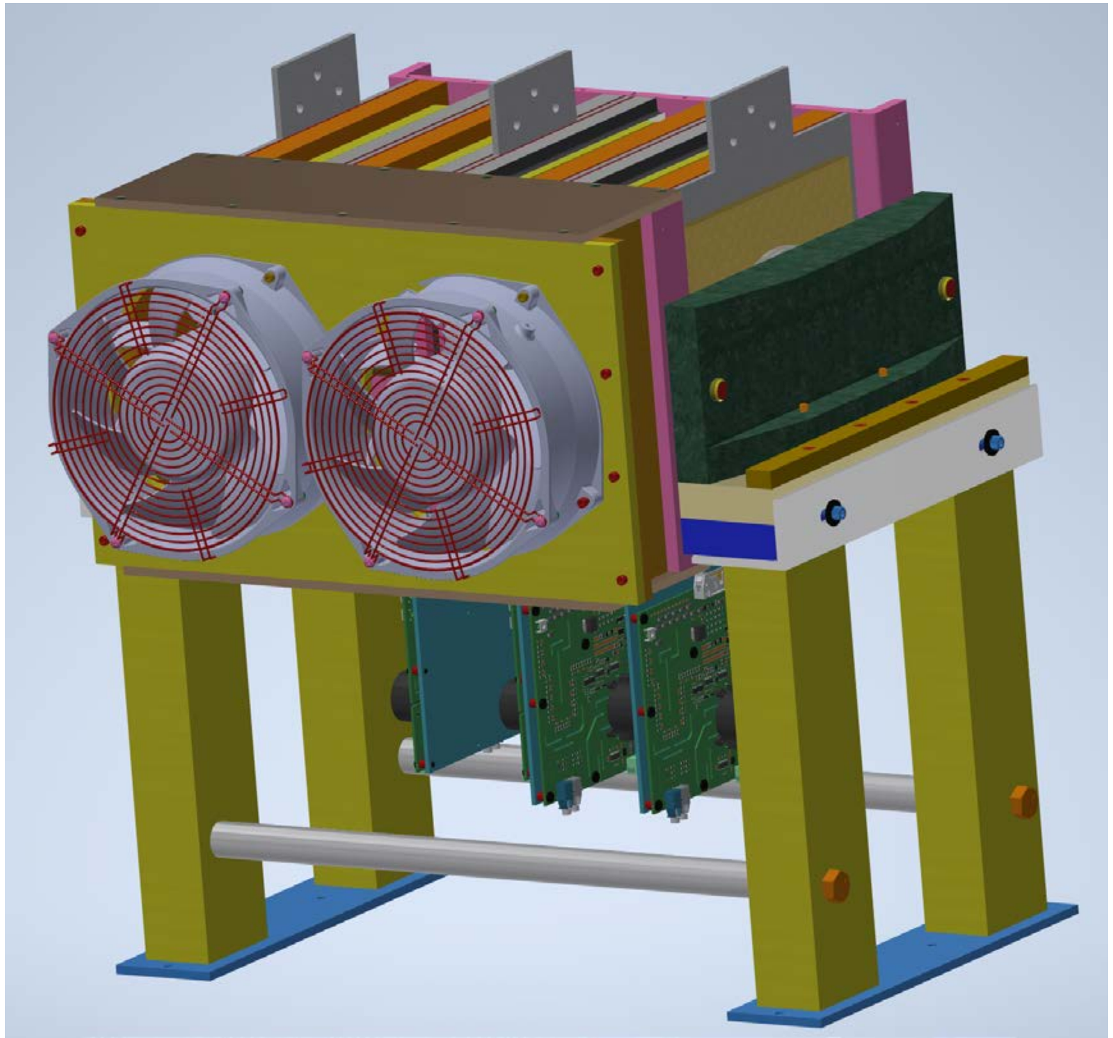
H-Bridge + gate drivers

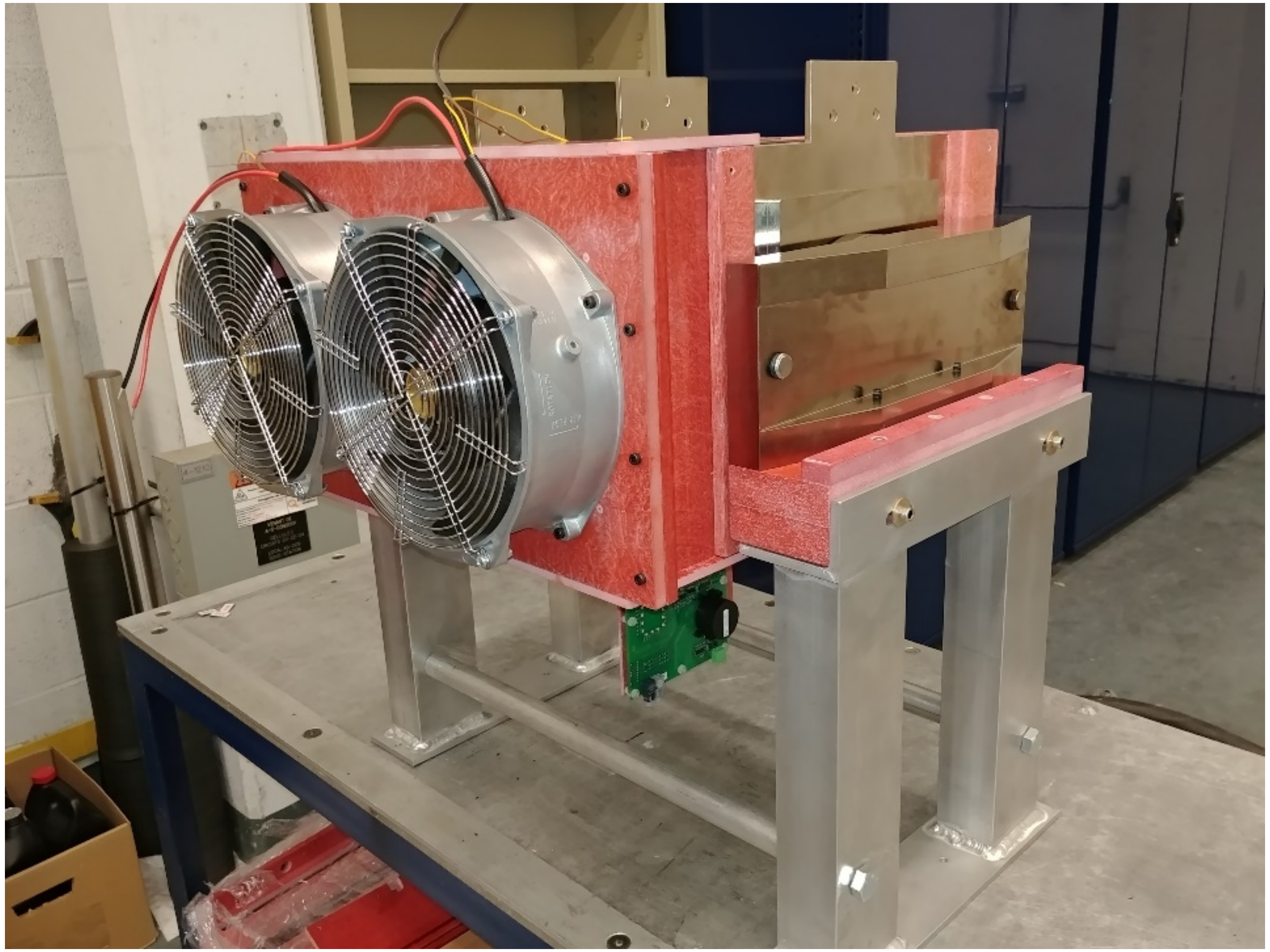
IGBT Presspack



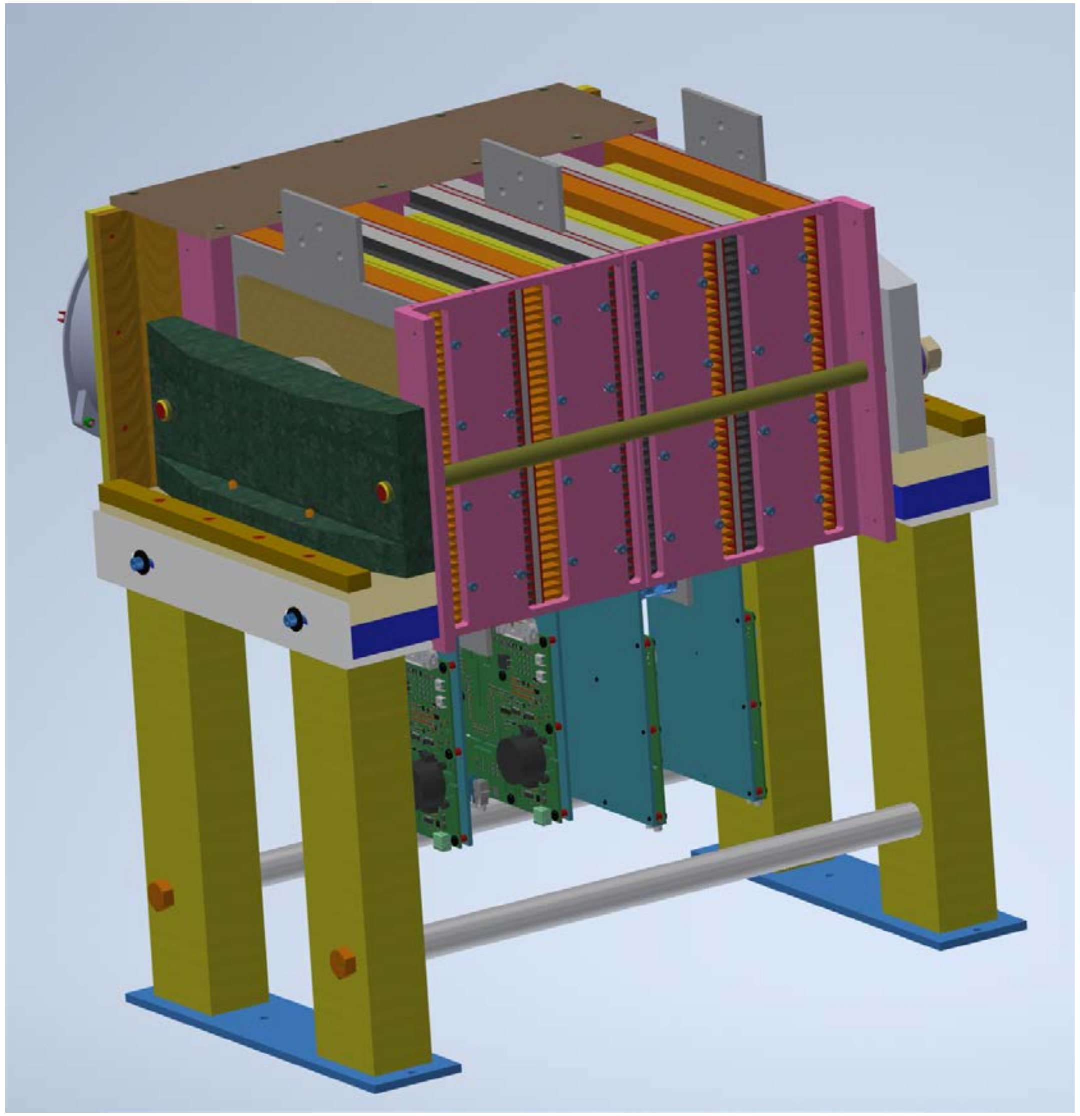


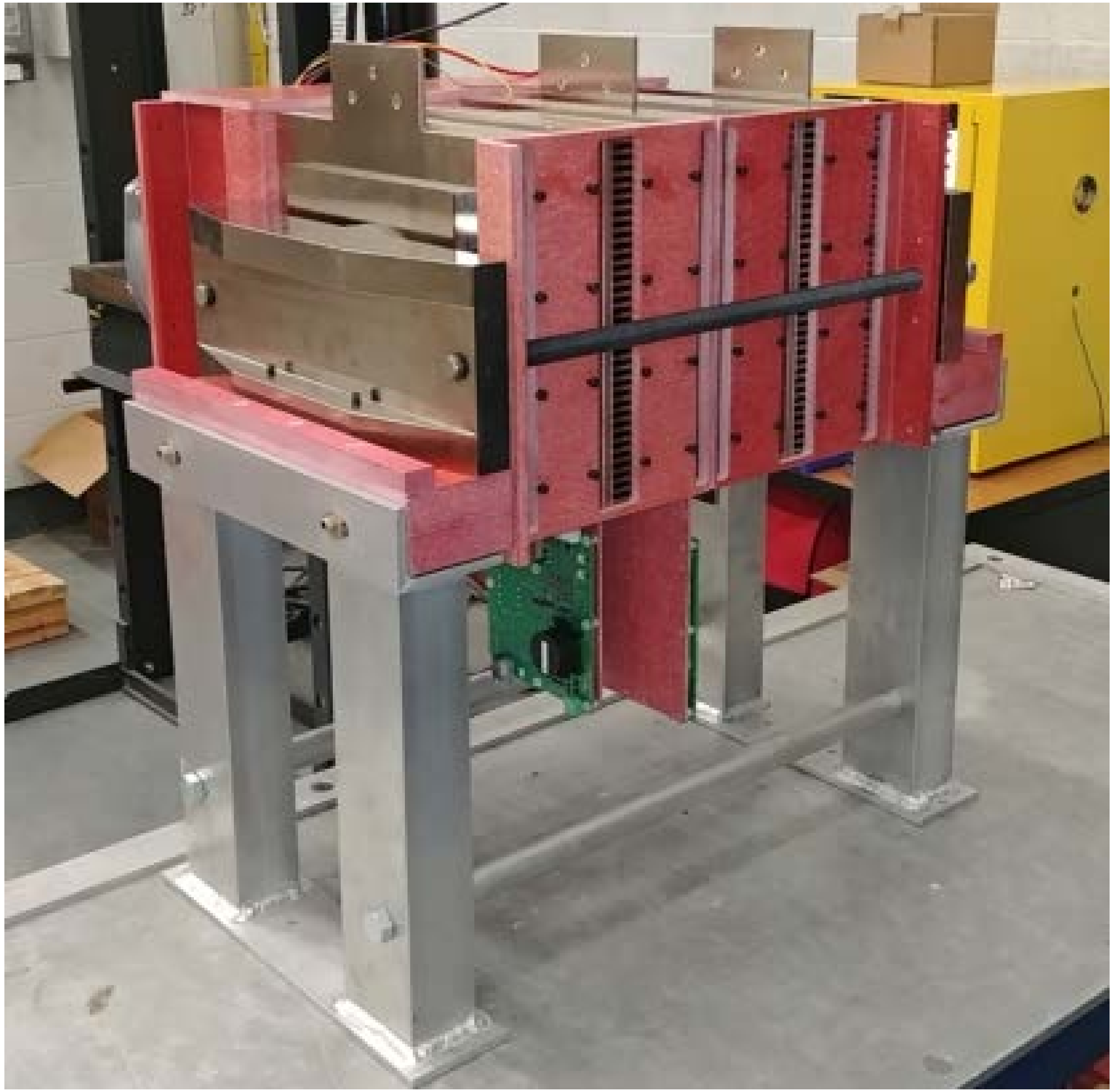
Power amplifier design: H-Bridge



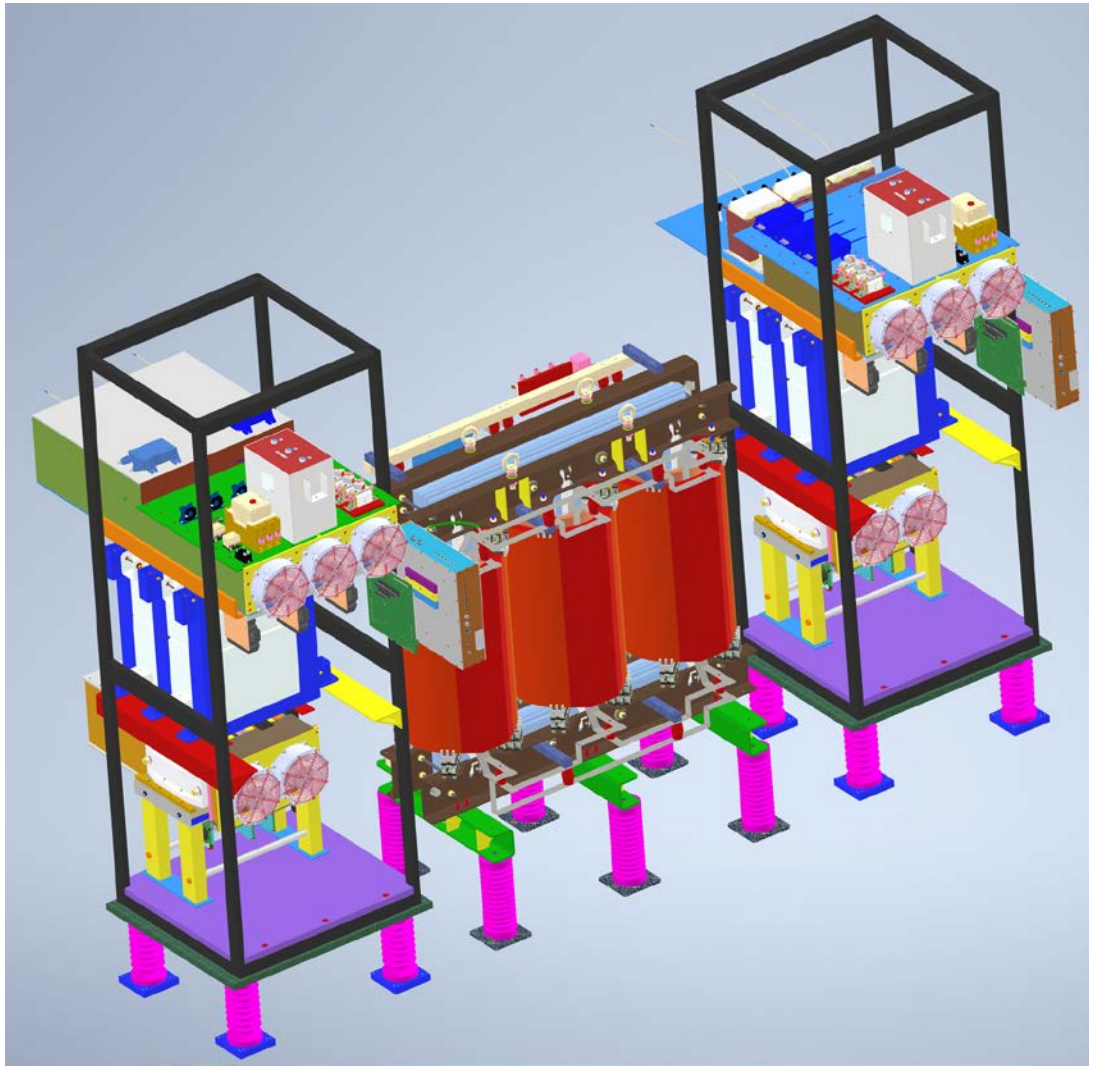


Power amplifier design: H-Bridge

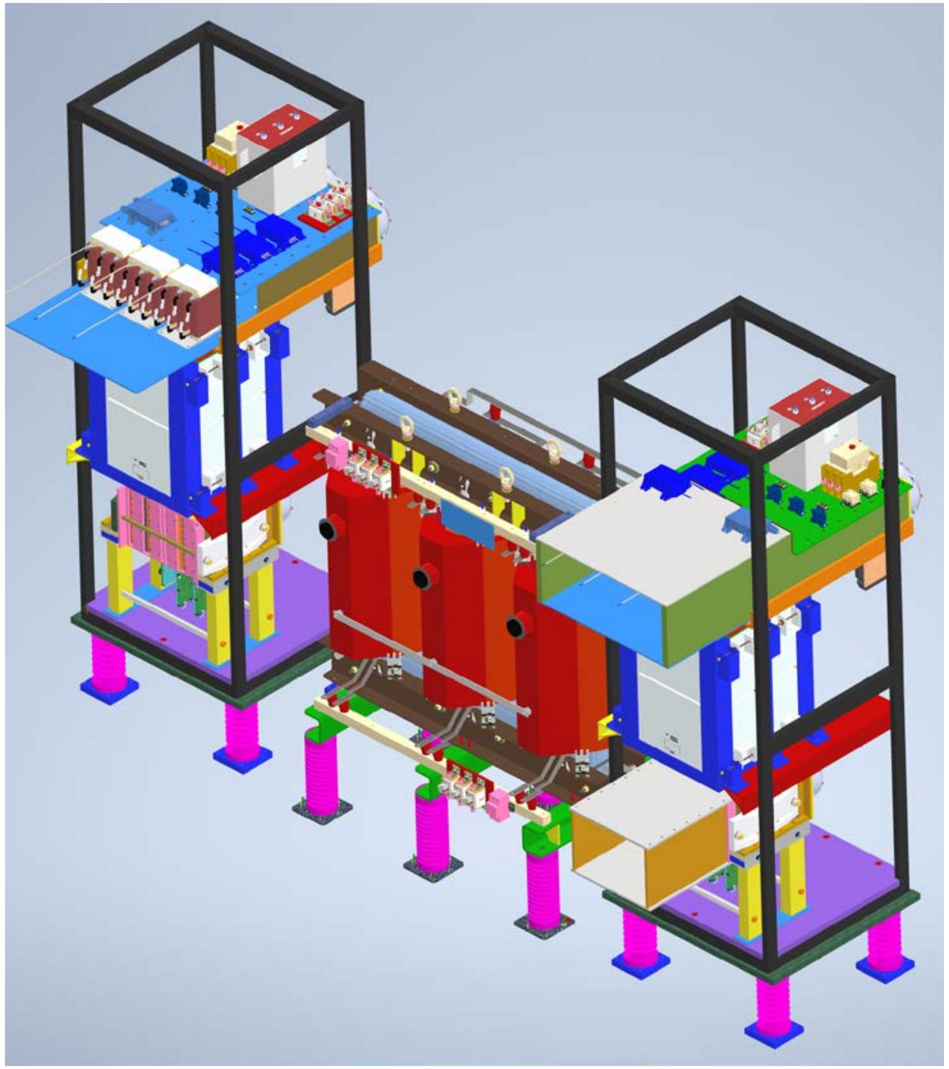




Power amplifier design: Transformer supplying two racks of converters

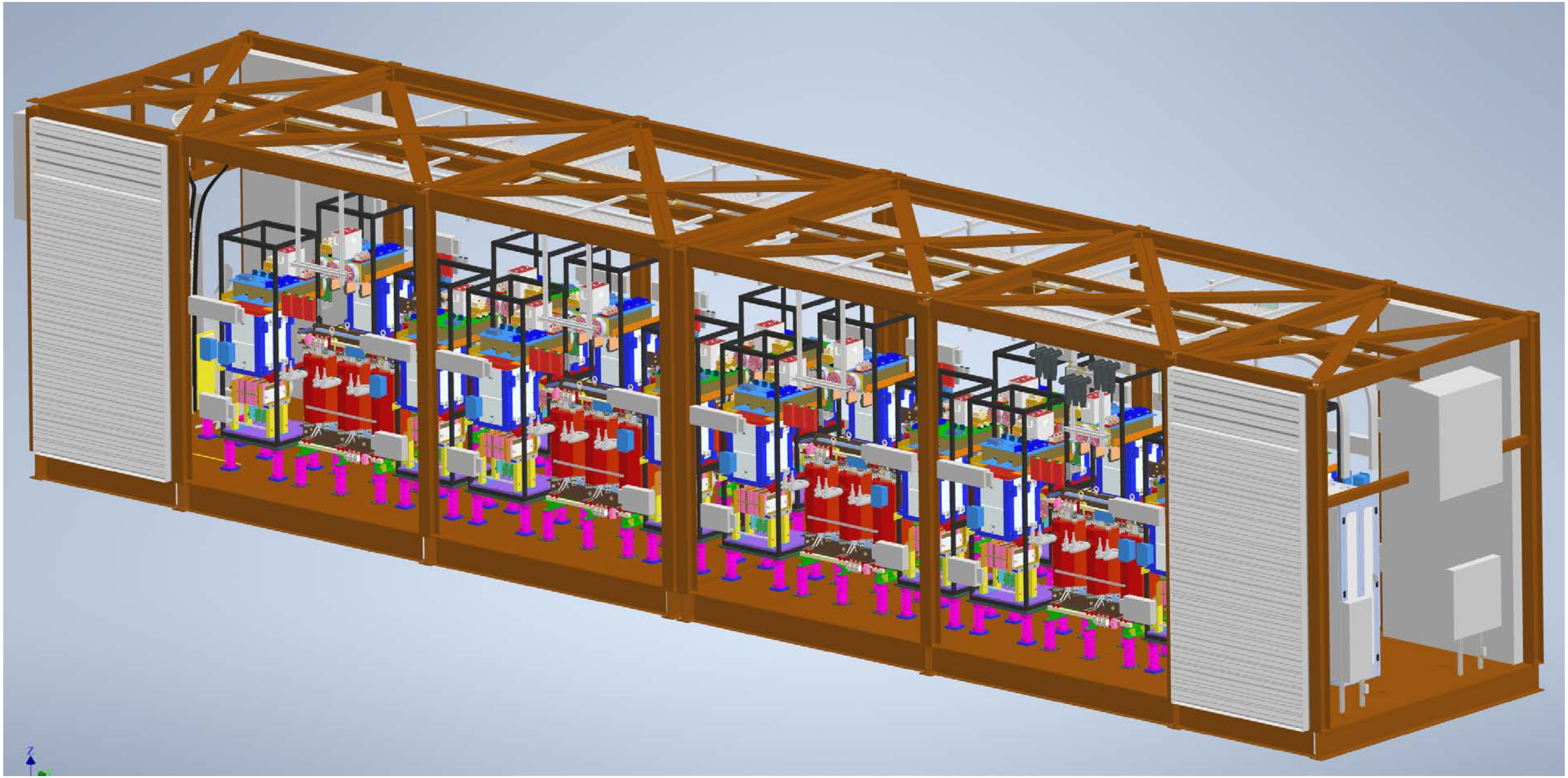


Front view



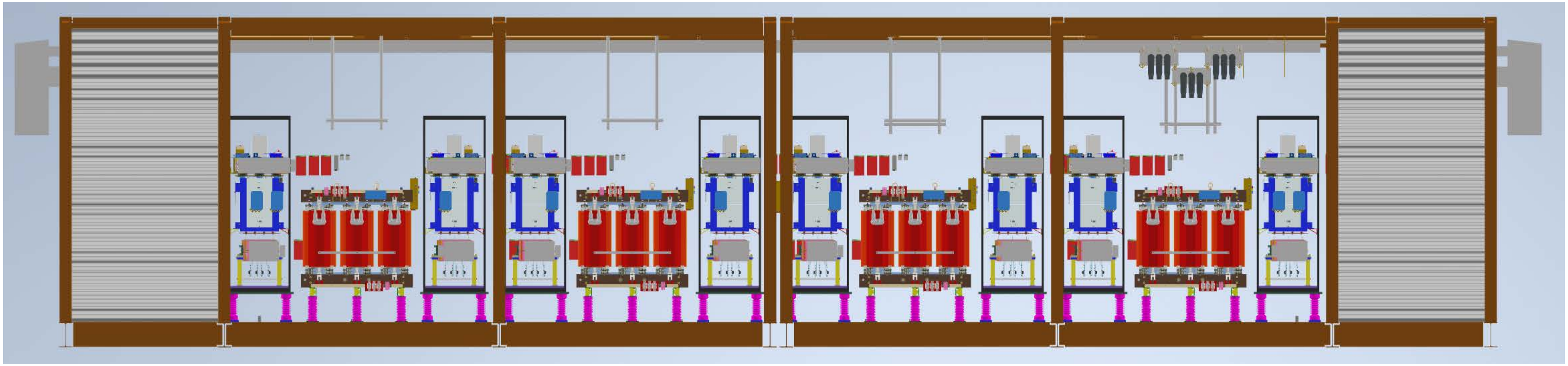
Rear view

Power amplifier design: E-House design (a total of 3 E-Houses will be required, 1 per phase)



Power amplifier design: E-House design

Length ≈ 62 feet



Power amplifier design: Geotechnical works for installation of the E-Houses (September 2022)

Conclusion

- **SimP is an in-house designed infrastructure specifically for PHIL**
  - Power electronic converters design
  - Design and validation of the control of power electronic converters
  - Design of a general closed-loop control for EMT-type PHIL
  - Design of the real-time simulator Hypersim
  - Design of the distribution test line

- **SimP is for:**
  - Optimal design of the network of the future
  - Significant benefits at IREQ and for partners

Appendix: publications

- O. Tremblay, H. Fortin-Blanchette, R. Gagnon and Y. Brissette (2017), Contribution to stability analysis of power hardware-in-the-loop simulators. IET Gener. Transm. Distrib., 11: 3073-3079. https://doi.org/10.1049/iet-gtd.2016.1574

- O. Tremblay, D. Rimorov, R. Gagnon and H. Fortin-Blanchette, "A Multi-Time-Step Transmission Line Interface for Power Hardware-in-the-Loop Simulators," in IEEE Transactions on Energy Conversion, vol. 35, no. 1, pp. 539-548, March 2020, doi: 10.1109/TEC.2019.2941567.

- D. Rimorov et al., "Power Hardware-in-the-Loop Testing of Residential PV Inverters in the Conditions of Weak Network," 2020 IEEE Power & Energy Society General Meeting (PESGM), 2020, pp. 1-5, doi: 10.1109/PESGM41954.2020.9281876.

- O. Tremblay (2020, Ph.D.). “Contribution to the design of the closed loop control of a real time power simulator”. École de technologie supérieure, Montreal, Electronic doctoral thesis (https://espace.etsmtl.ca/id/eprint/2693/)

- D. Rimorov, O. Tremblay, K. Slimani, R. Gagnon and B. Couillard, "Gain Scheduling Control Design for Active Front End for Power-Hardware-in-The-Loop Application: An LMI Approach," in IEEE Transactions on Energy Conversion, 2022, doi: 10.1109/TEC.2022.3193930.

- O. Tremblay, D. Rimorov, J.-F. Haché, D. Guérette, R. Gagnon, "A Power Hardware-in-the-Loop Infrastructure for DER Integration," in CIGRE Session 2022