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

Distribution test line
25 kV

Network simulation in Hypersim
PHIL Simulator (SimP) at a glance

Network simulation in Hypersim

Distribution test line
25 kV

Amplifier
7.5 MVA @ 25 kV

Closed Loop
PHIL Simulator (SimP) at a glance

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

Network simulation in Hypersim
PHIL Simulator (SimP) at a glance

- Distribution test line: 25 kV
- Amplifier: 7.5 MVA @ 25 kV
- Designed specifically for PHIL
- Multicell
- Without output transformer
- Movable

Network simulation in Hypersim

- Design of a general closed-loop interface
- Designed specifically for PHIL
- Embedded in Hypersim
PHIL Simulator (SimP) at a glance

SimP
In-house global design of the PHIL infrastructure

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

Distribution test line
25 kV

Amplifier
7.5 MVA @ 25 kV

Network simulation in Hypersim

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

Hydro-Québec
### Project milestones

<table>
<thead>
<tr>
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<tbody>
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<td>Cascaded H-Bridge</td>
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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

Complete the PA
- 3-phase
- 1.5 PU overvoltage capability
- 10 PU overcurrent capability
- DC to 1 kHz in closed-loop
IREQ
Substation
25 kV
Test Line
Phase A

Transformateur
360 kVA/180 kVA
180 kVA
25kV/960V/960V

Active Front End
167 kVA

Bus DC
1.5 @ 2.2
kVdc

H-Bridge
167 kVA

Power amplifier design: topology

Hydro-Québec
Power amplifier design: topology
Power amplifier design: topology
IREQ
Substation 25 kV
Test Line Phase A
16 H-Bridges
-2.2/0/+2.2 kV

Power amplifier design: topology

Transformateur
360 kVA/180 kVA
180 kVA
25kV/960V/960V
Active Front End
167 kVA
Bus DC
1.5 @ 2.2 kVdc
H-Bridge
167 kVA

SECONDAIRE_01
SECONDAIRE_02
SECONDAIRE_15
SECONDAIRE_16
PRIMAIRE_1
PRIMAIRE_6

Test Line
Phase A

Sut
25 kV
Power amplifier design: topology
Power amplifier design: topology
6TH INTERNATIONAL WORKSHOP ON GRID SIMULATOR

Power amplifier design: topology

IREQ Substation 25 kV

Test Line Phase A

Transformateur 360 kVA/180 kVA/180 kVA 25kV/600V/600V

Active Front End 167 kVA

Bus DC 1500 @ 2.2 kVdc

H-Bridge 167 kVA

Vout: 0 to 35.2 kV peak

Freq: DC to 7 kHz open loop
DC to 1 kHz closed-loop

16 H-Bridges in cascade

Vac
Vac filtrée
Power amplifier design: transformers insulation
Power amplifier design: transformer 372 kVA 25 kV/960V/960V

Output 960 V

Insulator

25-kV isolated

25-kV windings
Vacuum Cast Coil (VCC)
Power amplifier design: transformers test setup
Power amplifier design: rack and converters

Active Front End (AFE) with filter & meters
Control
DC Bus Capacitors
H-Bridge
Insulators

Front view
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)

Heat sink (heat pipe)
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
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 (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/)
