Workstream 1 update

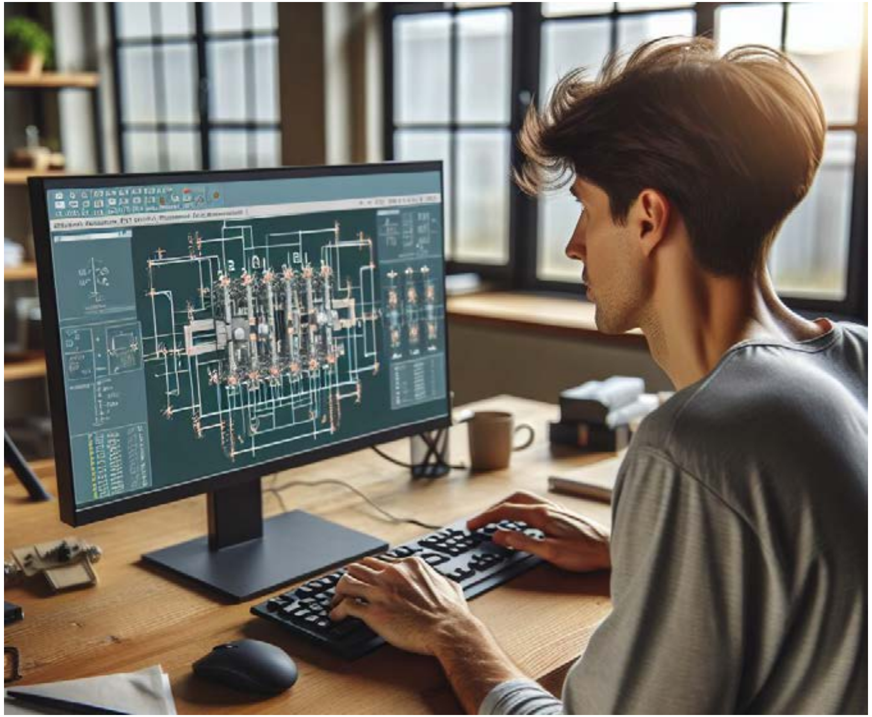
FAN Workshop
4 February 2025

Drs Josh Schipper, Veerabrahmam Bathini, Radnya Mukhedkar and Neville Watson

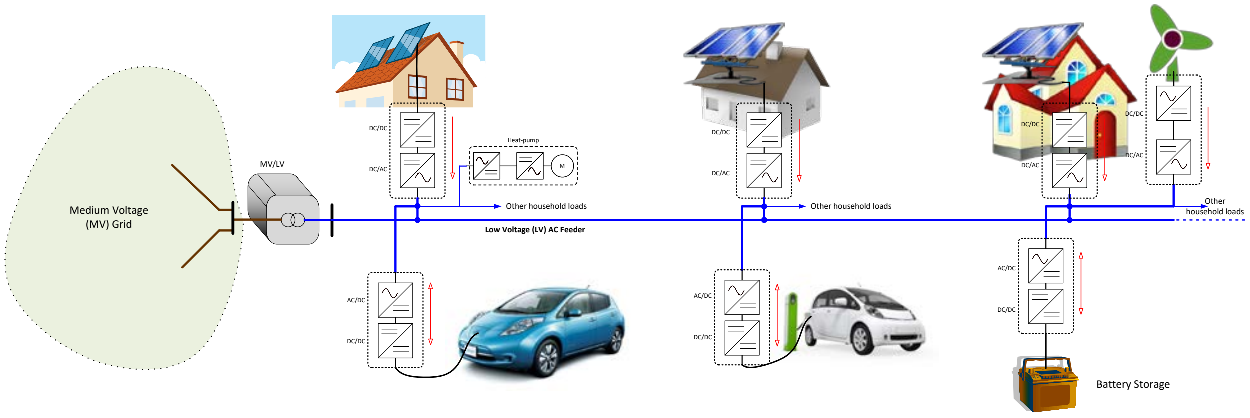
Future Architecture of the Network
TE WHATUNGA HIKO

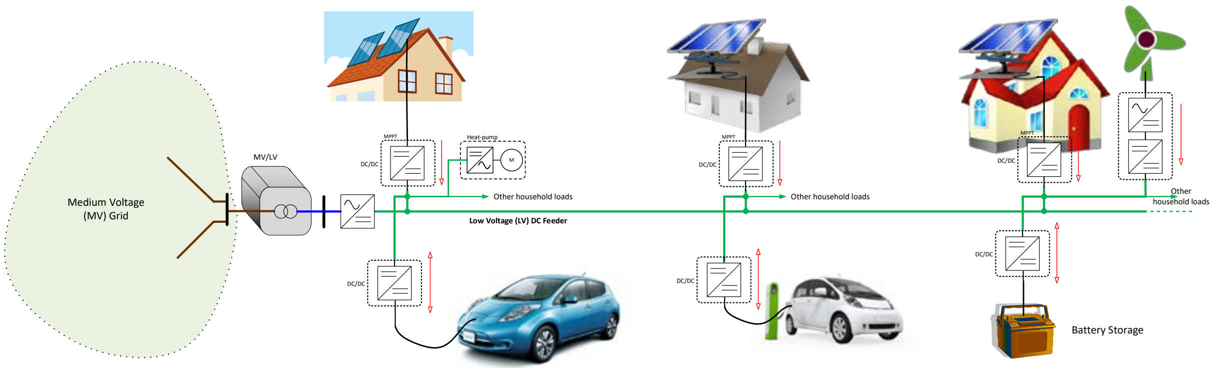
Outline

- Future Architecture of the Network (FAN)
- Workstream 1 Overview
- Activities of WS1 researchers

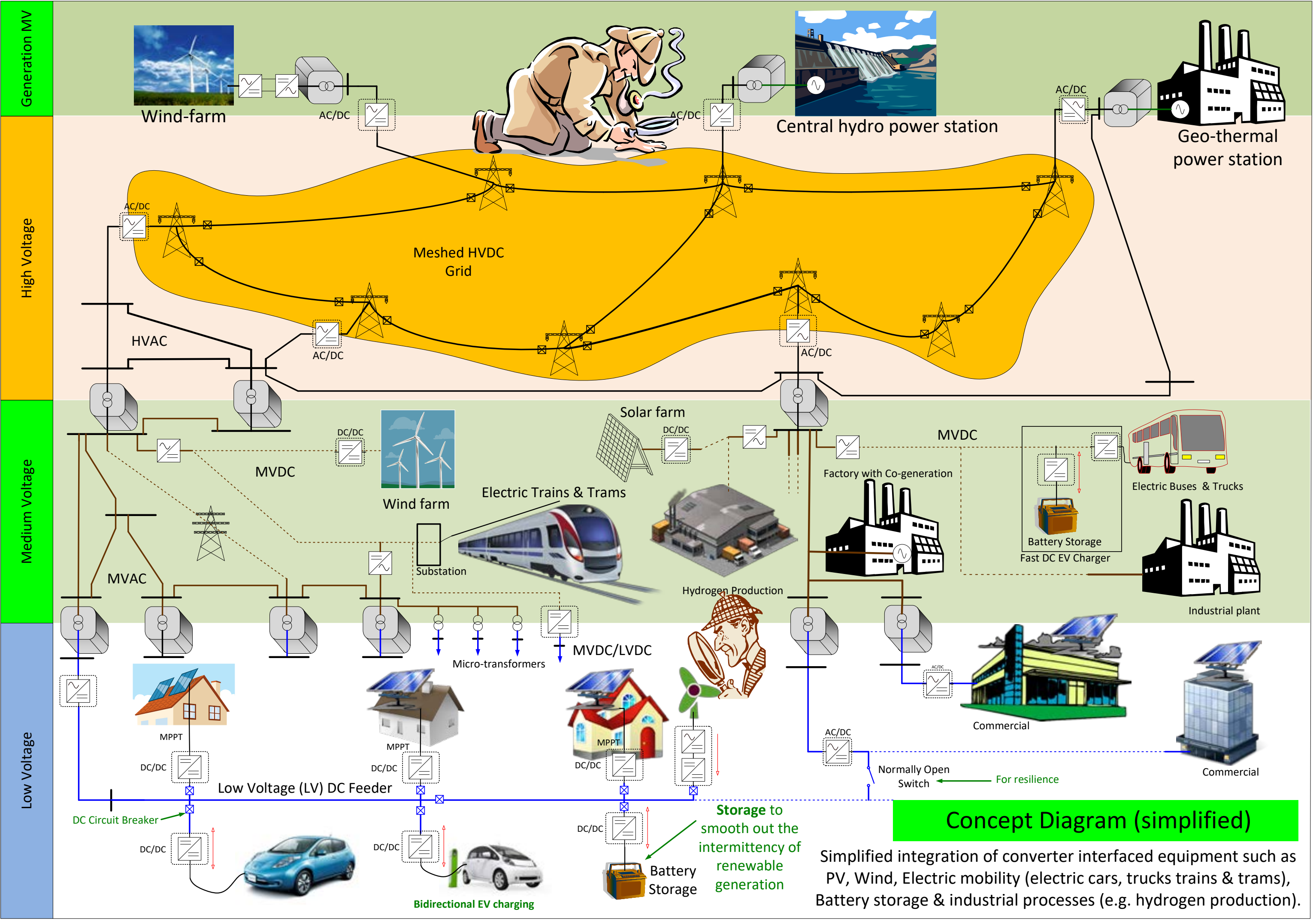


Future Architecture of the Network (FAN)





Concept Diagram



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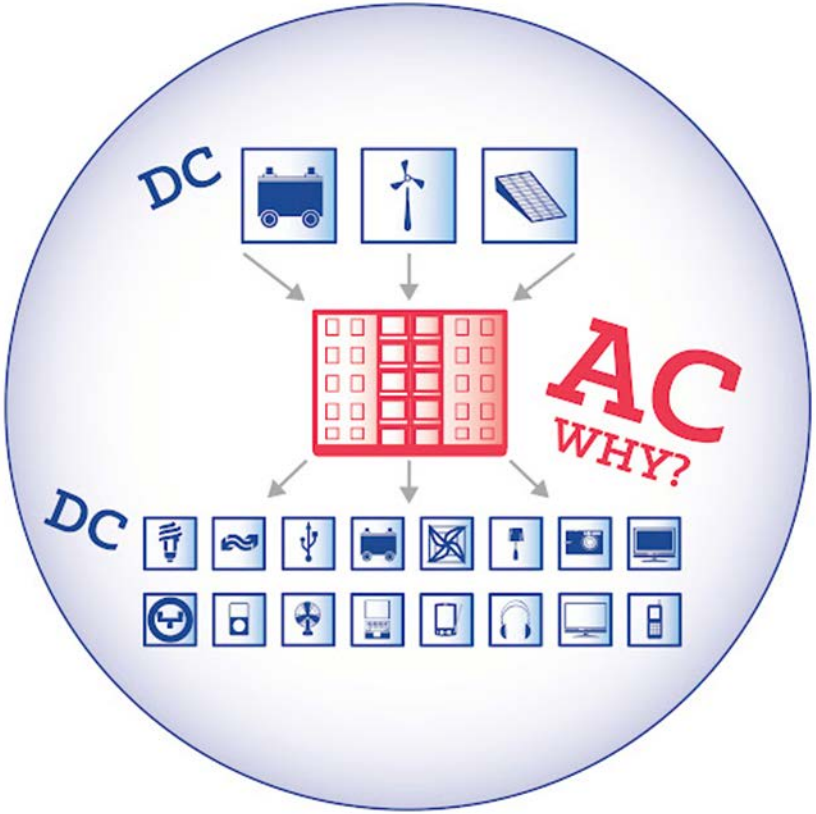
Why a Hybrid AC-DC Power system?

- There is an optimum voltage for a given distance and power to be conveyed.
  - The AC transformer is a mature technology with a high reliability and efficiency (Up to 99.7% for large power transformers)
  - DC/DC converters are available for lower voltage levels, but unlike to be available at 400 kV in the MW range in the foreseeable future.
  - A lot of money already invested in AC transformers
- Gives the best of both worlds. Easy integration of new technologies and easy translation of system voltage.
- DC already used for reticulation in some industries.
- Lower losses (Conversion and transmission).
- Direct integration of DC-based generation and loads.

Motivation

The question is not whether DC conveyance and DC systems will have a role in the system moving forward, but where should it be used, how is it to be implemented and how fast should it be deployed.



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About FAN

www.fan.ac.nz

Full Research programme name:

Architecture of the Future Low-Carbon, Resilient, Electrical Power System

Short-form name of the programme:

Future Architecture of the Network (FAN)

or *Te Whatunga Hiko*

7-year project (started in the latter part of 2020)

Science Leader: Professor Neville Watson (University of Canterbury)

Contact: **futurearchitecturenetwork@canterbury.ac.nz**

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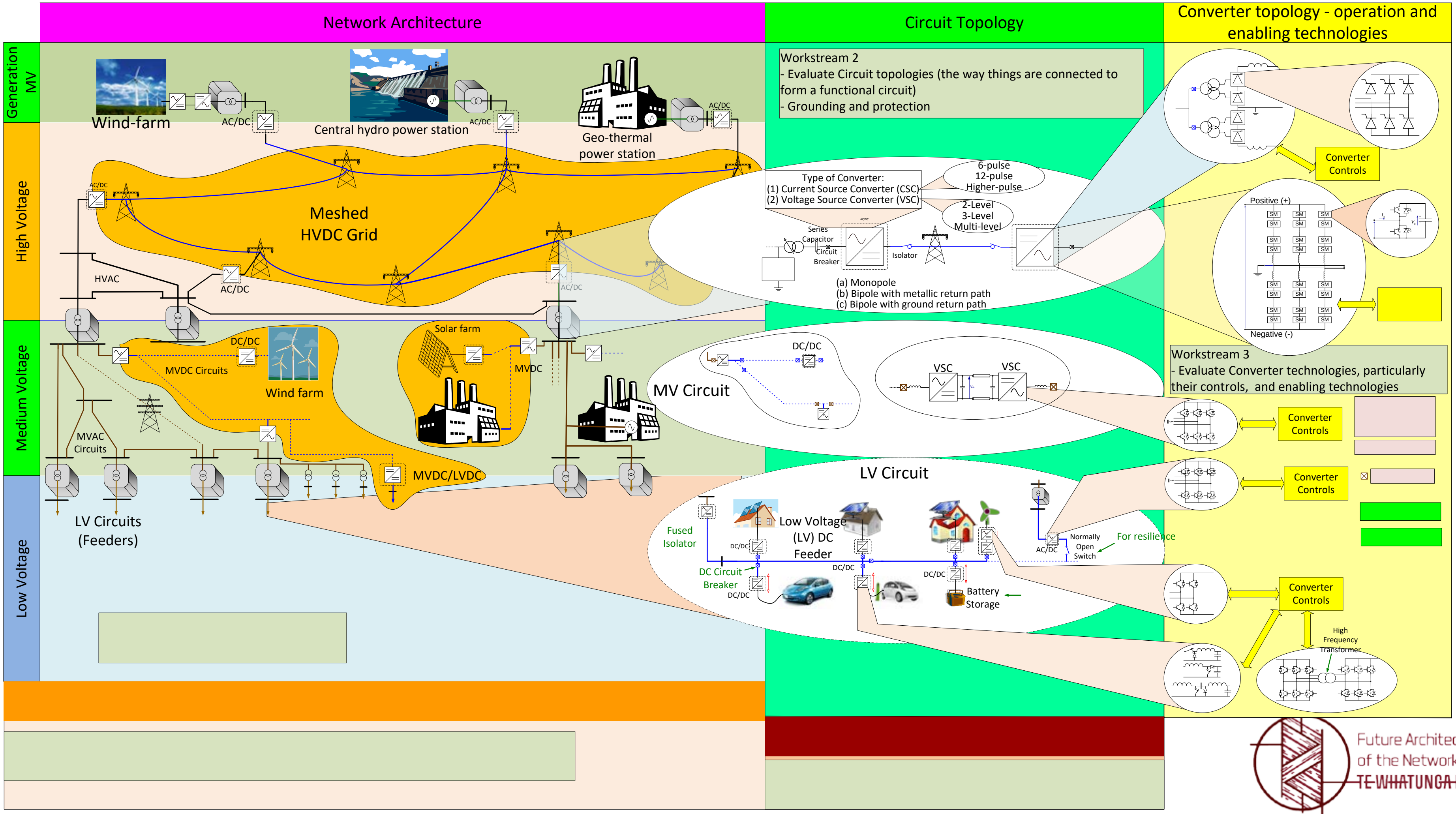

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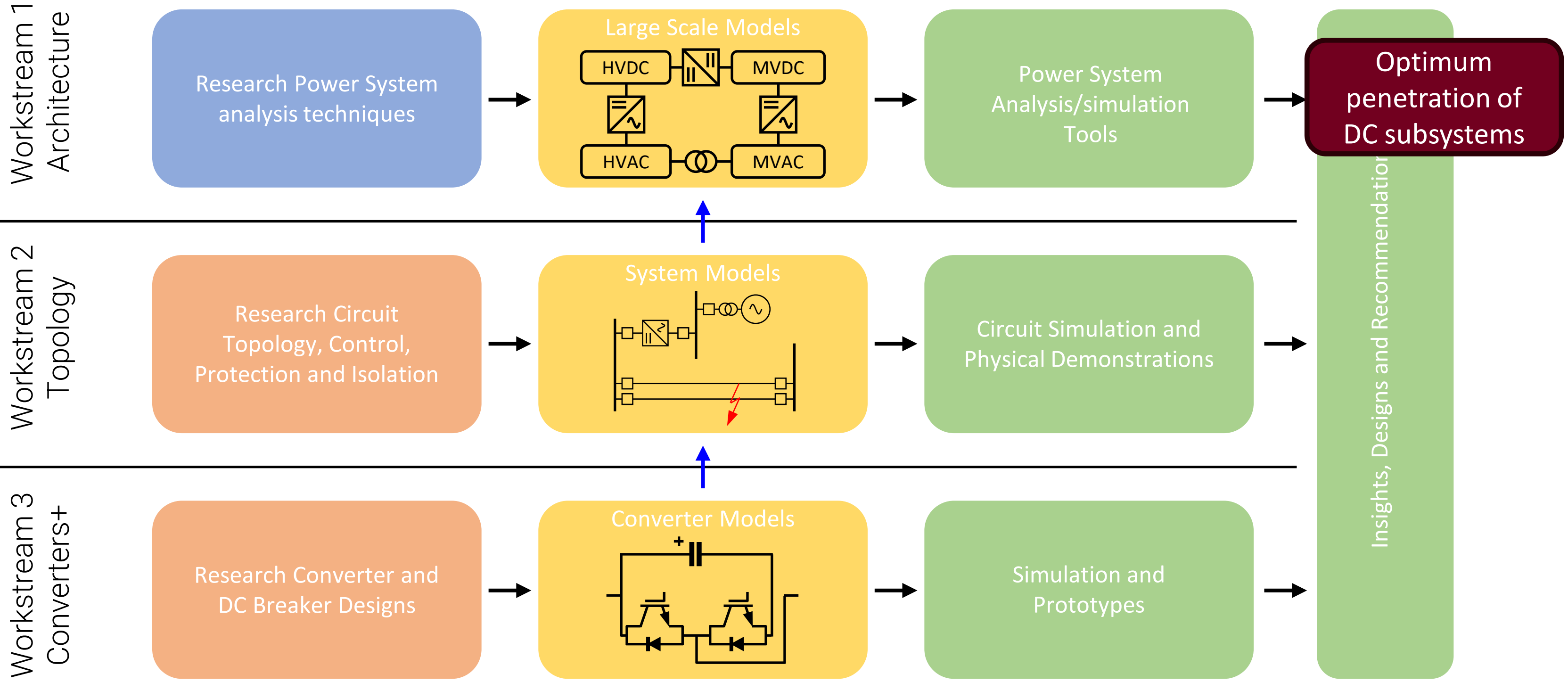
Overview


Workstream 1
Architecture
Research Power System analysis techniques
Large Scale Models
HVDC
MVDC
HVAC
MVAC
Power System Analysis/simulation Tools
Optimum penetration of DC subsystems
Workstream 2
Topology
Research Circuit Topology, Control, Protection and Isolation
System Models
Circuit Simulation and Physical Demonstrations
Workstream 3
Converters+
Research Converter and DC Breaker Designs
Converter Models
Simulation and Prototypes
Insights, Designs and Recommendations

Workstream 1 Overview

Workstream Objectives

We will develop a large-scale digital model encompassing DC grids and their interface to AC grids. They will enable operational steady-state, dynamic and transient studies associated with distributed power electronic converter interfaced technologies.

People

- Researchers
  - Radnya Mukhedkar (WS1 Lead, Germany)
  - Veerabrahmam Bathini (EPECentre)
  - Josh Schipper(EPECentre)
  - Nirmal Nair (UA)
  - Neville Watson (UC)
- PhD
  - Choidorj Adiyabazar
  - Christian Yap
  - Dilshani Maheepala
- ME (part-time)
  - Saranya Ramani
- Summer Students
- Final year project students

Strategic Intent: WS 1 – Network Architecture

Key questions	KPI	Target
To what extent has progress been made towards the strategic intent of the Research Programme and in delivering benefit for New Zealand? a. The Research Programme is making significant progress towards achieving its strategic intent. b. The Research Programme demonstrates a well-considered and strategic approach to planning, implementation and delivery (pathway to impact).	The strategic intent of this programme is to help resolve global challenge of transitioning to a low greenhouse gas emission society and economy, by finding solutions that efficiently manage future integrated energy flows through appropriate design of the electrical transmission and distribution systems. It means we will: 1. Define technical solutions towards this long-term objective, which will contribute to the 100% renewable objective and to increase resilience in the electrical power system 2. Engage with end-users who will build, develop and use these solutions in the future 3. Inform government regarding strategies and investments 4. Develop technical capability within New Zealand 5. Position New Zealand as internationally recognised in this area.	**By end of June 2024:** We will have developed a power-flow analysis tool for a hybrid AC/DC network on all voltage levels, working with: - Transpower and EDBs to understand their planning and operational study methodologies and requirements - Power system software solution providers to ensure that the research outcomes can be embedded into existing tools. **By end of June 2025:** We will have developed an analysis tool for fault analysis for a large hybrid AC/DC network, working with: - Transpower and EDBs to understand their prevalent AC fault analysis and protection co-ordination philosophy - Technology providers to understand the practical implementation of converter interfaced technologies **By end of June 2027:** We will have developed a dynamic analysis tool for a large hybrid AC/DC network on all voltage levels, working with Transpower and EDBs to share the knowledge, Beta version network models and tools to assess high penetration of DC in an AC system.

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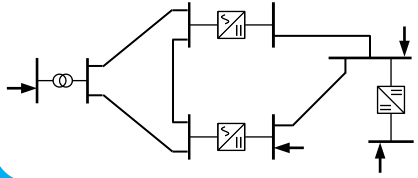
Objectives of Workstream 1

Tools

POWER-FLOW ANALYSIS



Capabilities

- To simulate hybrid AC-DC network topologies with detailed models of converter technologies.
- Capable of simultaneous simulation of both:
  - Transmission and Sub-transmission networks
  - Sub-transmission and distribution networks
  - AC and DC networks

FAN Outcomes

- Feasibility study to optimise DC integration

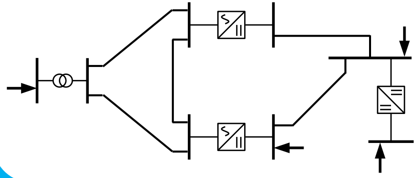
Basis for Future Industry Tool

- For Planning
- For Contingency Analysis/ Security Assessment

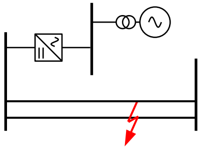
Objectives of Workstream 1

Tools

POWER-FLOW ANALYSIS



SHORT-CIRCUIT ANALYSIS



Static Assessment

Capabilities

- To simulate hybrid AC-DC network topologies with detailed models of converter technologies.
- Capable of simultaneous simulation of both:
  - Transmission and Sub-transmission networks
  - Sub-transmission and distribution networks
  - AC and DC networks

FAN Outcomes

- Collaborate with Workstream 2 to understand the impact of protection requirements on circuit topology

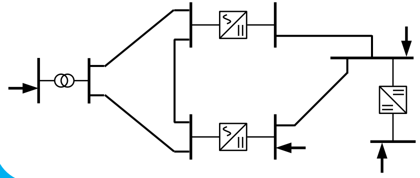
Basis for Future Industry Tool

- To address protection coordination
- Design of protection system and associated settings

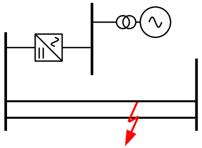
Objectives of Workstream 1

Tools

POWER-FLOW ANALYSIS

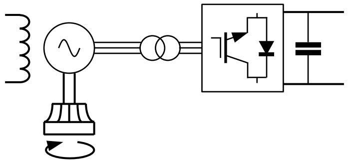


SHORT-CIRCUIT ANALYSIS



Static Assessment

DYNAMIC ANALYSIS



Capabilities

- Gives due consideration to the influence of power electronic converters on the dynamics of the network.
- Capable of simultaneous simulation of both:
    - Transmission and Sub-transmission networks
    - Sub-transmission and distribution networks
    - AC and DC networks

FAN Outcomes

- Determine the system security requirements on network architecture.
- Assess the impacts of converter control design on whole networks.

Basis for Future Industry Tool

- A planning and operational tool for assessing network stability.

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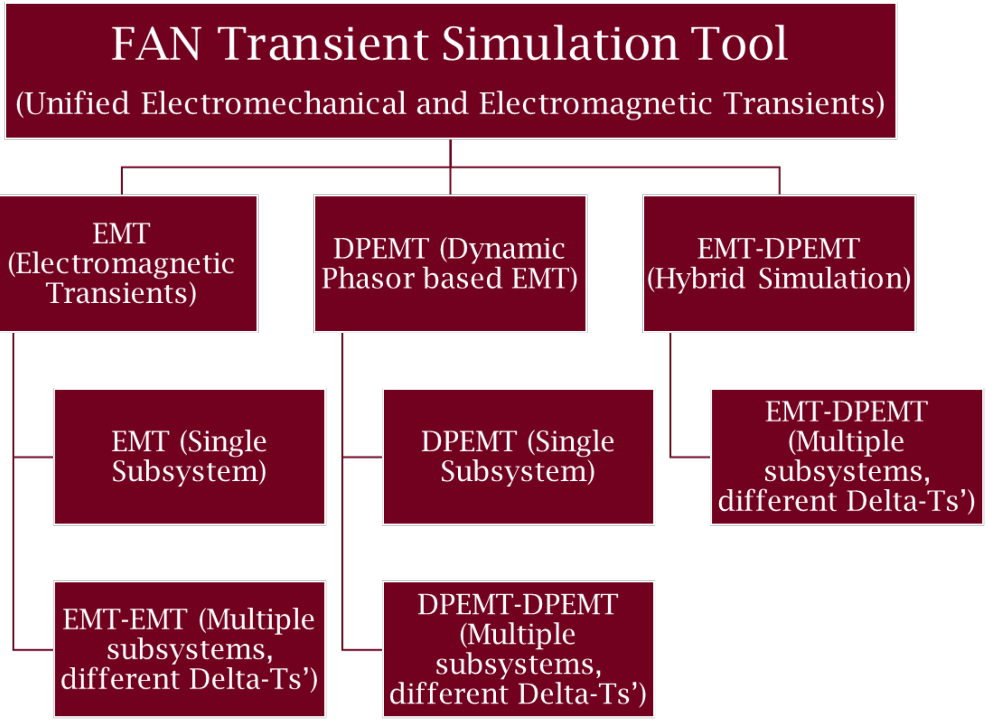
Dr Veerabrahmam Bathini

Activities

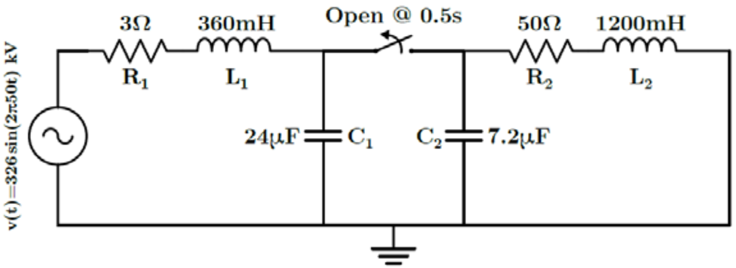
- Software tool development
  - Power-flow tool
  - EMT tool
- Case study completed.
- Supervising final year project sponsored by Unison.
- Supervising summer students.
- Assisting part-time Masters student.
- Veerabrahmam has been working part-time with Orion. (Oct-Dec).

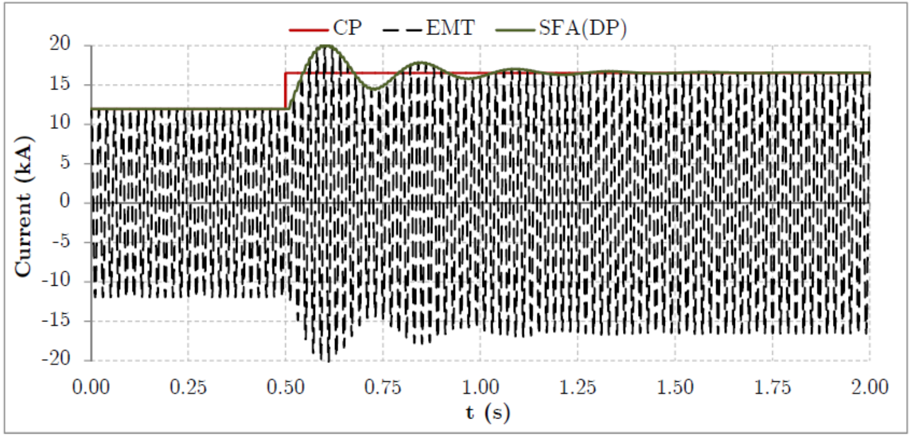
FAN Transient Simulation Tool



FAN Transient Simulation Tool Features

Hybrid Simulation EMT-DPEMT



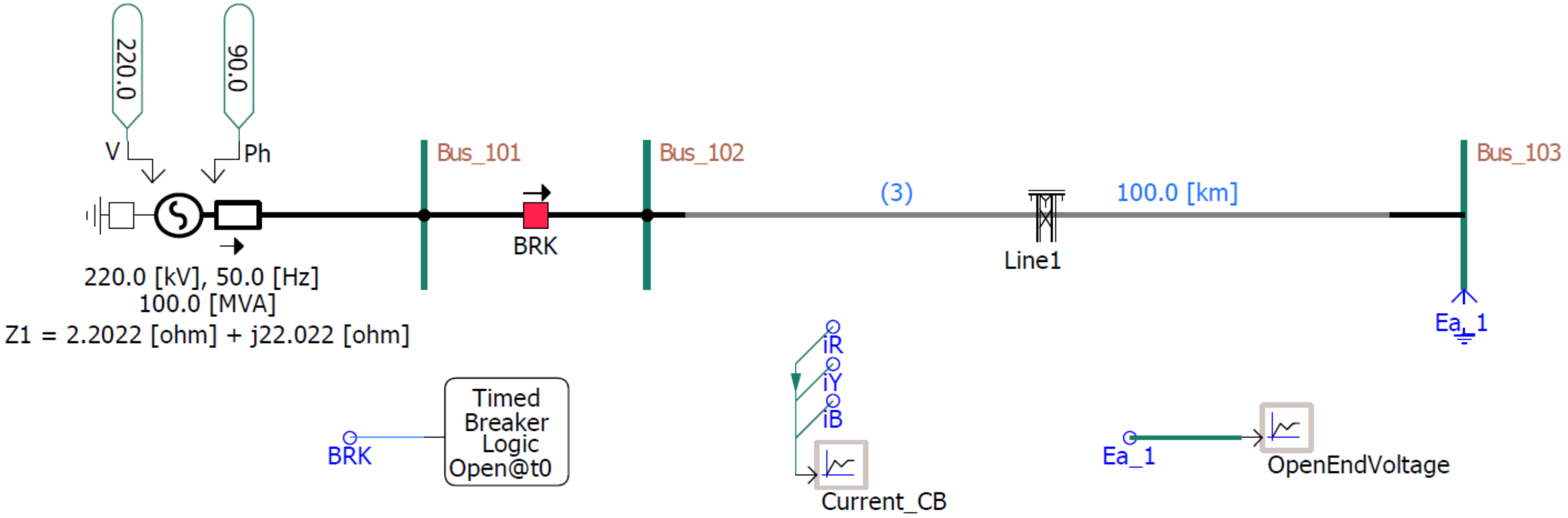


CP : Constant Phasor
EMT : EMTP
SFA : Shifted Frequency Analysis (DPEMT)

FAN Transient Simulation Tool Features

- Subsystems and Parallel Processing.
- Initialisation of network and control state variables from power-flow results.
- One simulation tool for all voltage levels similar to FAN power-flow tool
- GPU based Multi-level MATE (Multi Area Thevenin Equivalent) solution for large scale hybrid AC-DC systems.

Line Energisation Study



No Control

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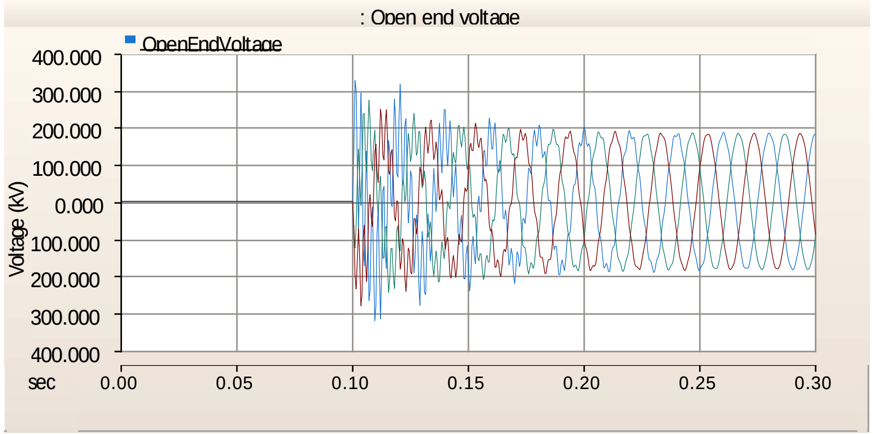
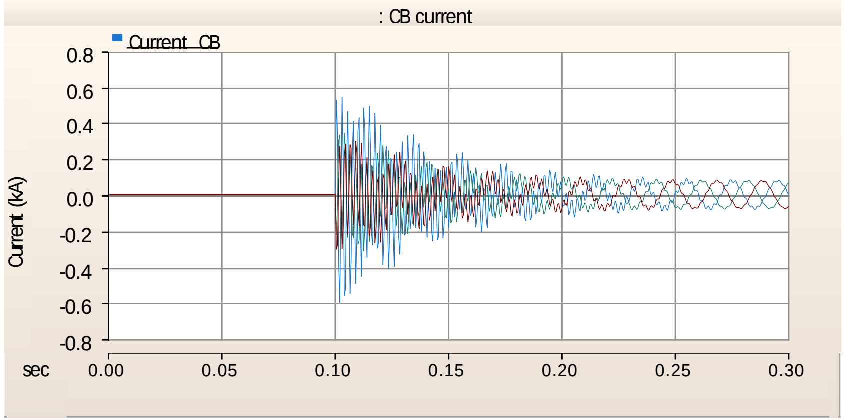
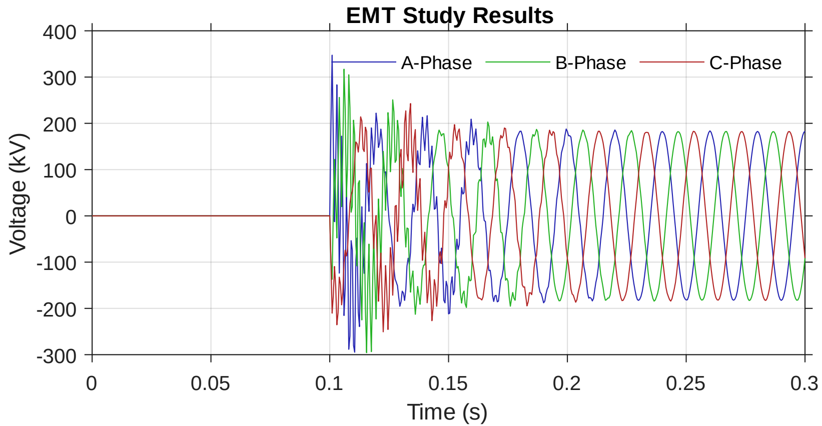
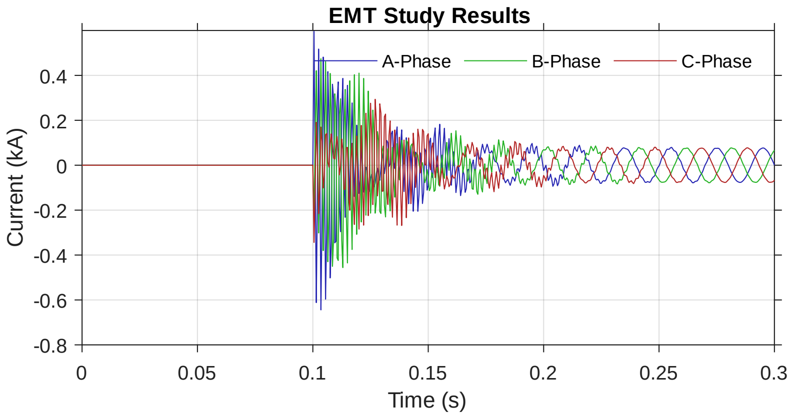
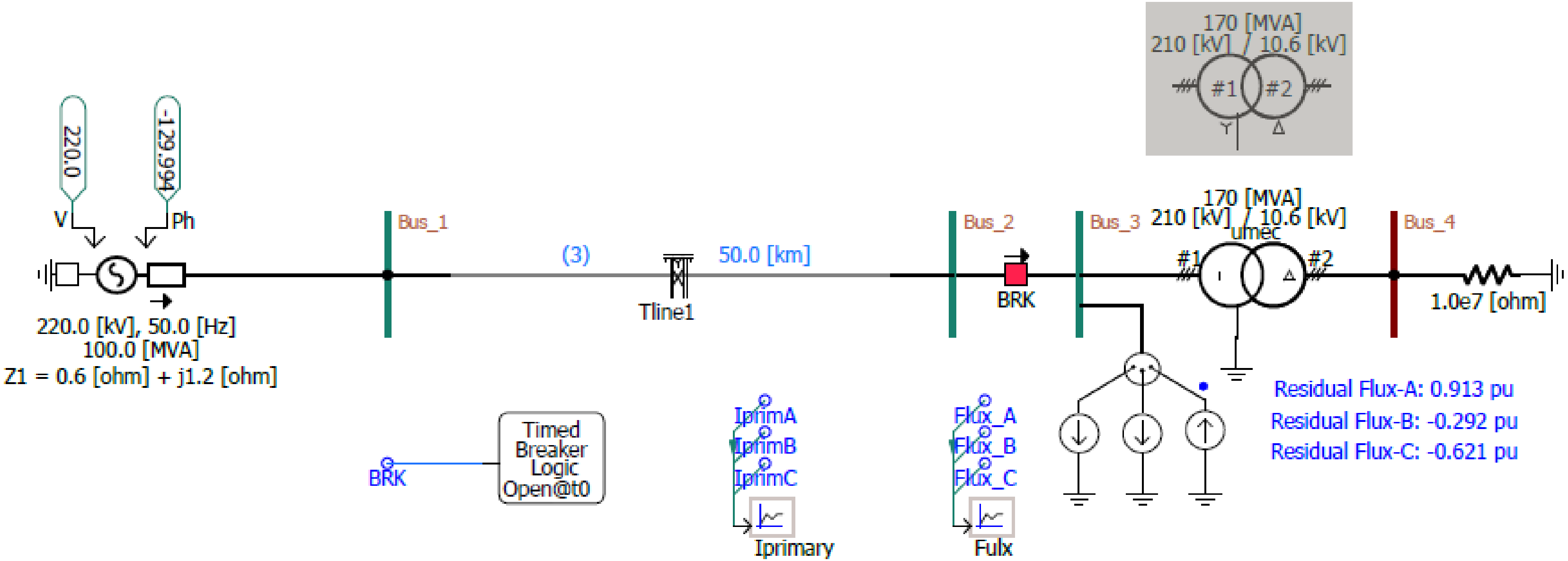








Transformer inrush current



Fact Sheet: Transformer Inrush current study using MicroTran software, 2003
B. Holmgre, R.S. Jenkins and J. Riubrugent, Transformers inrush current, CIGRE Paris paper 12-03, 1968

Primary side Inrush Current

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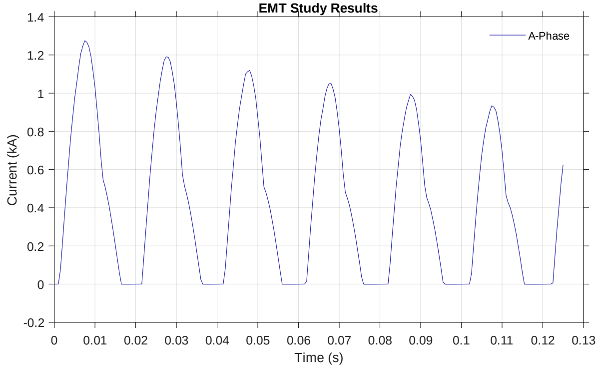
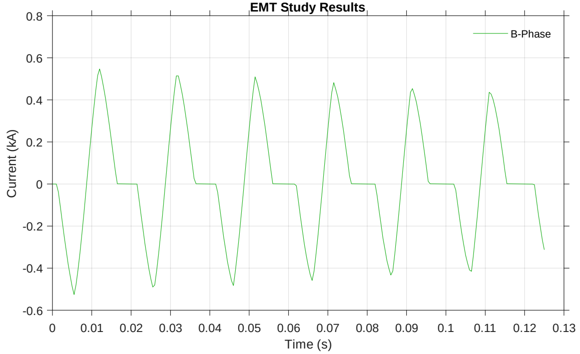
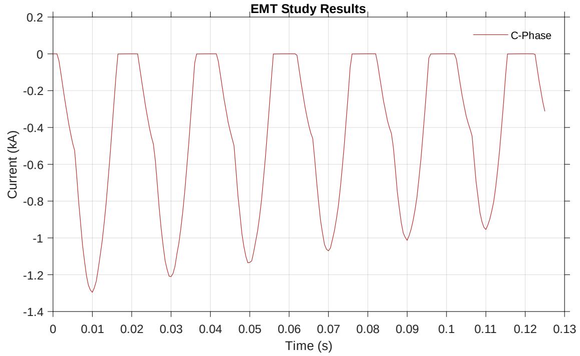






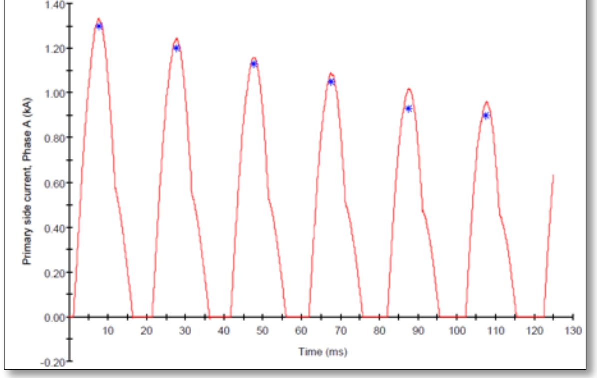


Fig 5: Current phase A on primary side (* = measured).

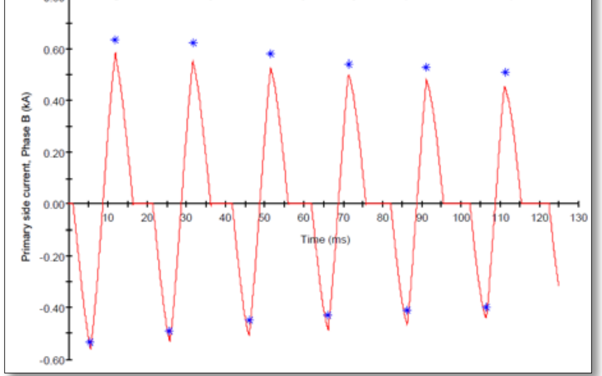


Fig 6: Current phase B on primary side (* = measured).

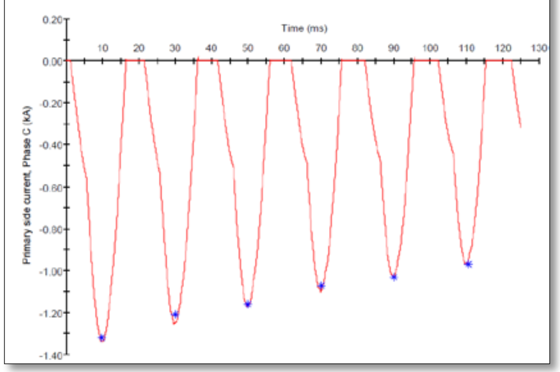
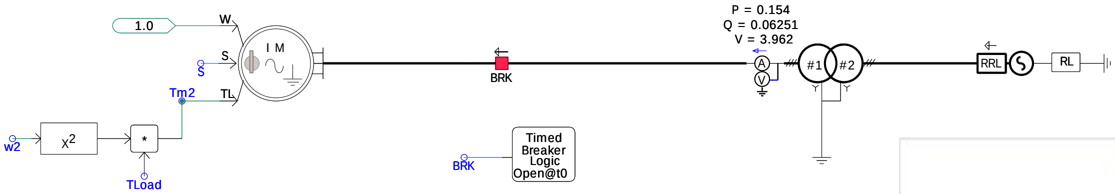
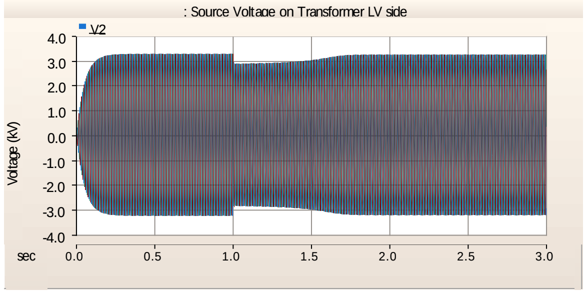
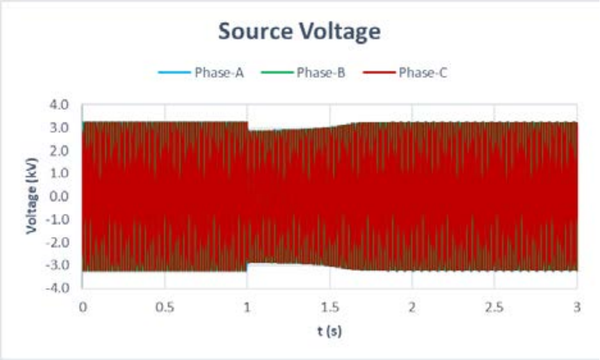


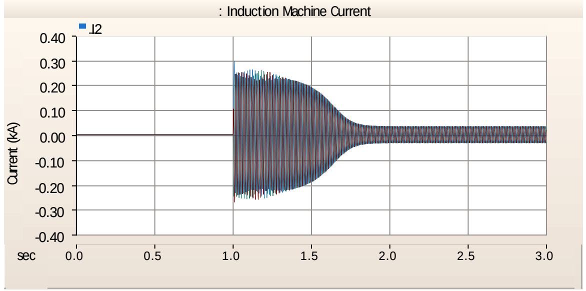
Fig 7: Current phase C on primary side (* = measured).

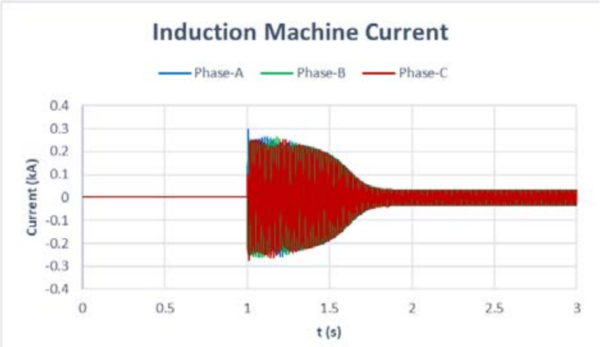
Induction Machine Starting



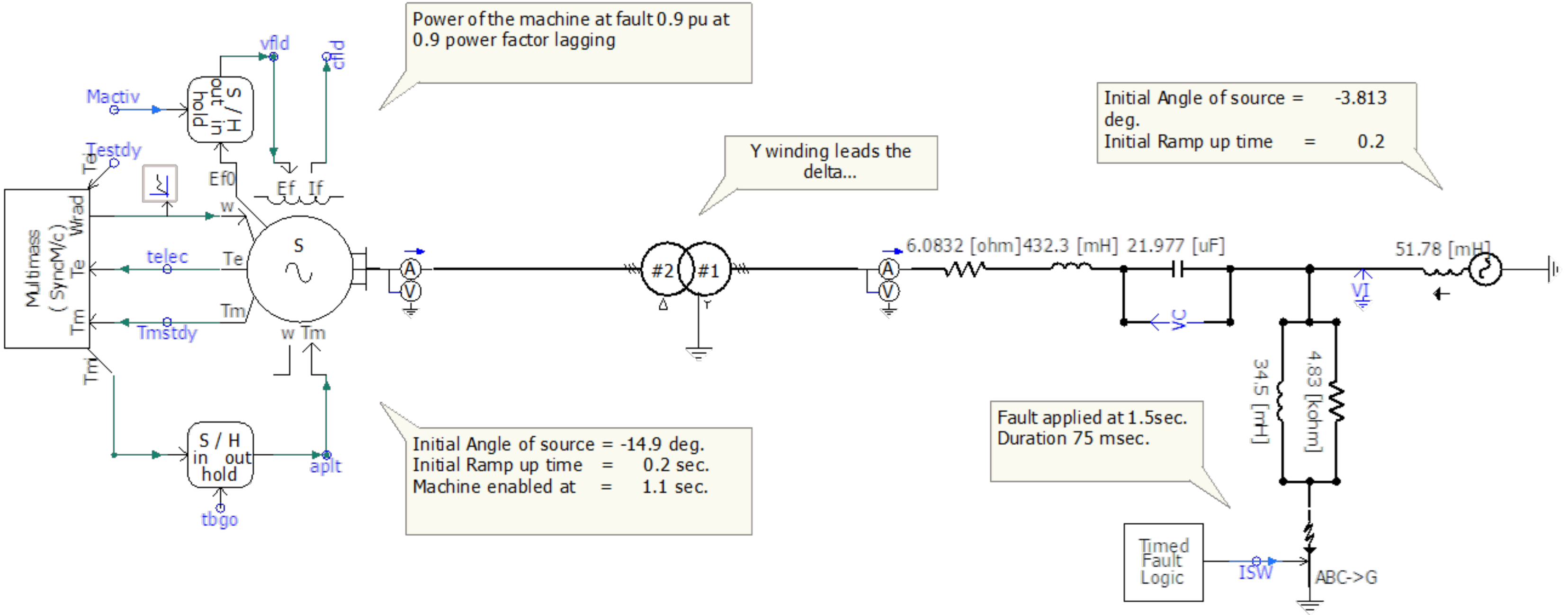








IEEE First Benchmark model for SubSynchronous Resonance



Classification: In-Confidence

Results for SSR IEEE benckmark model

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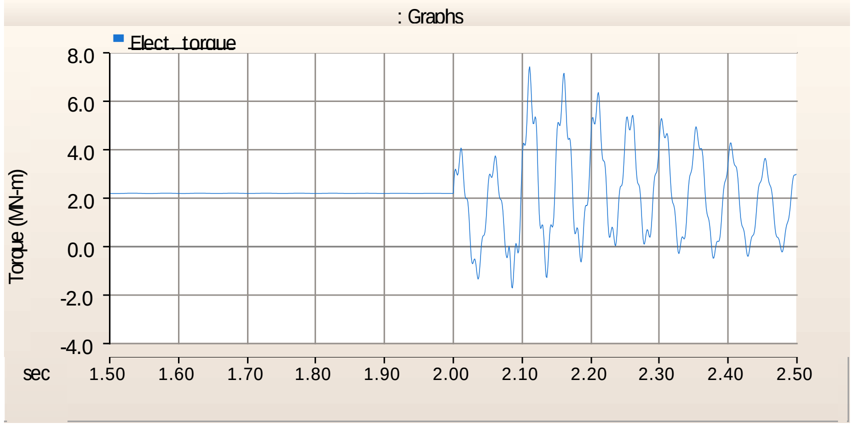
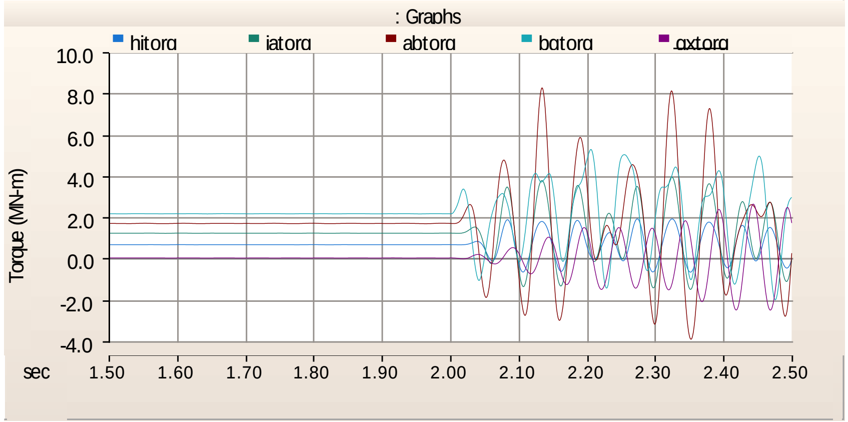
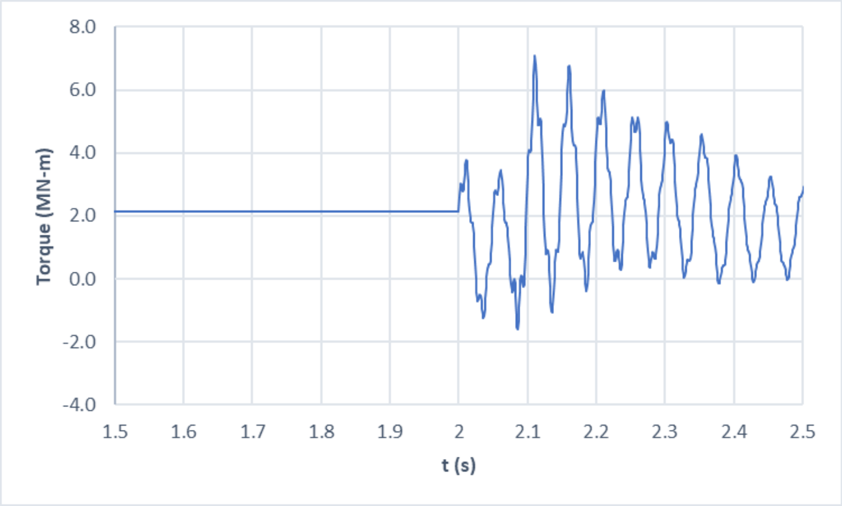
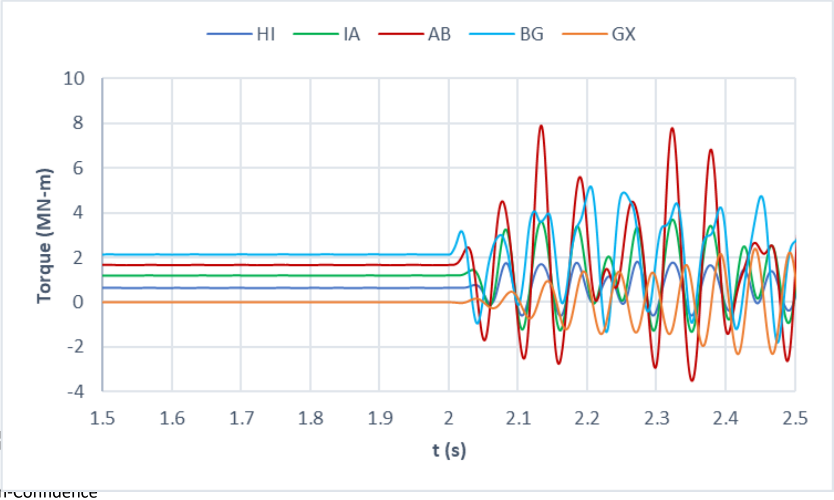








Dr Josh Schipper

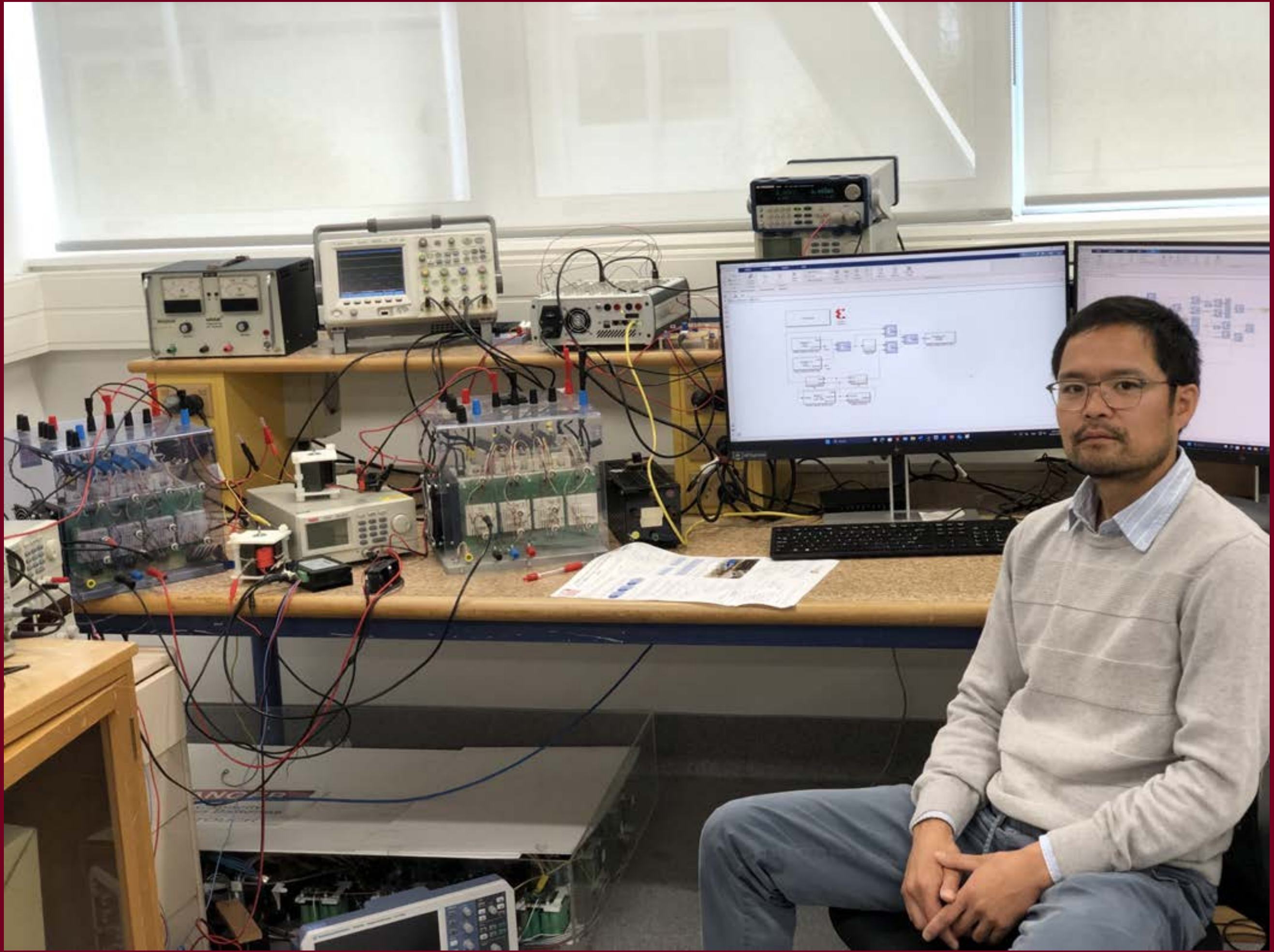
Activities

- Presented the paper “AC versus DC networks – Control and stability through modelling”, at the conference “DC Verteilnetztagung” in Goerlitz Germany. (11-12 April 2024)
- Conducted experimental work at Technische Universität Dresden (TU Dresden) to contribute data to the paper called “Generalized Harmonic Domain Analysis”. (April 2024)
- Gave a seminar at TU Dresden. (April 2024)
- Completed two journal papers which are presently under review:
  - Generalised Harmonic Domain Analysis for Transformer Core Hysteresis Modelling (January 2025)
  - Revisiting power system analysis for hybrid AC/DC grids (June 2024)
- Supervising summer students

DC Verteilnetztagung", Goerlitz Germany. (11-12 April 2024)

Choidorj Adiyabazar

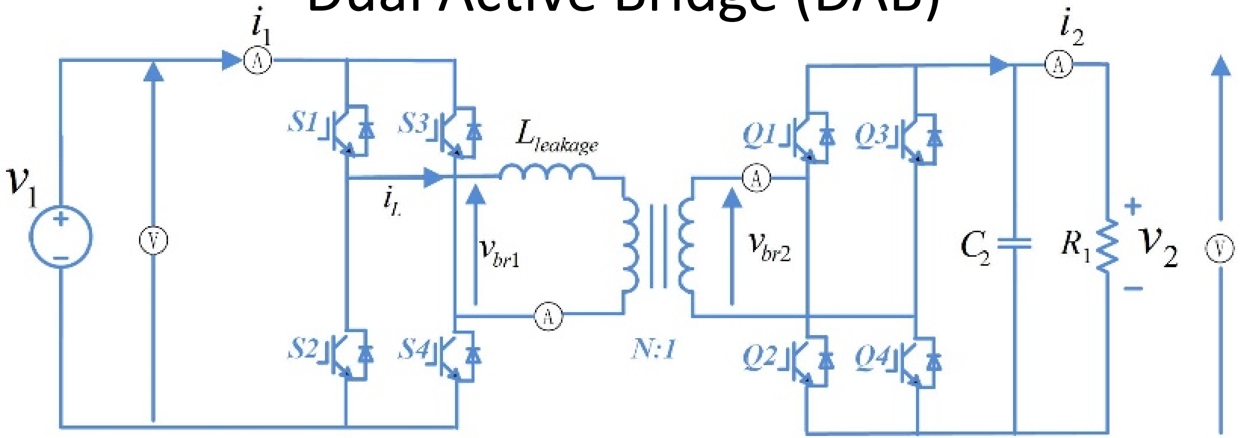
Topic: Modelling and Control of Dual Active Bridge (DAB) DC/DC Converters in DC Grids.



Activities

- Presented his work to TU Dresden (online). (January 2025)

Dual Active Bridge (DAB)



Work to date and research plan

DC/DC Dual Active Bridge (DAB) interaction with AC/DC converter

Modelling of DC/DC DAB converter (completed)

- A linear reduced-order model was developed for the DC/DC DAB and then validated using PSCAD.

Passivity analysis (completed)

- Develop a linear control method for the DC/DC DAB converter using Passivity analysis to mitigate instability problems caused by CPL and interactions in the DC grid.

Verification of a DAB converter

- The digital control is implemented using dSPACE to verify DC/DC DAB converter is connected to the DC grid to stabilise and ensure the overall system's stability.

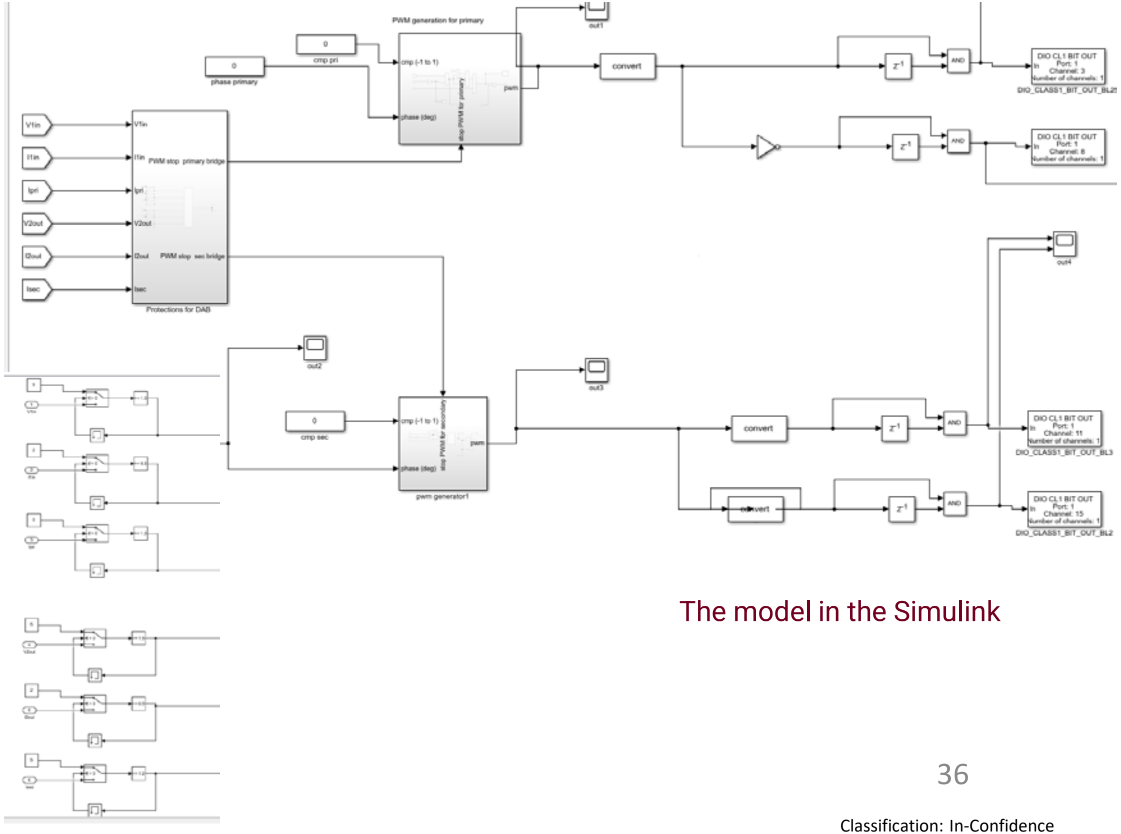
Modelling of DC/AC inverter

- A linearised DC/AC inverter with a linear controller model will be developed for use AC/DC hybrid grids.

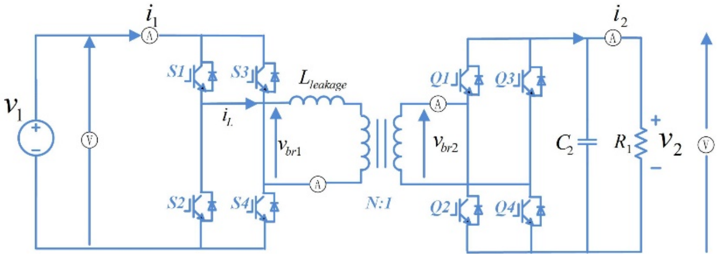
Analysis of interactions in AC/DC grids

- The interactions between DC/DC DAB converters and DC/AC inverters within the hybrid AC/DC grids will be analysed and mitigated using passivity analysis

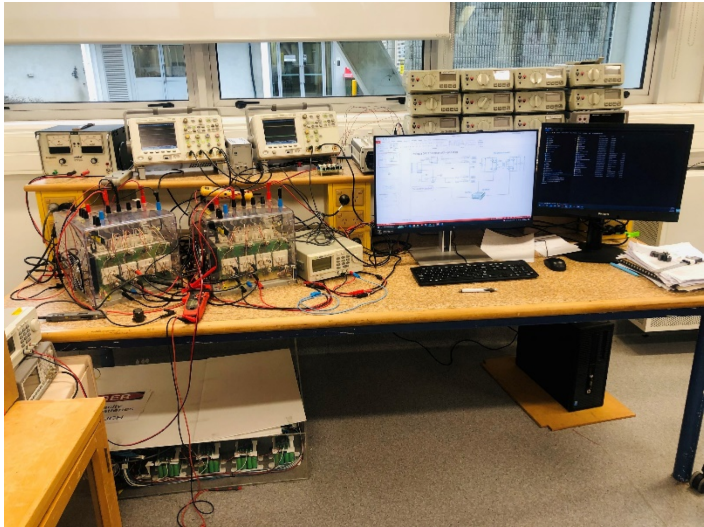
Laboratory setup



The model in the Simulink



Schematic of a DAB converter



TESTING OF A PROTOTYPE DC/DC DUAL ACTIVE BRIDGE (DAB) CONVERTER

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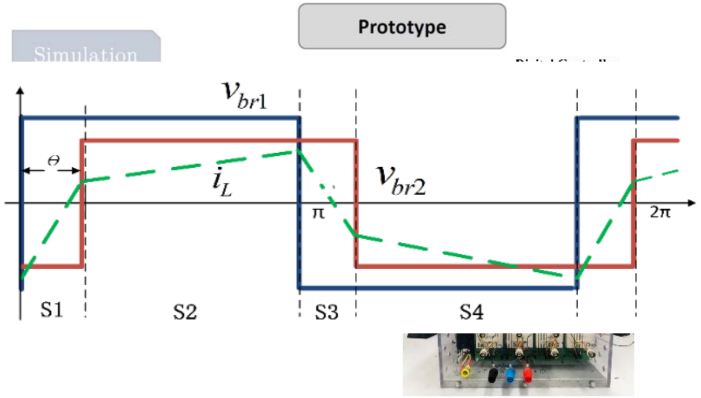
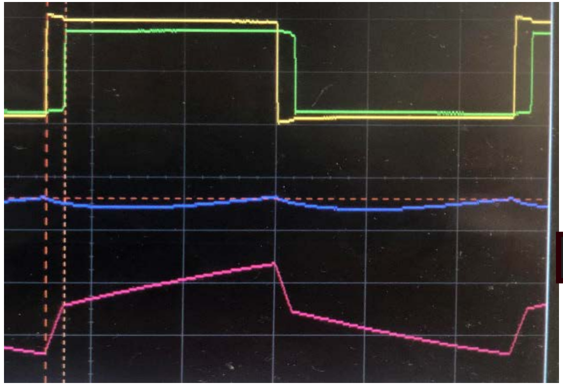
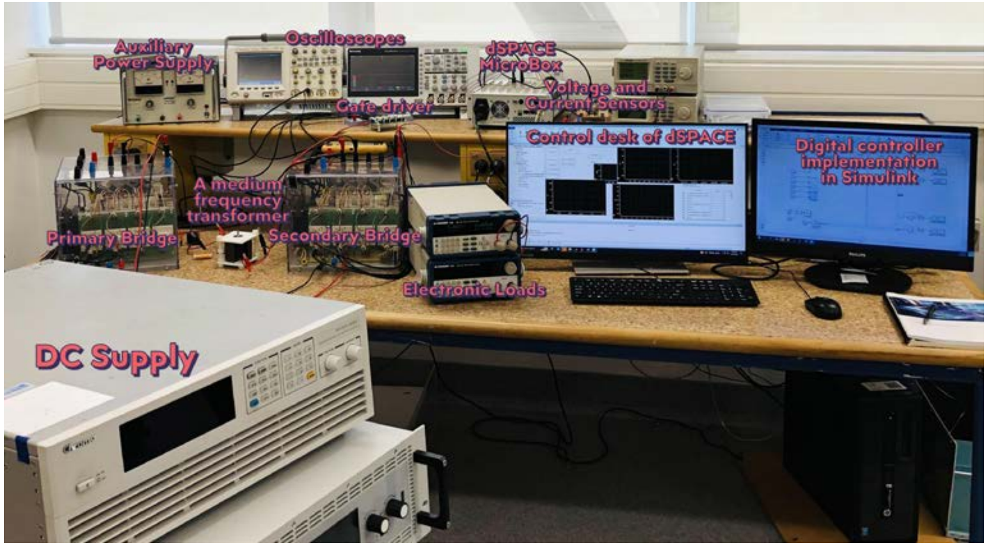




Testing and verification process



Low power prototype-experimental setup

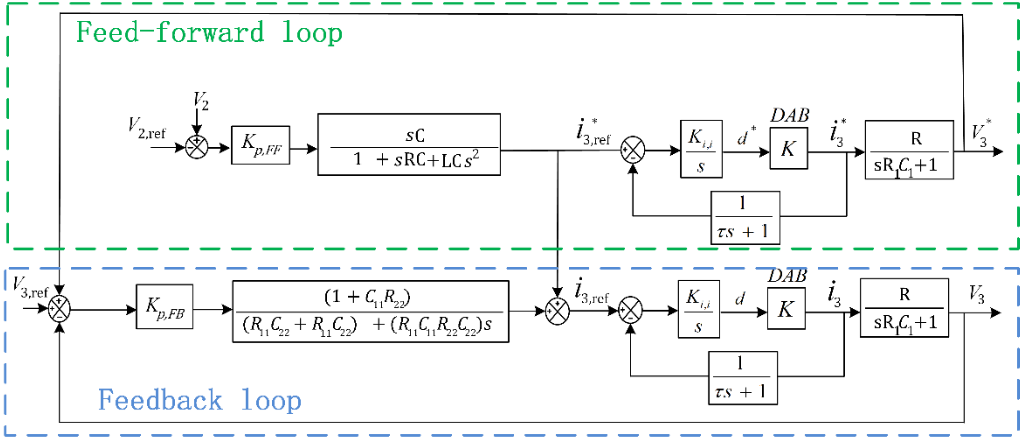
a)Yellow line represents the primary 48V AC voltage

b) Green line represents the secondary 46V AC voltage

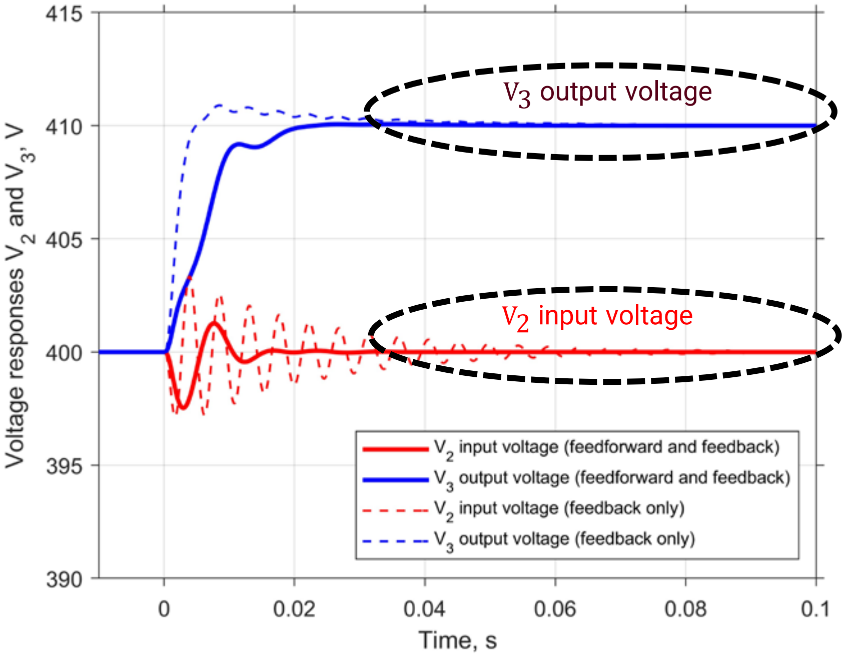
c) Blue line represents DC output current

d) Pink line represents the transformer leakage current

Passivity stability analysis



Block diagram of the feedforward and feedback controller



Step response $V_{3,\mathrm{ref}}$ in the output voltage reference

Christian Yap

Topic: Steady-state fault analysis of hybrid AC/DC networks using generalized converter models

Activities

- Completed his Ph.D. confirmation report, and passed the oral. (Aug 2024)
- Presented the paper "*Fault Analysis of Hybrid AC/DC Networks*", at the ISGT Asia conference, Bengaluru, India , 10-13 November 2024.

Test case

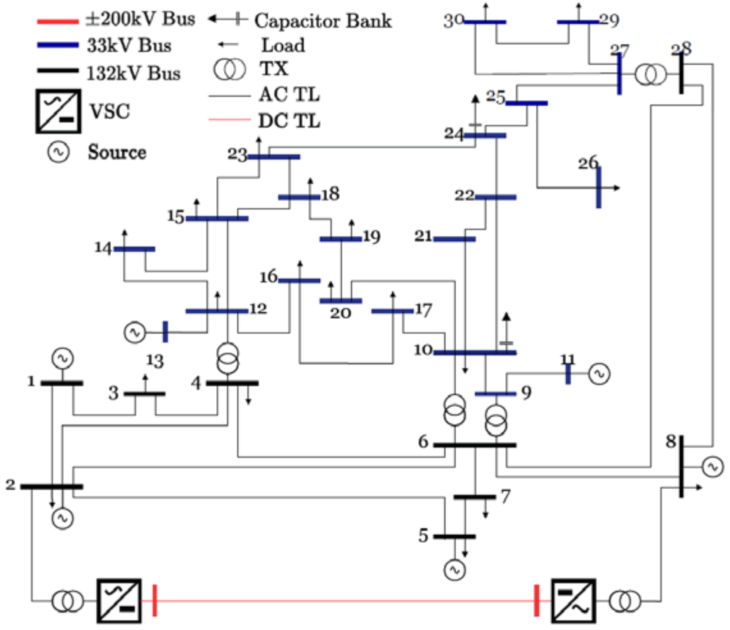


Figure 5.1: Augmented IEEE30 bus with point-to-point HVDC-VSC

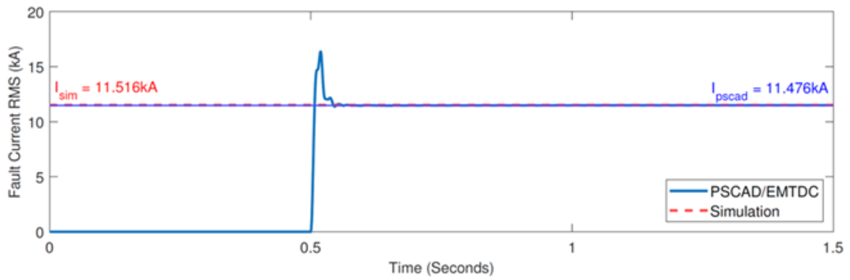


Figure 5.7: RMS fault current for fault at bus 8

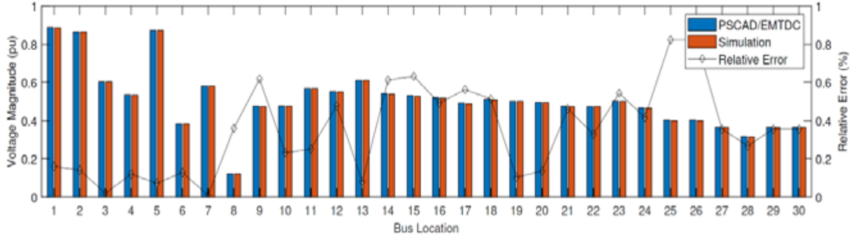


Figure 5.8: Faulted system voltage profile comparison for fault at bus 8

FRT was activated for both VSC terminals

Dilshani Maheepala

Topic: Dynamic/ transient analysis of hybrid AC-DC systems

Activities

- Has developed research proposal.

Proposed methodology is to extending stability analysis of parametric impedance models to include nonlinear dynamics. Conversion of black-box models to parametric models should make them more robust and applicable across a broader range of operating conditions.

Collaboration

International Collaboration

- Indian Institute of Science
- Technische Universität Dresden

Summer students

Summer students

FANTail: FAN Tool for Analysis and Interactive Layout

Offline Plotting and Analysis Software to Visualise FAN-Transient Simulation Tool Results

Summer Student: Sridhar Vannada

A Proof of Concept on Converter Controller Initialisation from Power-flow Results

Summer Student: Shen Liu

Part-time Masters Student: Saranya Ramani

Modelling LVDC Networks using FAN Power-flow Tool for Analysing System Benefits

FAN Research Partners

Future Architecture of the Network
TE WHATUNGA HIKO
FAN2025
Auckland, New Zealand
4/5th February

New Zealand

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

THE UNIVERSITY OF AUCKLAND
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NEW ZEALAND

AUT UNIVERSITY
NEW ZEALAND

VICTORIA UNIVERSITY OF WELLINGTON
TE HERENGA WAKA

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Overseas – University of Cambridge, Aalborg University