PACE
ACCELERATING ELECTRIFICATION

MERIT: Medium Voltage Resource Integration Technologies

NREL Section

Principal Investigator: Gab-Su Seo

Affiliation: National Renewable Energy Laboratory

Team Members: Jay Sawant, Bowen Yang, Vikram Roy Choudhury, Ramanathan Thiagarajan, and Barry Mather

MERIT Overview

Project Objective: Develop modular, cost-effective, and scalable technologies at medium voltage (4.16 kV to 34.5 kV) that will reliably integrate a range of distributed energy resources (solar, wind, fuel cells, etc.) on to the grid.

Target Metrics:
- >97% efficiency
- 40+ year service life
- >90% up-time

Project Pillars

Advanced Components and Power Stages	Advanced Converter Systems	Resource Integration& Management Systems	Grid Integration and Demonstration@scale
Materials & Components, Embedded Controllers	Power Stages & Sub-System Prototypes	Auxiliary Systems, Software Platforms, Algorithms, System Prototypes	Demo Use Case
VALLEY OF CHALLENGES	VALLEY OF CHALLENGES	VALLEY OF CHALLENGES	VALLEY OF CHALLENGES
Sandia National Laboratories; Wolfspeed; SEMIKRON innovation+service; Microchip; HITACHI	Oak Ridge National Laboratory; Virginia Tech; University of Colorado Boulder; University of Arkansas; Sandia National Laboratories	Oak Ridge National Laboratory; ViridiParente; EATON; Texas; NREL Transforming ENERGY	NREL Transforming ENERGY; Pacific Northwest National Laboratory; Southern Company; OPAL-RT Technologies
TRL 2–7	TRL 3–7	TRL 4–7	TRL 5–7
Advanced Components	MV PE Subsystems Inverters converters	Software platforms, Real-time Optimization	**Novel multi-port Medium Voltage PE System: Future pilot**

NREL Focus: Converter Development and System Integration

MV Converter Prototype Development

MV Power Electronics System Integration

Impact Analysis of MV Power Electronics

Project Pillars

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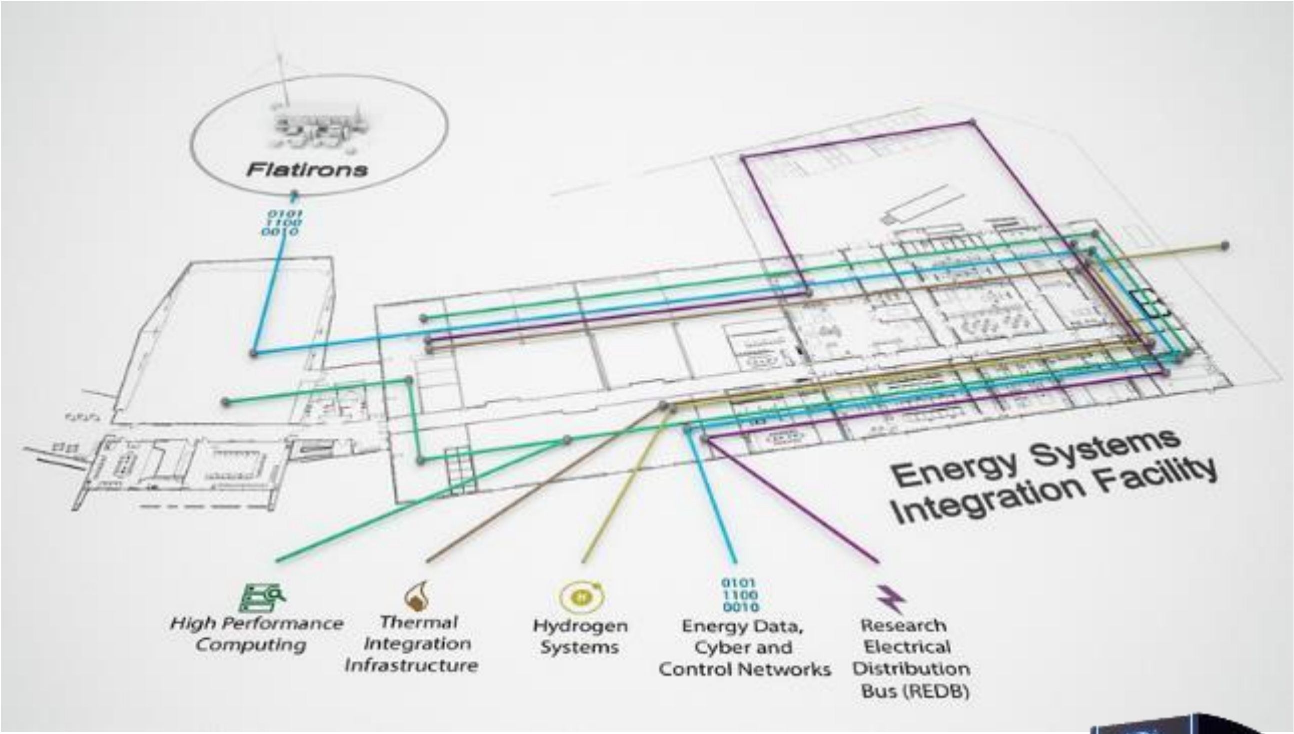
NREL for MERIT – MV Technologies at Scale

- Background: Hard to find places to systematically validate and promote MV and HV technologies at scale. NREL can provide the place.
- Unique Capability: 13.2kV 2MW Scale (ESIF)
- Proven track records in the past DOE efforts.
  - 13.2kV prototype built and tested (DOE SETO) – Use for MERIT
  - 4.16kV prototypes (DOE AMO)
- Numerous System Integration efforts
  - CHIL and PHIL tests proven effective for renewable integration
  - Device-level to system-level using RT simulation environment

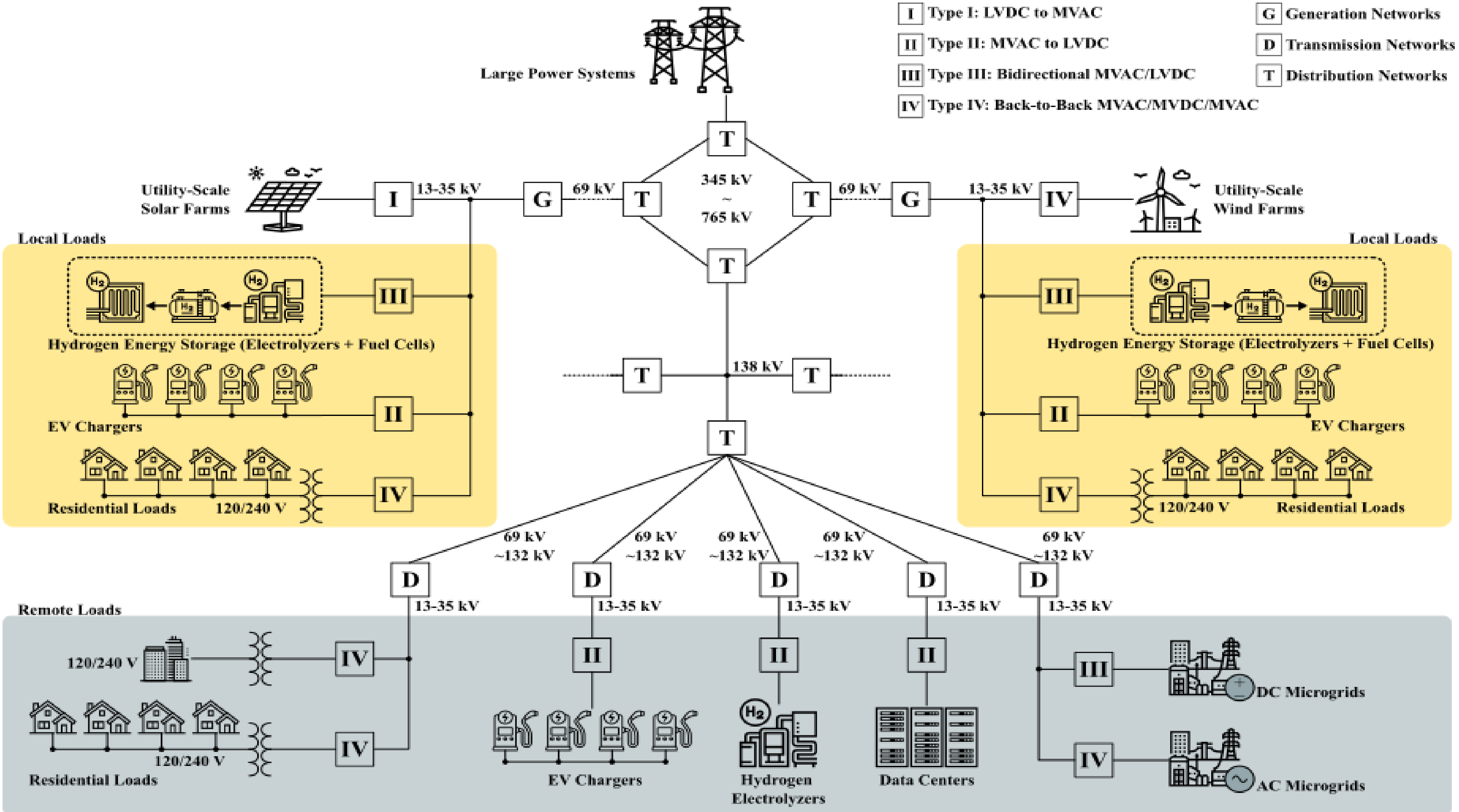


NREL Task Structure

Task ID	Performer	Task Description	
T6 NREL Task 1	NREL	MV PE prototype development, evaluation, and grid integration testing. It includes module development and evaluation, converter development and evaluation, and grid integration testing with power hardware-in-the-loop environment at NREL	MV Converter Technology Development and Demonstration
T7 NREL Task 2	NREL	High-fidelity electromagnetic model development of DERs and MV converters, and device and system level testing in real-time simulation environment.	System Integration of MV Converter-interfaced DERs
T8 NREL Task 3	NREL	Impact analysis to evaluate the impact of MV applications on power systems including cost and efficiency analysis.	MV Converter Impact Analysis
T9	ALL	Stakeholder engagement, gap analysis, and project management	Stakeholder Engagement and Gap Analysis

MV Converter Development - Vision

- Modular and scalable MV PEBB for Everything.



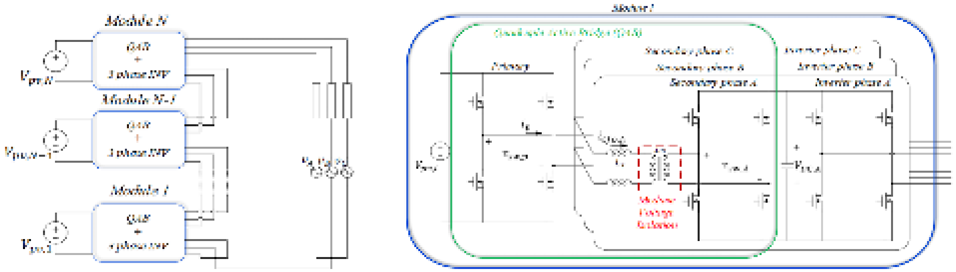
MV Converter Development and Demo

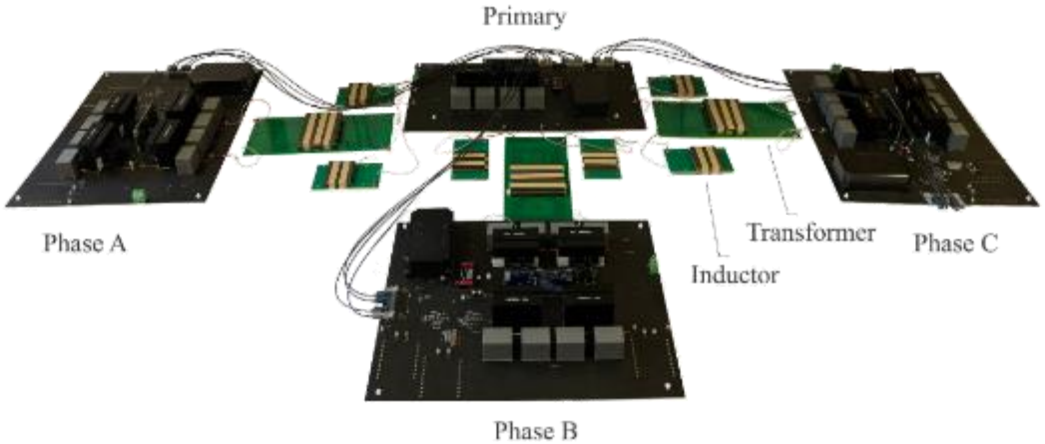
MV Converter Prototype for MERIT
- Modular and Scalable up to 13.2kV

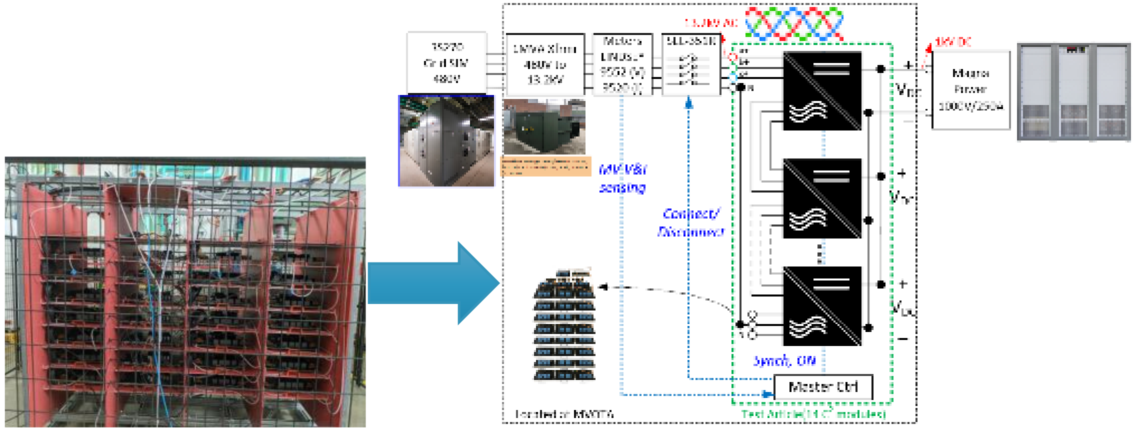
- Supported by DOE SETO
- PIs from CU Boulder and UT Austin
- Individual circuit + controller / module
  - Modular&Stackable 3ph AC-to-DC PEBB
  - MV isolation through 26kV HF Xfmr
  - Usable for a variety of cases: Series or parallel, or individual at each ac/dc side
- Can be used for demos for MV Hydrogen, MV EV XFC, PV, Wind…

Focus of GMLC

- **Identify** promising applications, **develop** controls and hardware, and **validate** in real-time simulation and PHIL





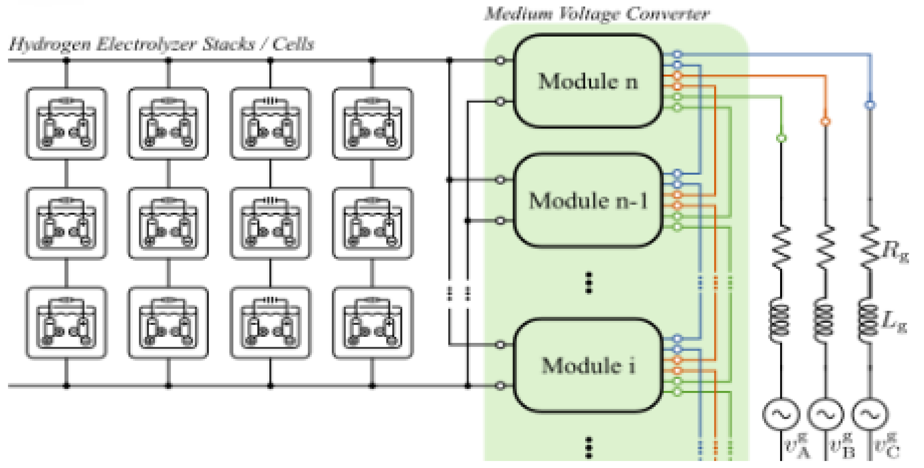


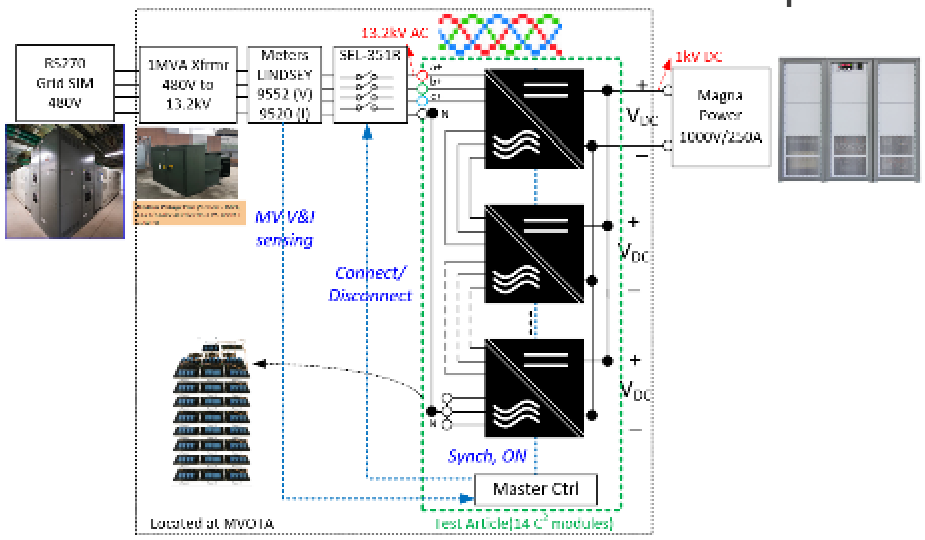
MV Converter Development and Demo – Future Works

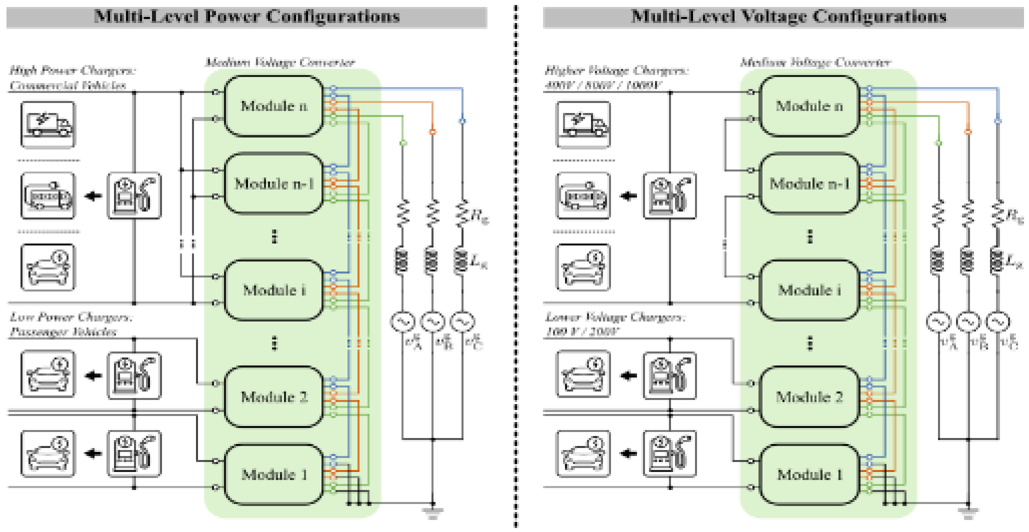
Develop Use Cases

MVAC-to-LVDC: H2 Electrolyzer, EV XFC, DC Dist.

- Develop converter control
- Develop grid-support functionalities
- Centralized and decentralized controls for reliability
- Validate in real-time simulations
- Validate in Controller Hardware-in-the-loop
- Validate in Power Hardware-in-the-loop







DER Models and Grid Integration - Overview

Need for High Fidelity DER Models

- EMT models for MV converter development and HIL testing
- Can evaluate not only converter technology feasibility but also system impact

DERs considered for this GMLC-PACE

- Distributed Generations
  - PV and Wind
- Storage
  - Battery, hydrogen, fuel cell, pumped hydro, flywheel
- Other Grid assets: EV charging stations, SST for MGs, MV B2B converters.

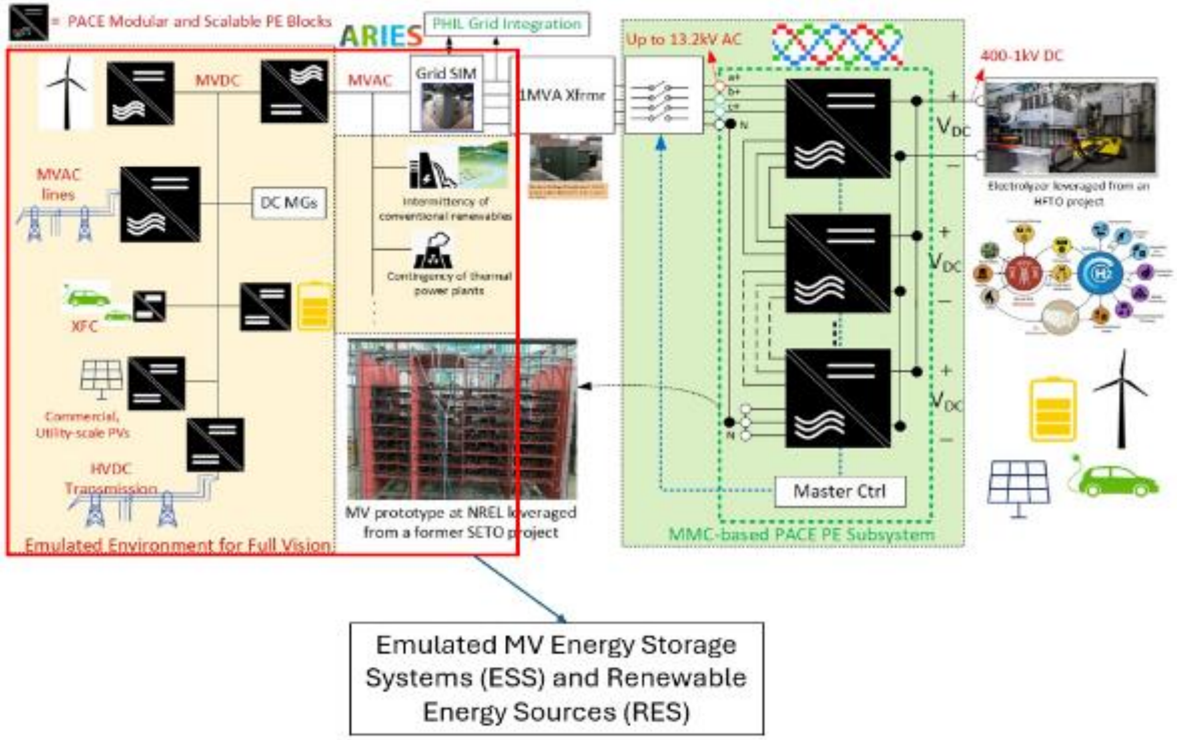
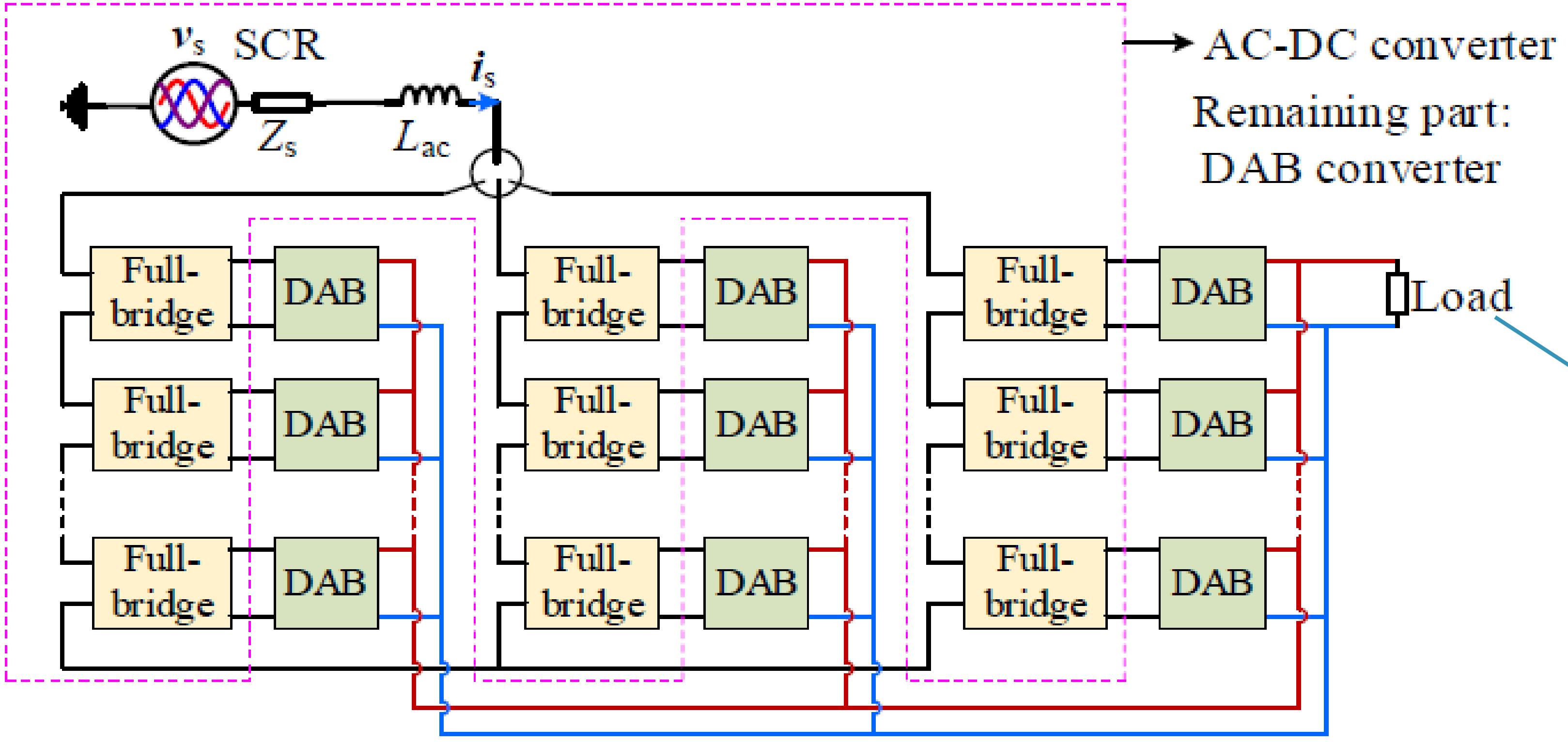


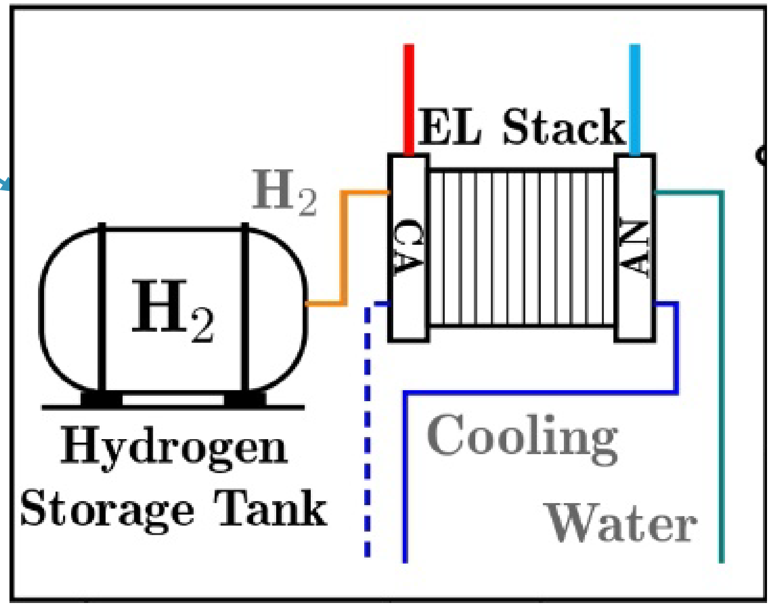
Figure 1. MV converters interfacing a variety of renewables and others.

Progress Update – MV Converter for H2 Electrolyzer

- System Architecture – CHB-based MVAC to LVDC converter for H2.



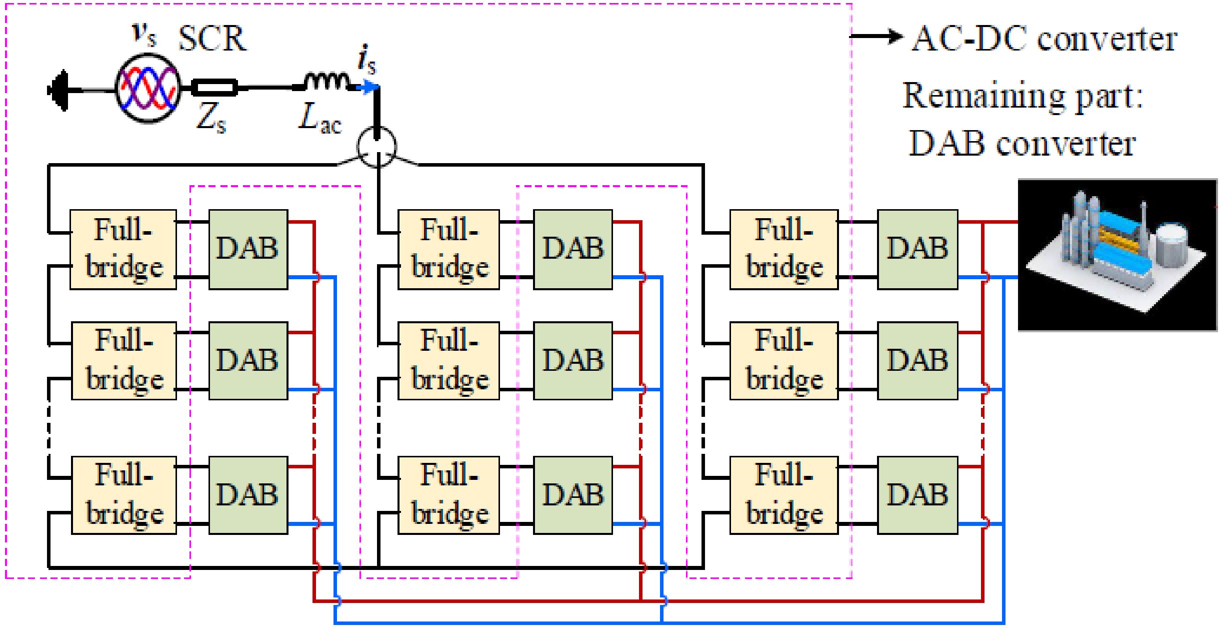
Power Conversion Stage



Electrolysis Plant with storage

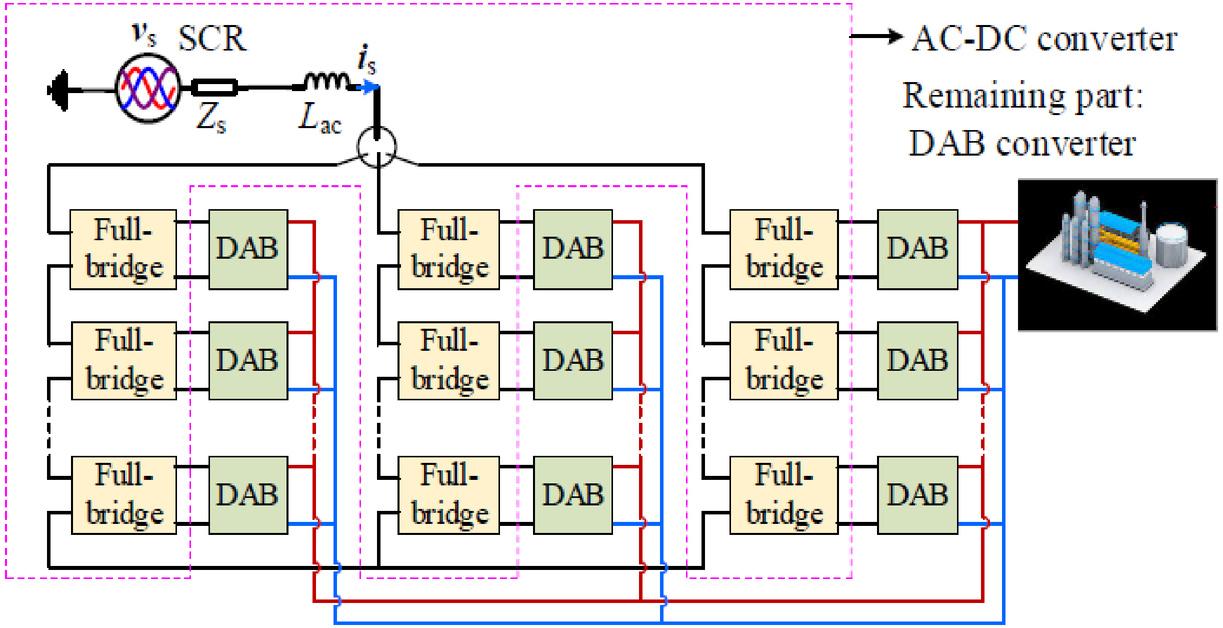
Electrolyzer Grid Integration Using MV Converters – AC-DC Full Bridge Converter and DAB Control

- 6 [Full bridge + DAB] stages per phase (18 total for 3ph)
- *dq* based outer-loop control of full bridge converter
- Inner loop with decoupled current control
- Low level controls include capacitor balancing control
- Phase-shift angle control used to control DAB output voltage
- DAB converter output voltage reference calculated using desired rate of hydrogen production

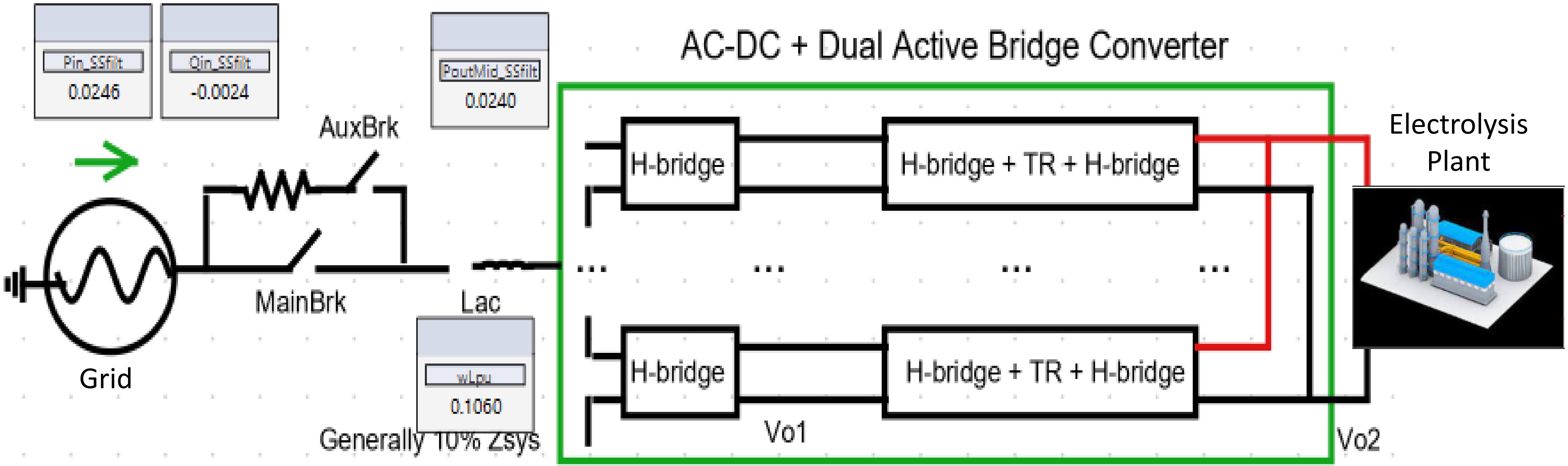


System Parameters

- Electrolysis Plant Power Rating – 100 kW
- 330 V/305 A
- Each phase has 6 full bridge converter + DAB stages – 18 stages/modules in total
- Output of each DAB stage taken in parallel as input to electrolysis plant
- Grid – 10kV L-L RMS
- Output of FB converter stage – 1.5kV



Runtime Simulation Environment

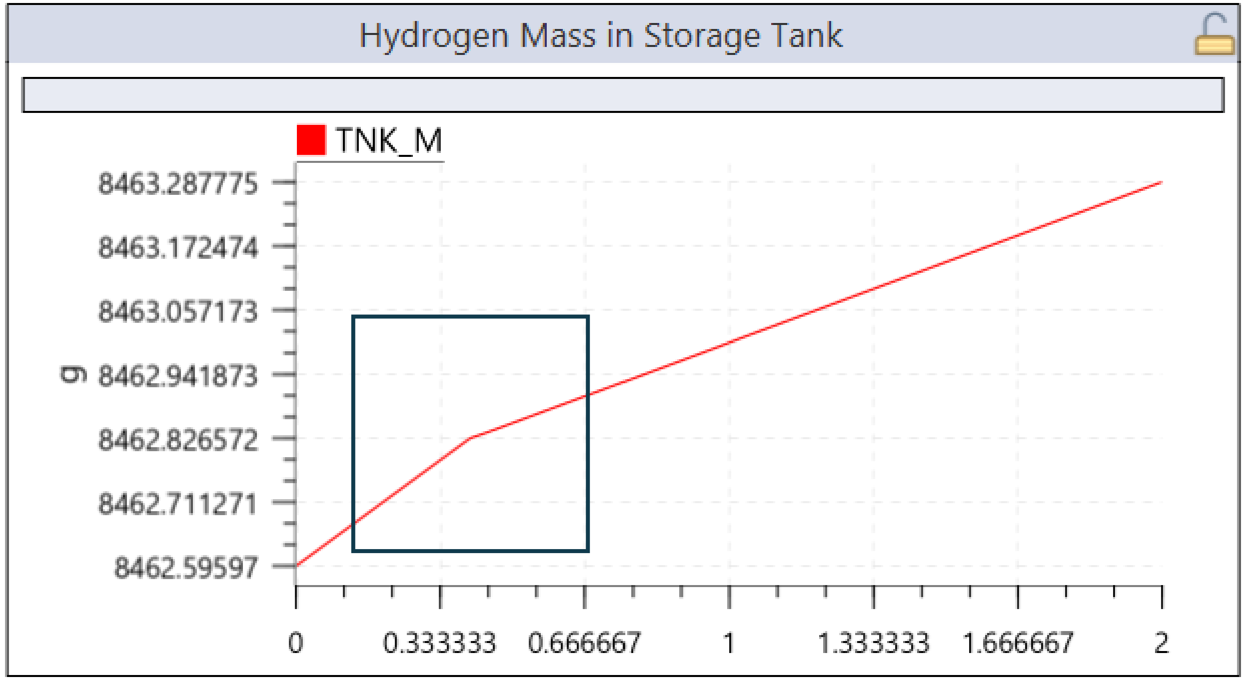


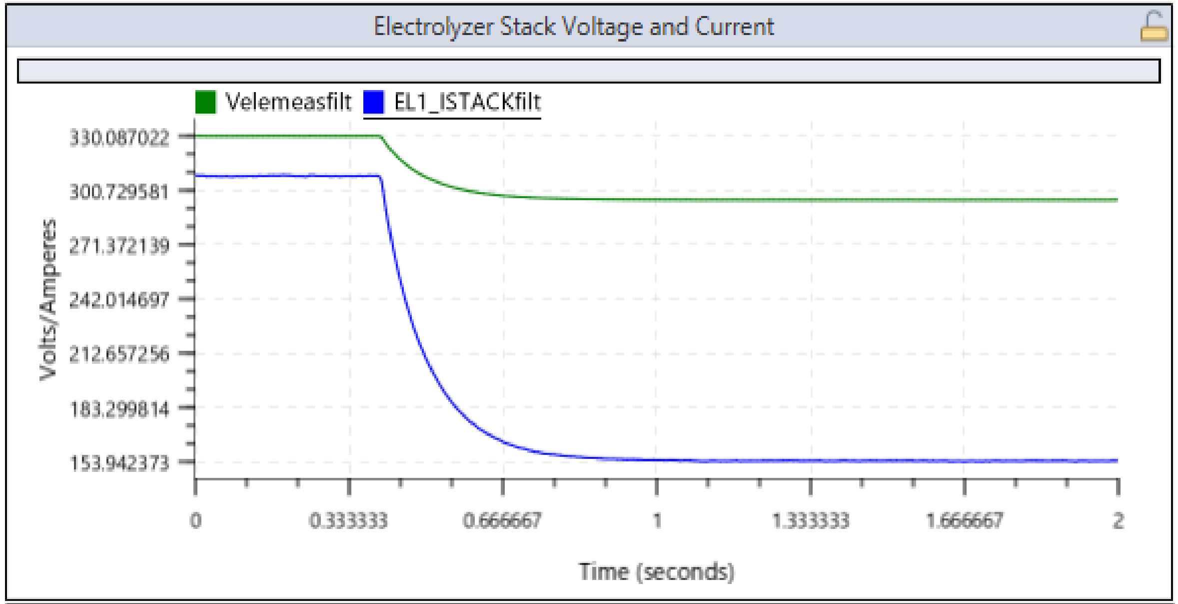
Startup Sequence

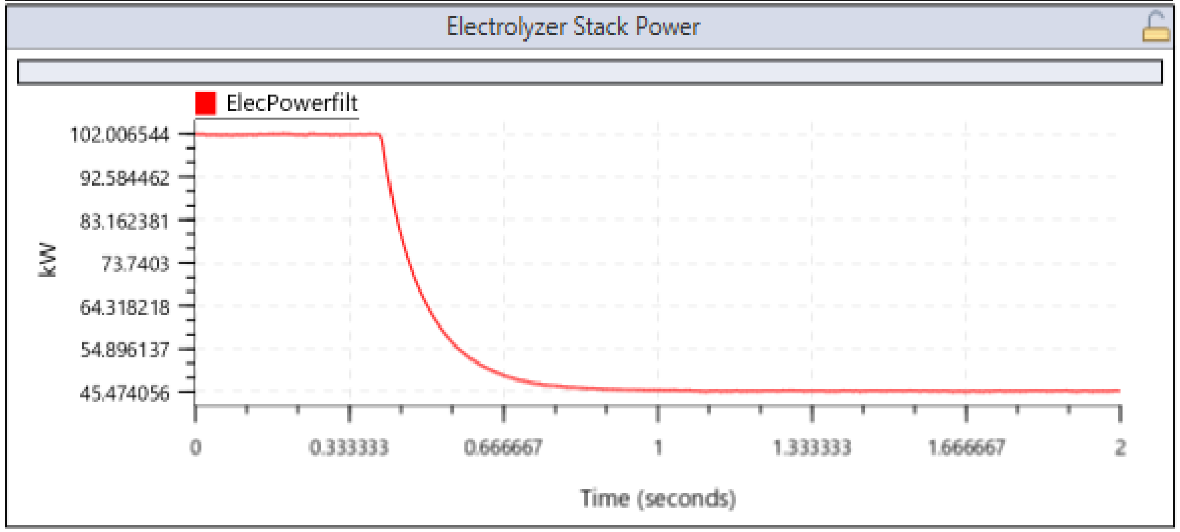
1) Aux Breaker closes for initial charging,
2) Main Breaker Closes,
3) Aux Breaker Opens,
4) System Controllers enabled to regulate the current consumed by electrolyzer to desired value

Simulation Results – Setpoint Change in Current

- With a setpoint change in current, the DAB adjusts its output voltage reference to regulate the current consumed by the electrolyzer
- The change in current results in a change in power consumed by the electrolyzer and a change in rate of hydrogen production

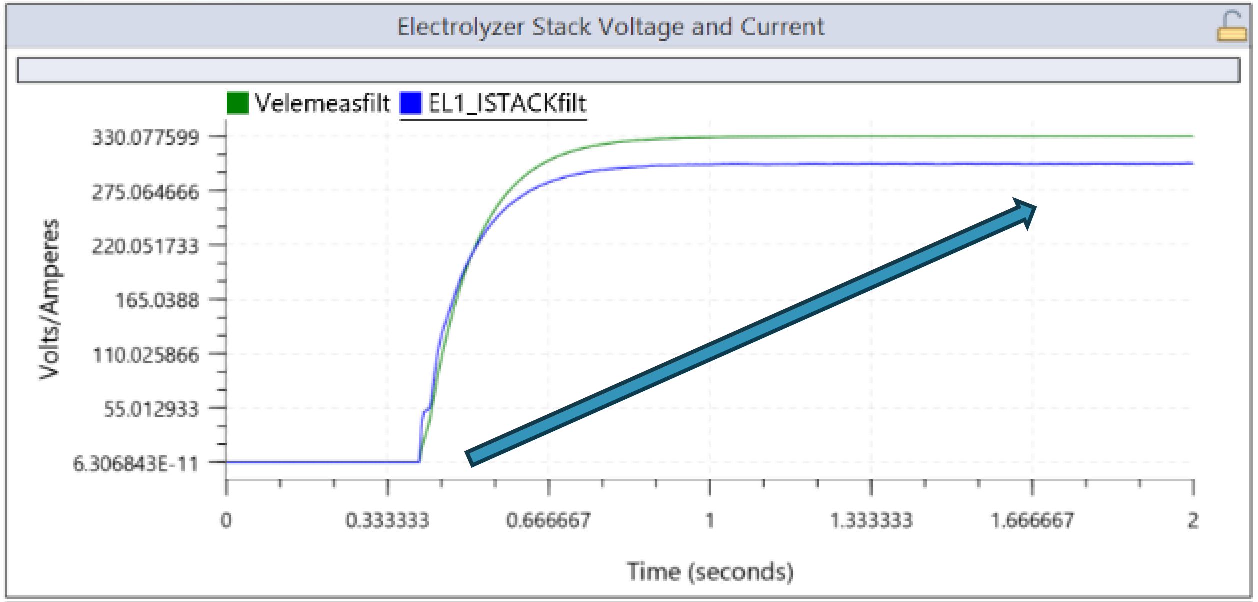


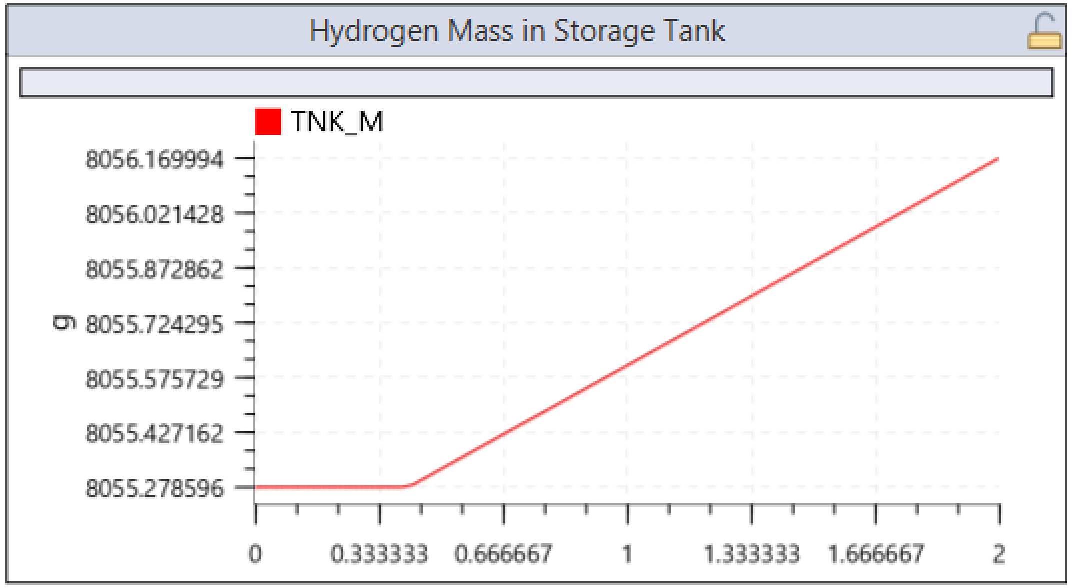


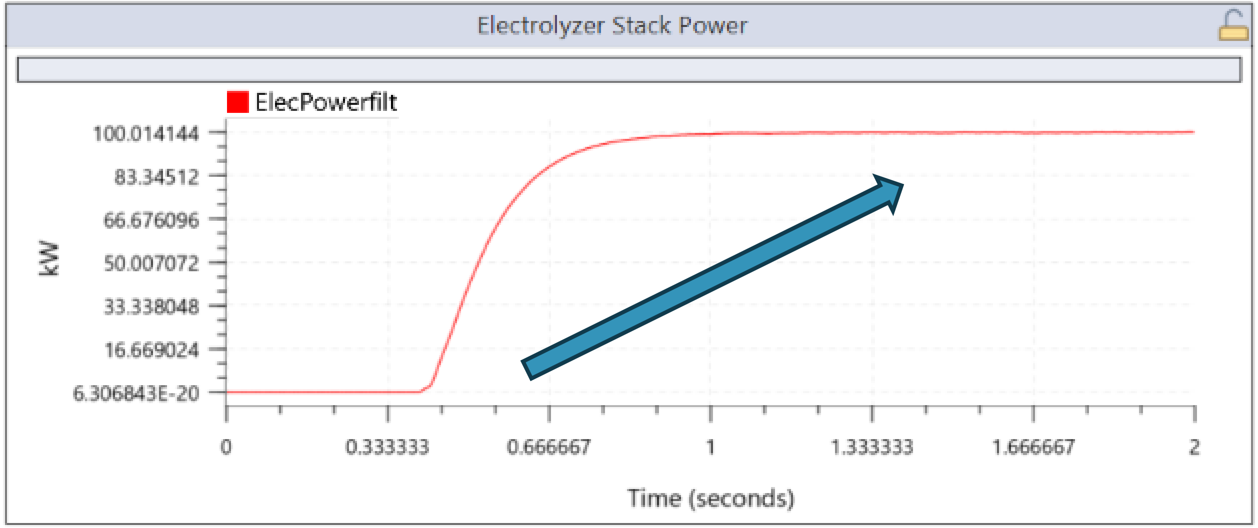


Simulation Results – Plant Startup

- As the controllers are enabled, the DAB converter regulates voltage at its output for the rated electrolyzer current consumption
- The hydrogen production rate is directly proportional to the electrolyzer current consumption
- As seen in the figures, at startup, the electrolyzer consumes rated current stably





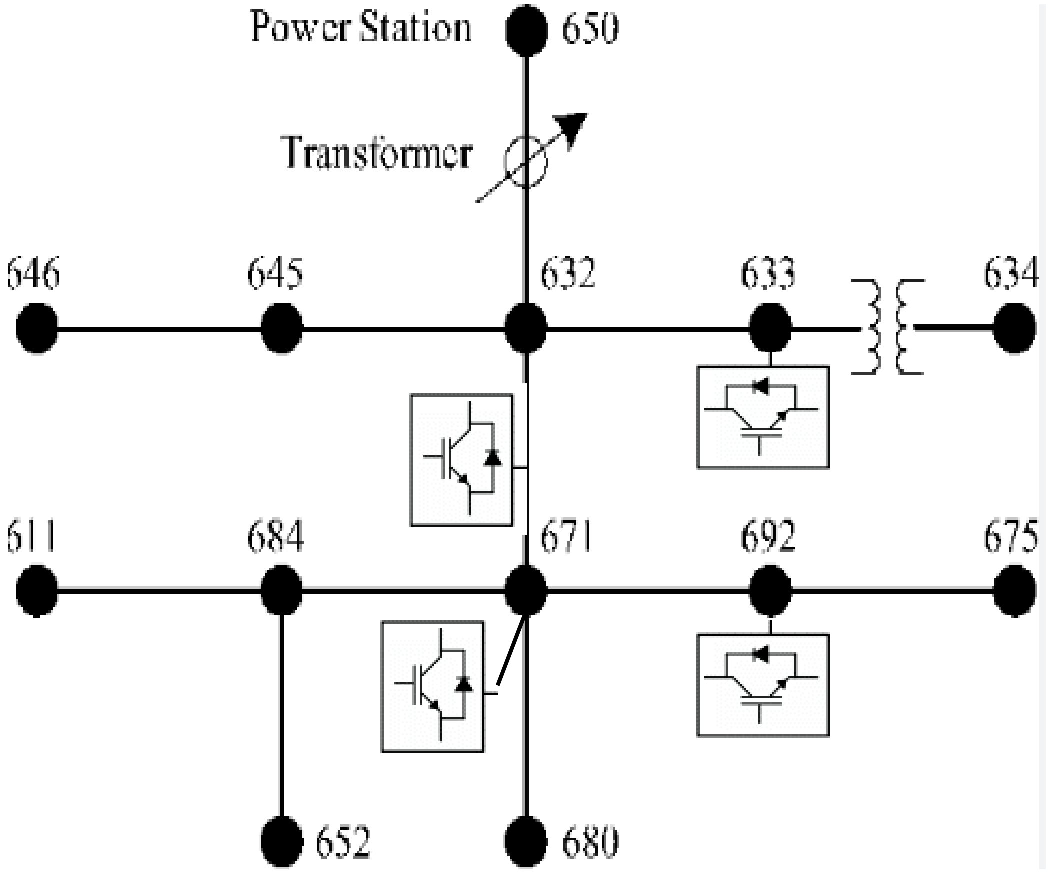


Impact Analysis Study of MV Converters

- DER integration studies in a QSTS tool at LV and MV levels in a modified IEEE 13 bus distribution feeder
- Study impact of *volt-var control* at MV vs LV levels
- Comparison of volt-var control performance at MV vs LV level studies to understand benefits of MV integration vs LV integration
- For LV integration, 3-phase grid-following DERs added at 480V L-L and interconnected to distribution feeder with an interconnection transformer
- For MV integration, 3-phase GFL DERs added at MV level (4.16kV L-L on this case) without a transformer
- Currently, only volt-var performance comparison is studied
- More cases to be studied in future work for technical as well as cost analysis of MV converters

Simulation Setup – IEEE 13 Bus System

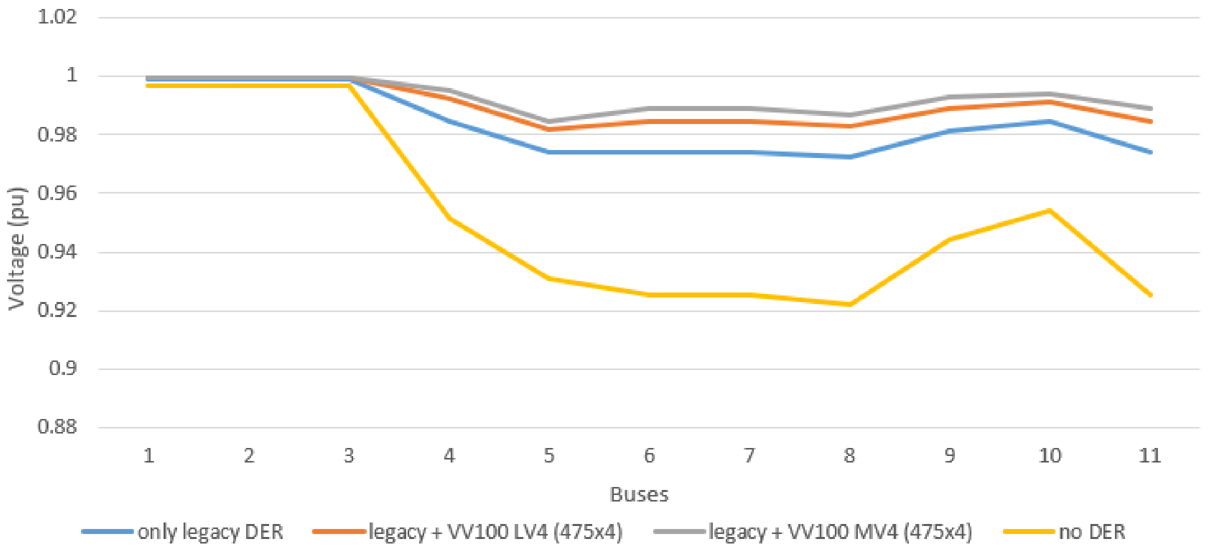
- Case 0 – no DERs added
- Case 1 – 50 % DER penetration doing only active power injection at 4 locations shown (noted as legacy DERs)
- Case 2 – Case 1 + additional 50% DER penetration with volt-var control at LV level (at same 4 locations)
- Case 3 – Case 1 + additional 50% DER penetration with volt-var control at MV level (no transformer, at same 4 locations))
- Effect of voltage regulator and varying substation voltage not considered (for now)
- Snapshot studies done at peak load case
- Time series simulations for varying substation voltage and load profiles will be considered in next steps

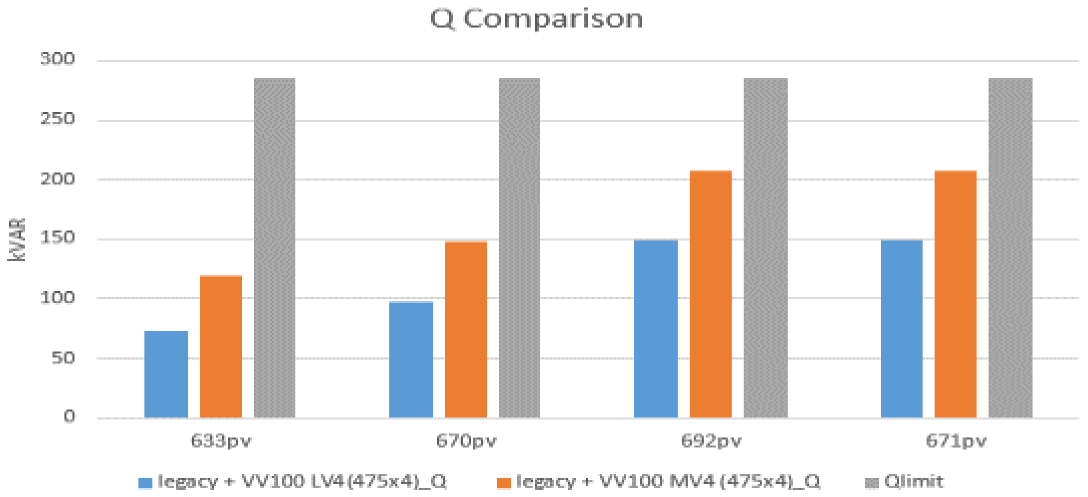


Simulation Results – 13 Bus System – MV vs LV Volt-Var Control of DERs at 100 % DER Penetration

- In no DER scenario (yellow curve), voltage is the lowest, all load is met by substation -> more voltage drop
- In the case with only legacy DERs (blue curve), voltage improves slightly
- In 100% DER penetration case with volt-var DERs added at LV level (orange curve), voltage is improved
- More improved voltage profile is seen with volt-var DERs added at MV level (grey curve)
- MV connected volt-var controlled DERs make more use of available Q headroom as compared to LV connected volt-var controlled DERs

Note : Initial volt-var analysis in QSTS tools, more cases will be studied in future work with QSTS as well as EMT simulations





THANK YOU

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Backup Slides

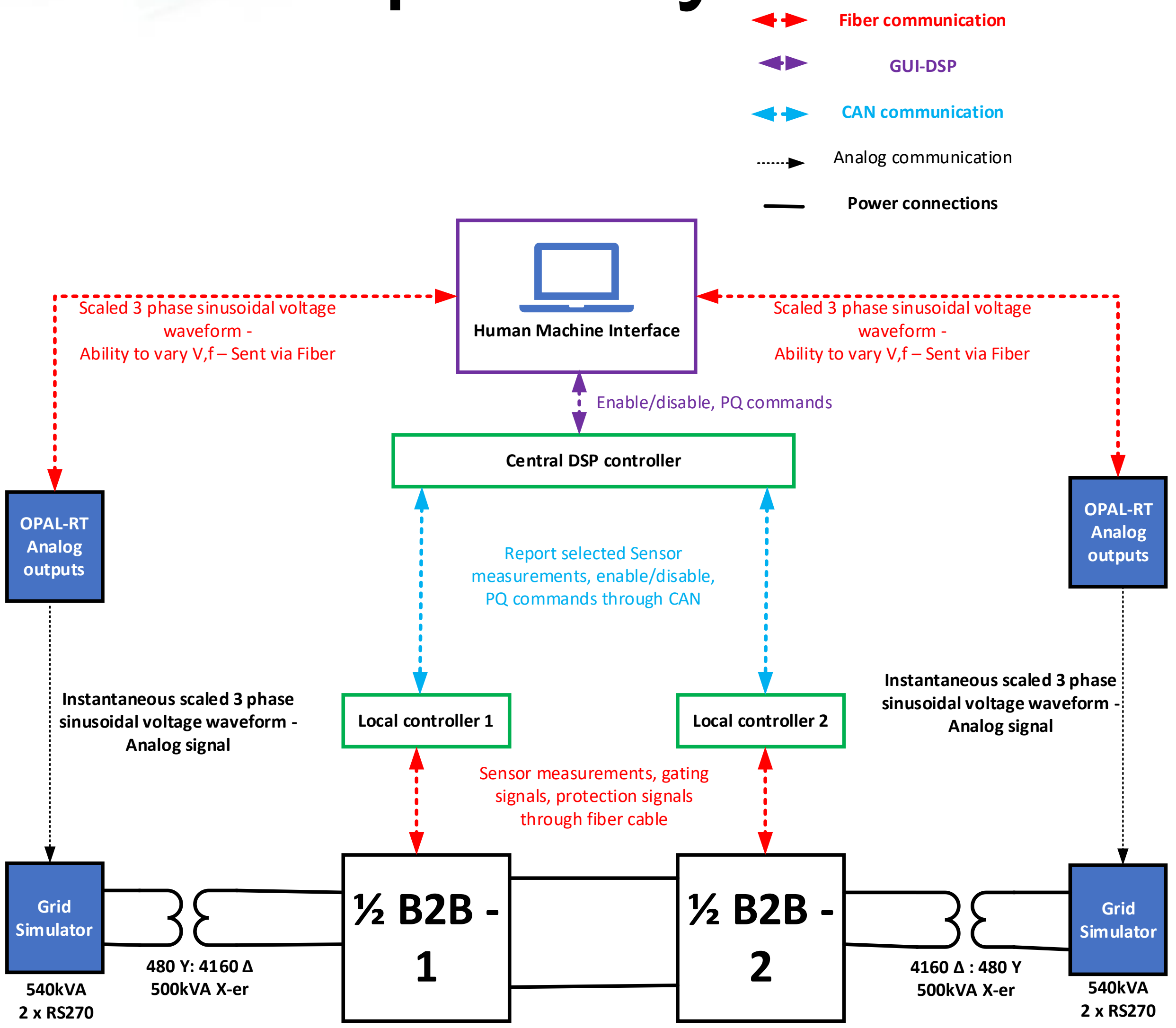
Future Works

- **Task 1 – MV Converter Module and System Development**
  - Will build simulation models for MVAC-LVDC conversion
  - Will start firmware development
  - Will finalize subcontracts: UT Austin and CU Boulder
- **Task 2 – Grid Integration of MV Converter-interfaced DERs**
  - Will study other DER technologies and their MV converter interfaces in real time simulation environment
- **Task 3 – Impact Analysis**
  - Will run preliminary test cases to evaluate the value of MV converters to gain more insights.

Milestone	Description	Scheduled Completion
M.NREL.1.1	MV Converter Module Development	BP1Q4
M.NREL.1.2	MV Converter Evaluation	BP2Q4
M.NREL.1.3	Grid Integration	BP3Q4
M.NREL.2.1	DER Model Development	BP1Q4
M.NREL.2.2.	System Model and Use Case Development	BP2Q4
M.NREL.3.1	Impact Analysis	BP3Q4

MV Power Electronics Test Capability

- 4160V back-to-back medium voltage converter testing
  - Indoor medium voltage testing area
  - 2 x 500kVA 480:4160 indoor rated transformers
  - 2 x 540kVA 480V grid simulators
- Demonstration performed at ESIF with 2 x MMC converters developed by academic partners (Ohio State University and Florida State University)
  - 10kV Wolfspeed SiC module-based submodule



Recent Outcomes: 2 MV Converter

- Demonstration of medium voltage converter testing in a back-to-back operation
- Bidirectional power transfer demonstrated successfully
- Both MMC converters were operated in inverter and rectifier modes
- Power rating of 100kVA and 5kV DC demonstrated successfully
- Advanced grid functionalities demonstrated
    - Asynchronous frequency operation
    - Voltage sags and swells
    - Volt-Watt
    - Volt-Var
    - Frequency-Watt