Multi-port Autonomous Reconfigurable Solar power plant (MARS): A Next-Generation Power Electronics Solution

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ORNL is managed by UT-Battelle, LLC
for the US Department of Energy

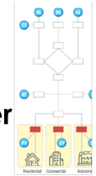
Outline

- Introduction to challenges with high penetration of power electronics (PE) in grids
- Advanced integration approaches

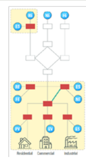
Introduction: PE Grid Challenges

Penetration* of Power Electronics (PEs)

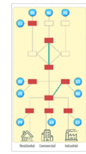
Traditional Power System
- Up to 20% PE



Intermediate Scenario
- Up to 50% PE



Future Scenario
- Up to 100% PE



*Penetration defined by weighed average of power flowing through PEs

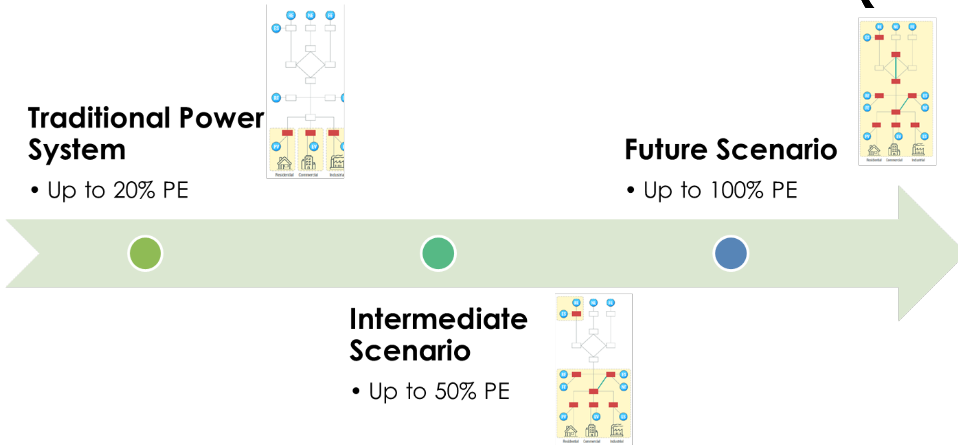
Power Electronics
- Inverter-based generations (eg, solar, wind)
- Power electronic loads (eg, electric vehicle chargers, extreme fast chargers, variable-frequency drives)
- Power flow controllers (eg, HVdc, FACTS)

More information may be found here: https://info.ornl.gov/sites/publications/Files/Pub141951.pdf.

HVdc – High Voltage Direct Current
FACTS – Flexible Alternating Current Transmission Systems

Introduction: PE Grid Challenges

Penetration* of Power Electronics (PEs)



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Power Electronics

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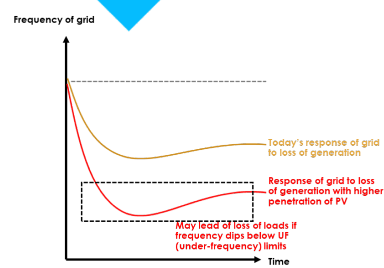
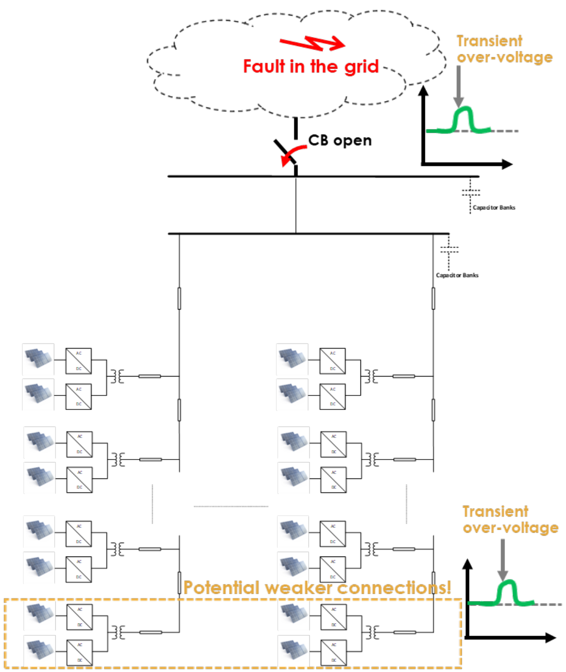


Challenges

- Observed reliability concerns
  - Reduced inertia
  - PE control interactions
  - Sub-synchronous interactions with series compensation
  - Increased sensitivity to external disturbance
    - Eg, Transient over-voltage or under-voltage shutdowns
  - Low short-circuit ratio networks
  - Voltage variability
- Other future concerns are expected as more studies performed

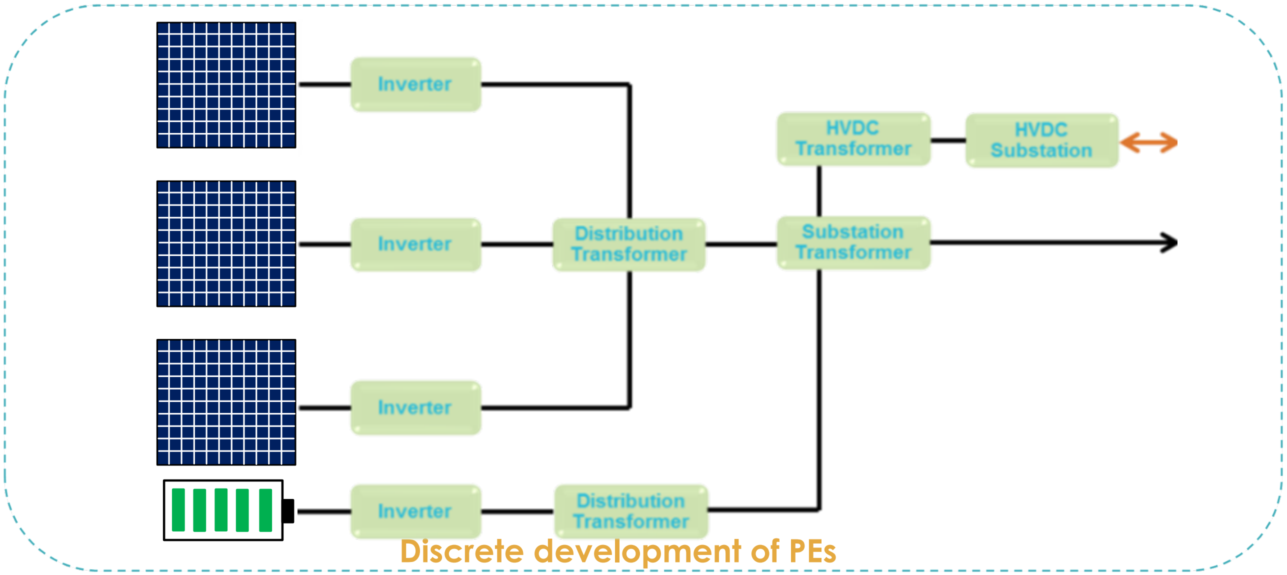


NERC: High Penetration PE Challenges

Advanced Integration Approaches: Multi-port Autonomous Reconfigurable Solar Power Plant (MARS), A Hybrid PV Plant

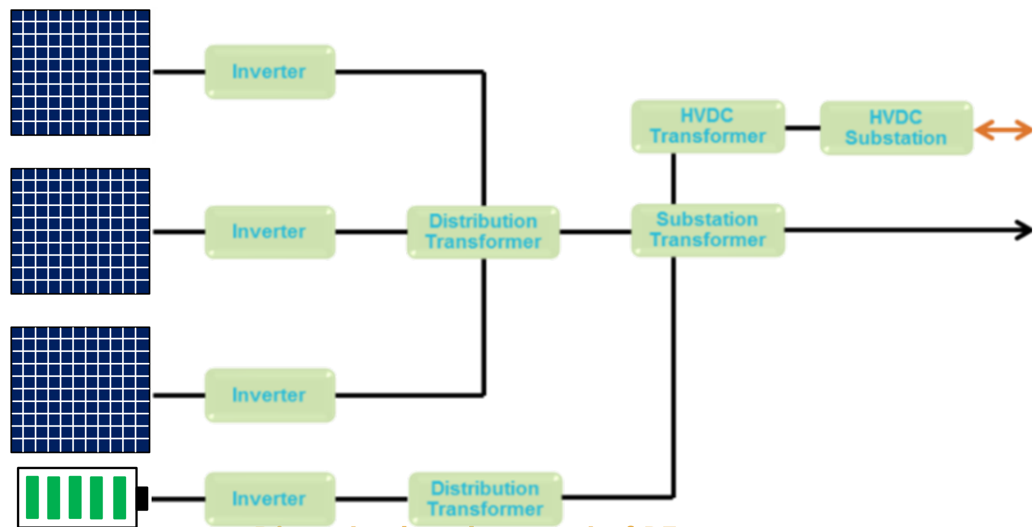
Project Team: Oak Ridge National Laboratory, ABB/Hitachi-ABB, Southern California Edison, Georgia Institute of Technology, Opal-RT

Existing State-of-Art



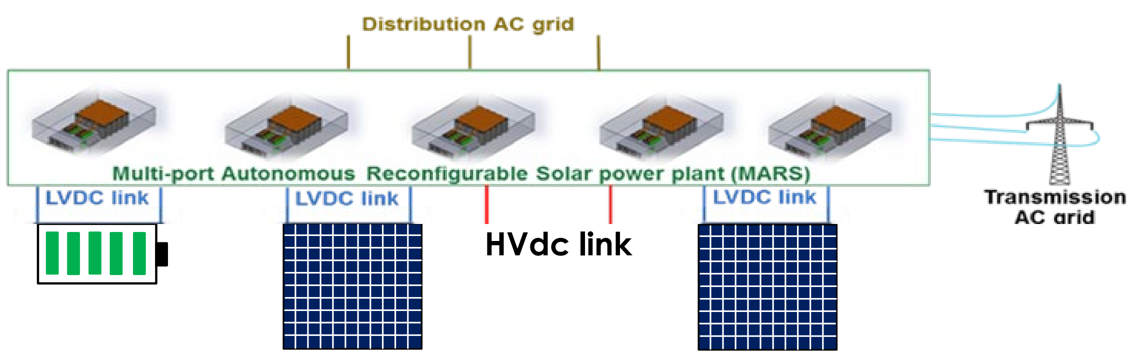
MARS: Integrated Solution Approach (A Hybrid PV Plant)

Integrated system approach similar to laptops (vs. desktop)



Discrete development of PEs

- Reduced PE and transformer interfaces: Reduces cost, Reduces losses
- Advanced control approaches for coordinated use of resources and improved grid support/ stability



Multi-port Autonomous Reconfigurable Solar power plant (MARS)

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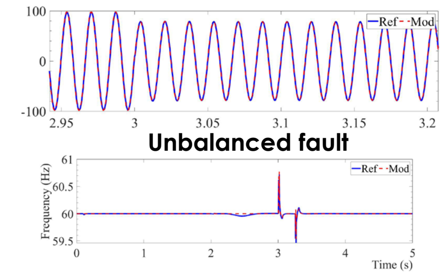
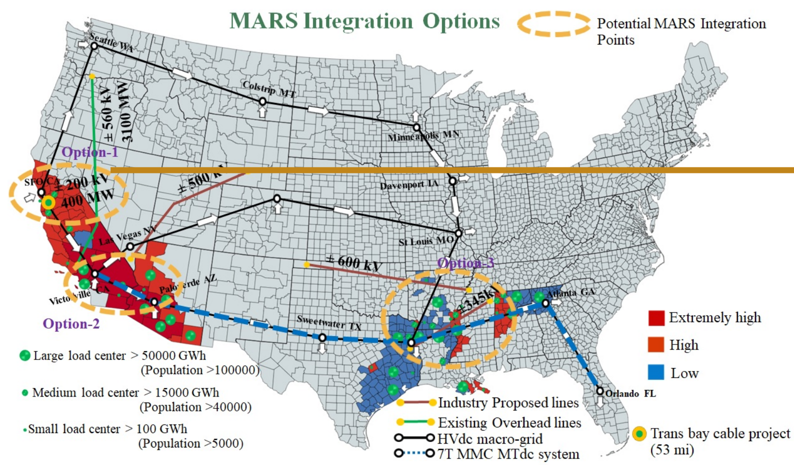
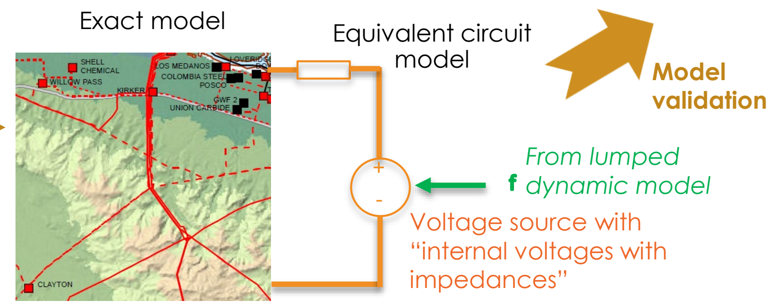
MARS Model

EMT Modeling of Grids

- Grid model for MARS at Pittsburg
  - **Models**: EMT grid models
  - **Data**: TS model from WECC
  - **Algorithm**: TS to EMT conversion and aggregated model development







Single-port equivalency shown as an example

PSS®E Planning TS Model → E-Tran → PSCAD EMT Model {Local Area Models}

PSCAD Lumped Models → Equivalent Circuit Conversion → PSCAD EMT Model {Local Area Models}

Local area dynamic model
- Exact model – nodes of interest
- Equivalent circuit model – rest of the nodes in the system

Lumped dynamic model
- Data-driven approach*

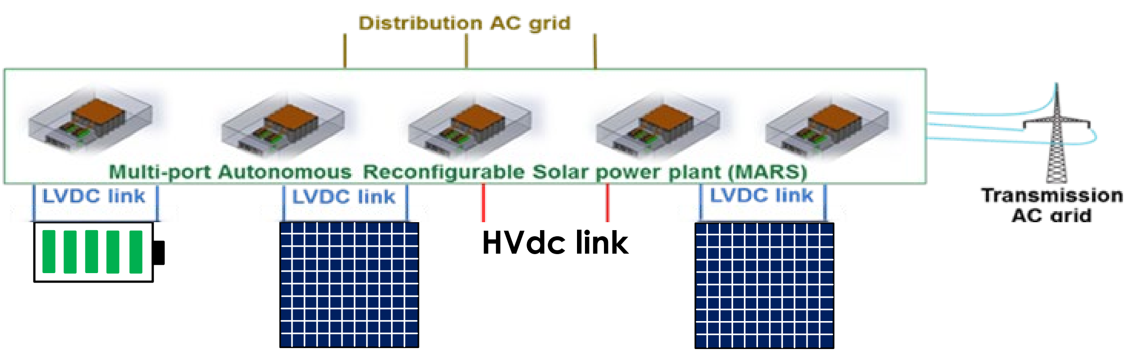
Integrated dynamic model
- Conversion: Voltage source "at terminal" to voltage source with impedances

TS to EMT model conversion methodology developed through extraction and lumped model representation

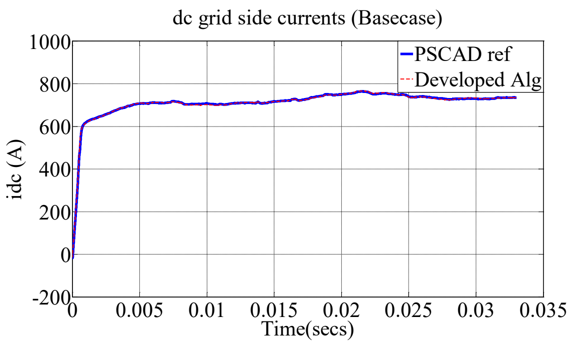
WECC – Western Electric Coordinating Council

EMT Simulation of MARS

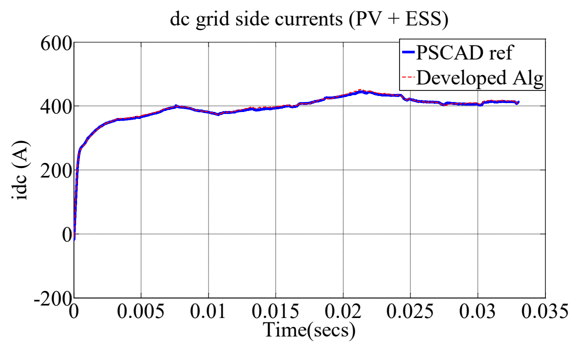
- Up to 8000x speed-up and >98% accuracy



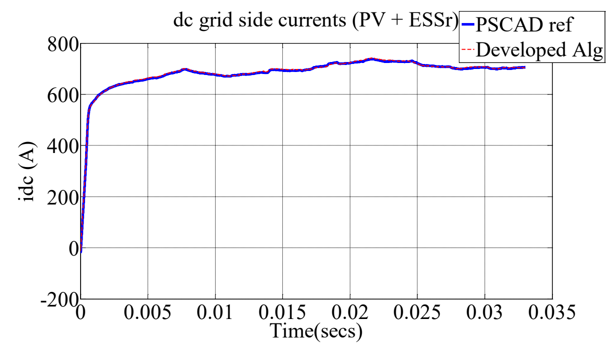
Basecase: No PV and ESS generation



PV+ESS: PV and ESS generation



PV+ESS: PV generation and ESS charging



Fast simulation algorithms developed (~ 8000x speed-up)

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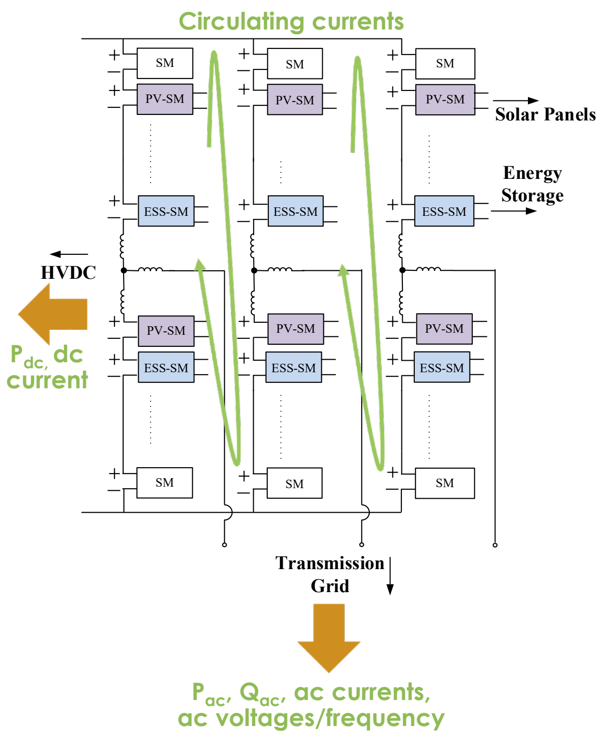
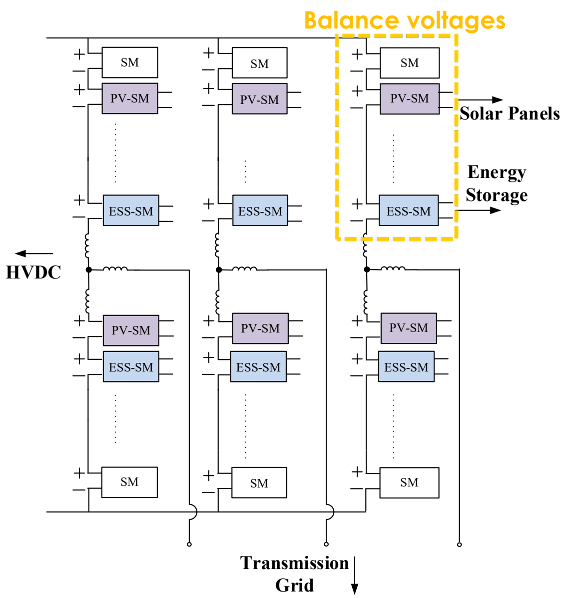
MARS Control Architecture

MARS Control Architecture: Overview



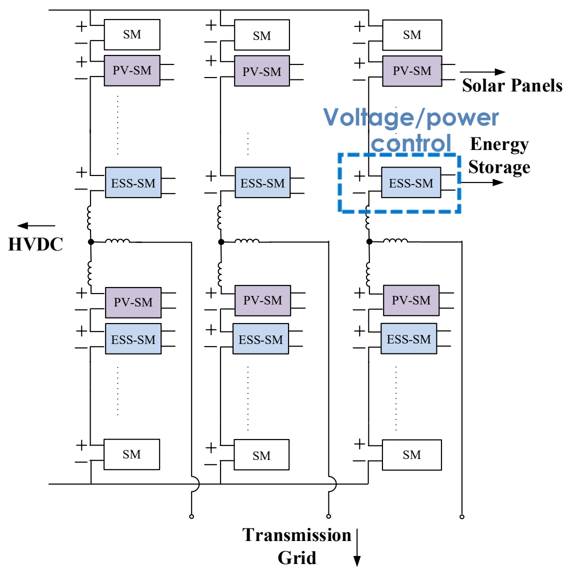
- Features in L1
  - Control of ***ac-side*** grid components
    - Voltages, currents, active/reactive power, frequency (including predictive features)
  - Control of ***dc link*** components
    - Voltages, currents, power
  - ***Internal states*** within MARS
    - Circulating currents
    - Balance energy between different SMs

MARS Control Architecture: Overview



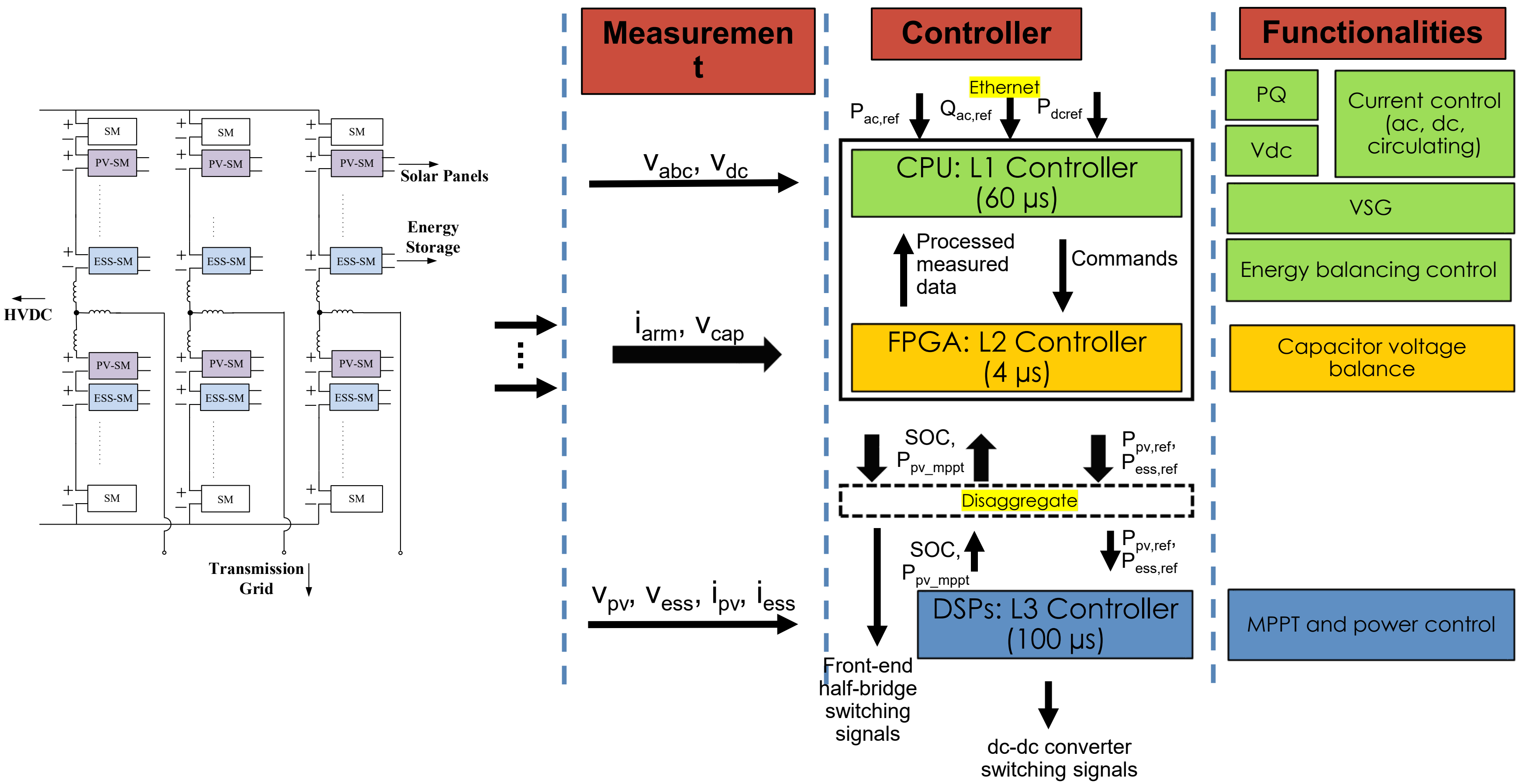
- Features in L2
  - Balance ***capacitor voltages*** in all SMs
  - Generate ***switching signals*** for a part of the SMs

MARS Control Architecture: Overview



- Features in L3
  - ***Voltage*** controlled in PV for power generation needed from PV
    - Internal ***current*** loop control for stability and limits based on rating
  - ***Power*** controlled in ESS
    - Internal ***current*** loop control for stability and limits based on rating

MARS Control Architecture: Overview



Control architecture for MARS

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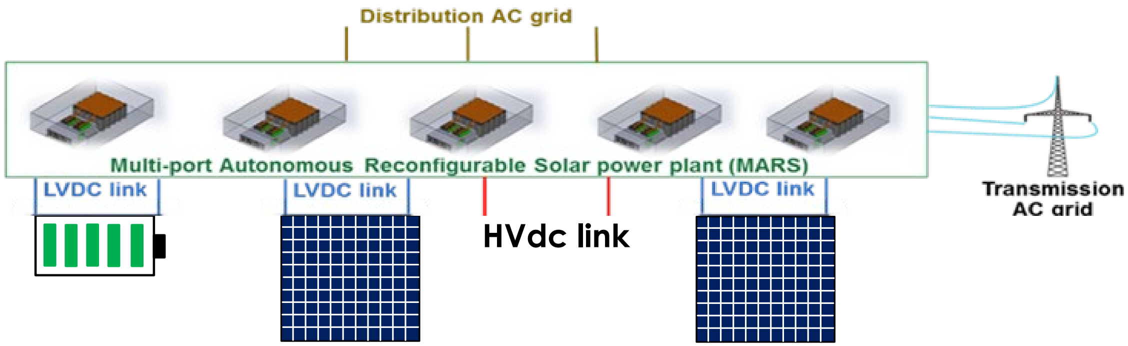
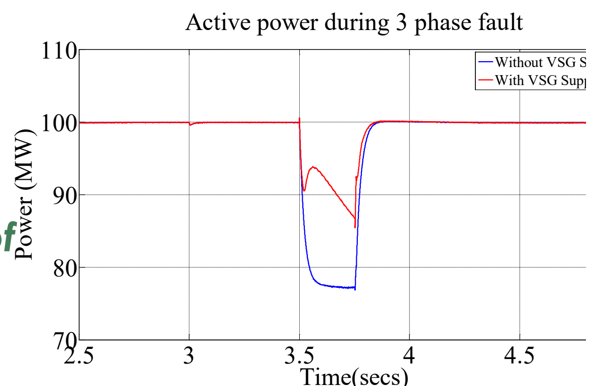
MARS Use Cases

MARS: Evaluation

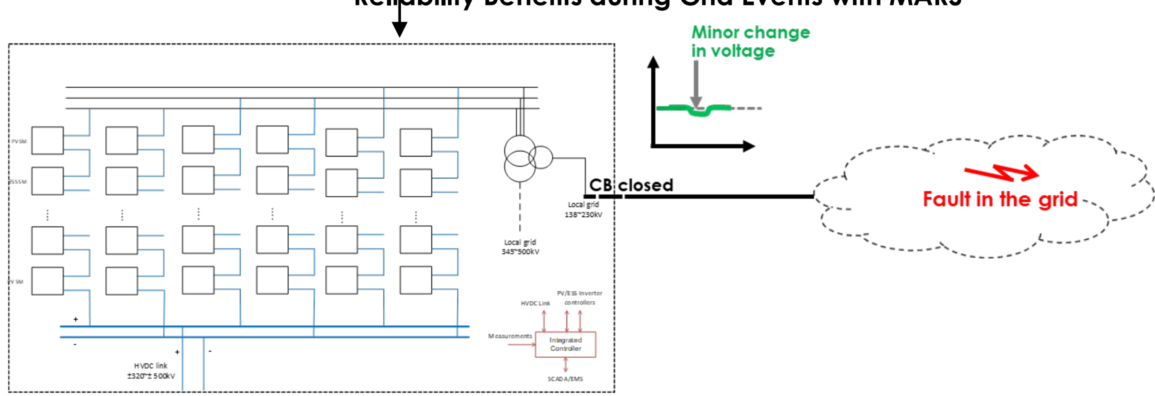


Momentary cessation can be removed in MARS

Reduced impact of external disturbance



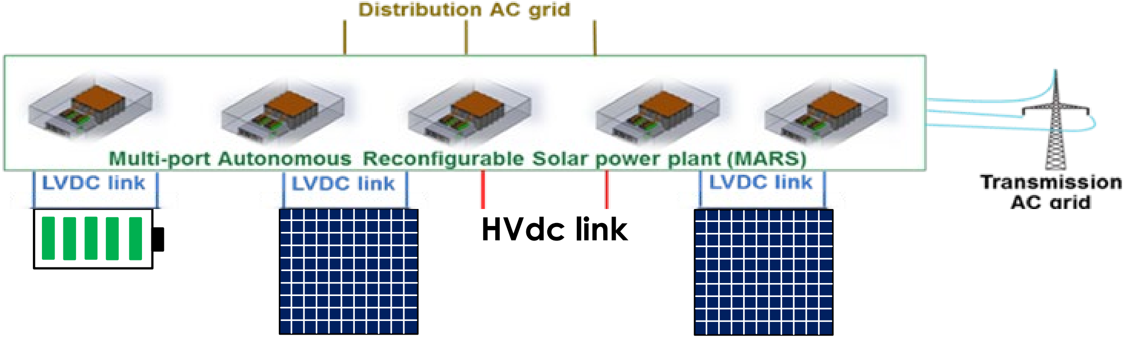
Reliability Benefits during Grid Events with MARS



Continuity of operation provided

SG – Synchronverter
VSG – Virtual Synchronous Generator
SCR – Short Circuit Ratio

MARS: Evaluation



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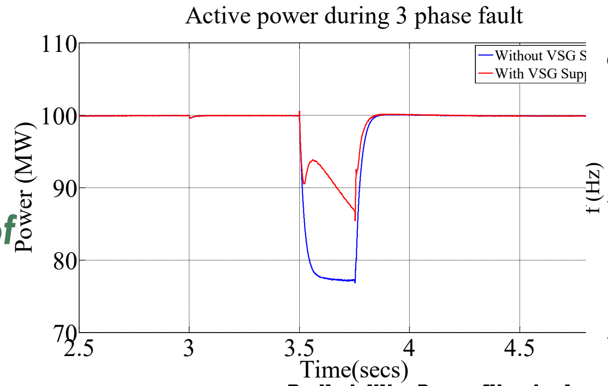

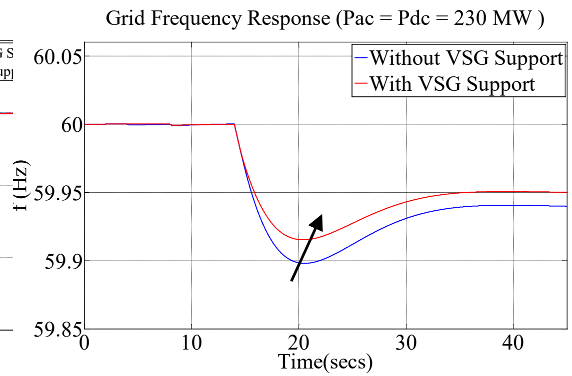

Inertial and primary frequency response can be provided by MARS

Reliability Benefits during Grid Events with MARS

SCR	Improvement in frequency response			
	SG		VSG	
	Nadir %	Steady state %	Nadir %	Steady state %
0.5	8.69	11.00	UNSTABLE	
2	15.75	15.07	15.05	7.67
4	16.04	15.18	15.72	7.81
10	16.37	15.66	16.87	17.34

Operations under low SCRs maintained

SG – Synchronverter
VSG – Virtual Synchronous Generator
SCR – Short Circuit Ratio

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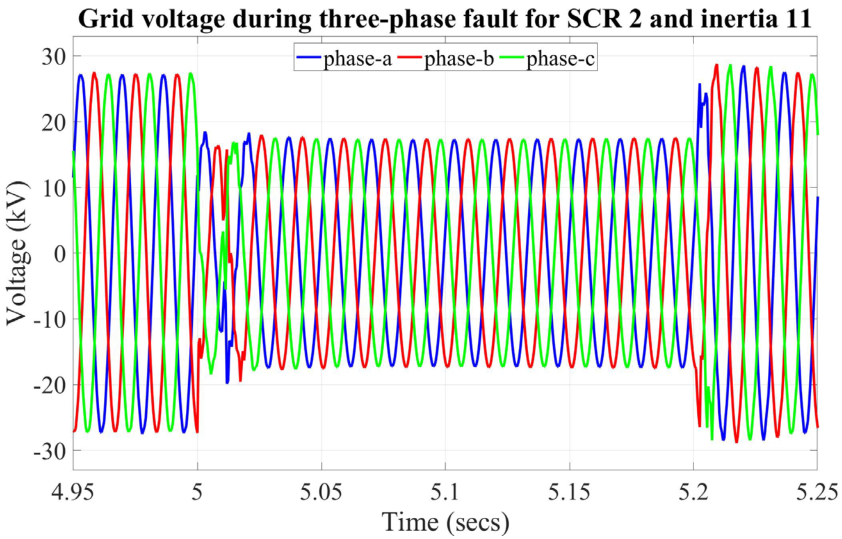
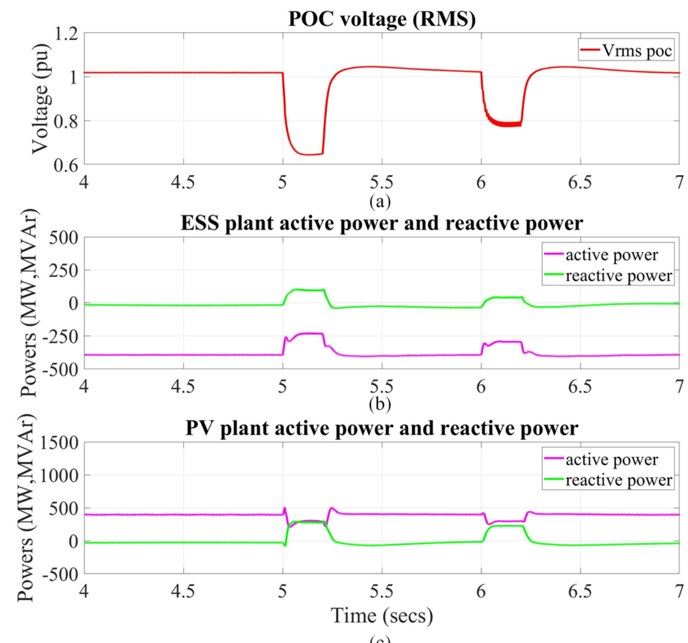
Existing Hybrid PV-ESS Comparison

Hybrid PV Plant: Upgrades

- **Scenario:** Low inertia low SCR (~ 2) connection to the hybrid PV-ESS plants
  - **Use Case:** Balanced and unbalanced faults of differing magnitudes, at different locations
  - **Requirements Identified:** Capacitor banks, large sized synchronous condensers, reactive power control in PV and ESS inverters
  - **Challenges:** Limited continuity of operations is feasible (smaller feasible region compared to MARS)



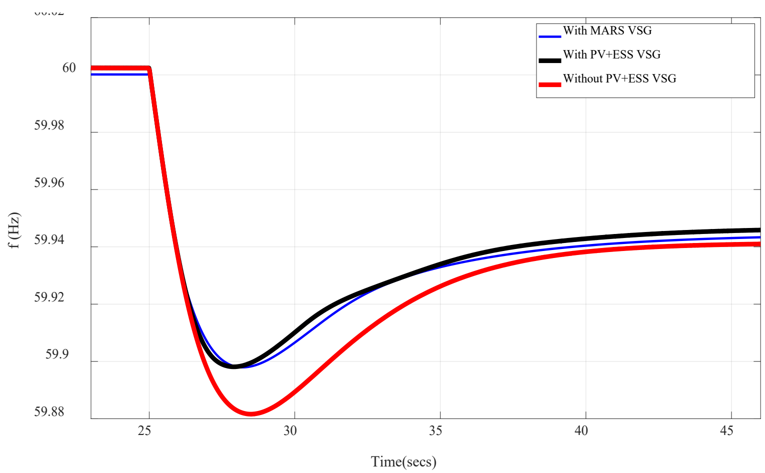
Improves SCR at POI (and maintains stable operation during faults)



Maintains active power similar to MARS operations

Hybrid PV Plant: Upgrades

- **Scenario:** Low inertia low SCR (~ 2) connection to the hybrid PV-ESS plants
  - **Use Case:** Loss of generation
  - **Requirements Identified:** Capacitor banks, synchronous condensers (~ 1:4), reactive power control in PV and ESS inverters, *VSG support in PV and ESS inverters*
  - **Challenges:** Coordination between two different resources can be a challenge



***Limited** stable integration of hybrid PV plants to low SCR grids may require large sized synchronous condensers along with VSG control*

Conclusions

- MARS provides improved region of stability (compared to hybrid PV with upgrades)
  - Different fault locations
  - Different fault magnitudes
  - Different SCR operating conditions

- Comparison of MARS with hybrid PV and upgrades indicates
  - Reduced costs of operation
  - Easier coordination

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