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Controller Hardware-in-the-Loop (CHIL) Testing and Verification of Networked Microgrids

Authors : Roshan Sharma, Niroj Gurung, Honghao Zheng, Aleksandar Vukojevic

Presenter : Roshan Sharma

Agenda

- ❑ Introduction
- ❑ Bronzeville Community and IIT Campus Microgrid
- ❑ Hardware in the Loop Test Setup at GrIT Lab
- ❑ BCM-ICM Cluster/De-cluster Process Flow
- ❑ RTDS-HIL Testing Results
- ❑ Challenges in Microgrid Cluster Implementation

Introduction

Microgrid

- Group of interconnected distributed energy resources (DERs) and loads
- Operating modes—Grid connected, islanded, clustered
- Facilitate higher penetration of renewable-based energy resources
- Enhance resilience of the power grid

Microgrid Master Controller (MMC)

- A centralized controller to monitor, control, and manage microgrid assets including DERs and DA devices
- MMC functionalities
  - Execute sequence of operation (SOO) for seamless transition of microgrid to various modes:
    - *Load Transfer, Grid-connected mode ↔ Partial/Full Island, Partial/Full Island ↔ Microgrid Cluster, Load restoration after fault, Black-start and restoration after grid outage*
  - Optimization and dispatch of DERs
    - Day ahead scheduling and real-time scheduling
    - Solar PV and BESS Coordination /Renewable firming
    - Peak shaving
  - Re-calibration of protection settings of DA devices

Microgrid Cluster

- Interconnection of neighboring microgrids to form network/cluster of microgrids
- Support from neighboring microgrid when local resources are exhausted
- Addition of another layer in resiliency
  - Optimal resource sharing and scheduling
  - Higher flexibility and efficiency
  - Provide ancillary services such as black-start

Bronzeville Community Microgrid and IIT Campus Microgrid

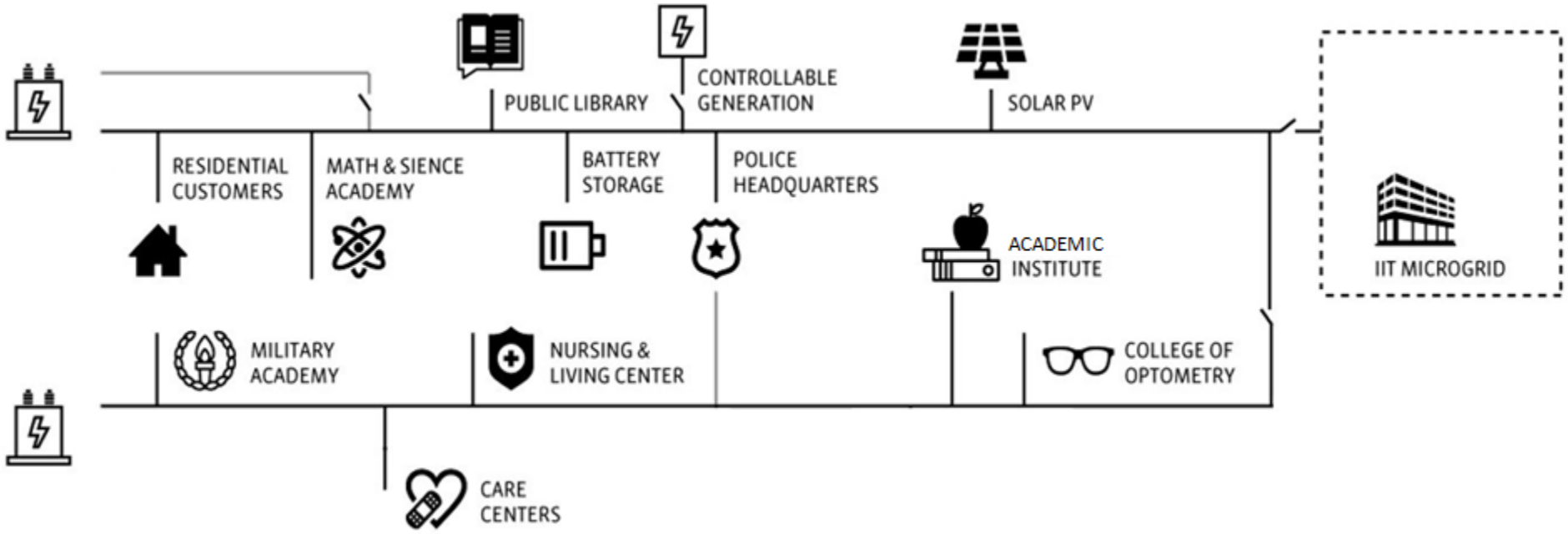
Bronzeville Community Microgrid (BCM)

- 7 MW aggregate load, serving approximately 1,000 residences, businesses and public institutions
- *Generation Mix:* 4.8 MW Gas generator, 750 kW solar PV, and 500 kW/2MWh Battery energy storage (BESS).

IIT Campus Microgrid (ICM)

- *Generation Mix:* 8 MW gas generators, 800 kW/1400 kWh BESS, and 350 kW PV system

When both microgrids are in islanded mode and BCM MMC foresees shortage of power, it sends emergency notification with cluster request to ICM MMC.



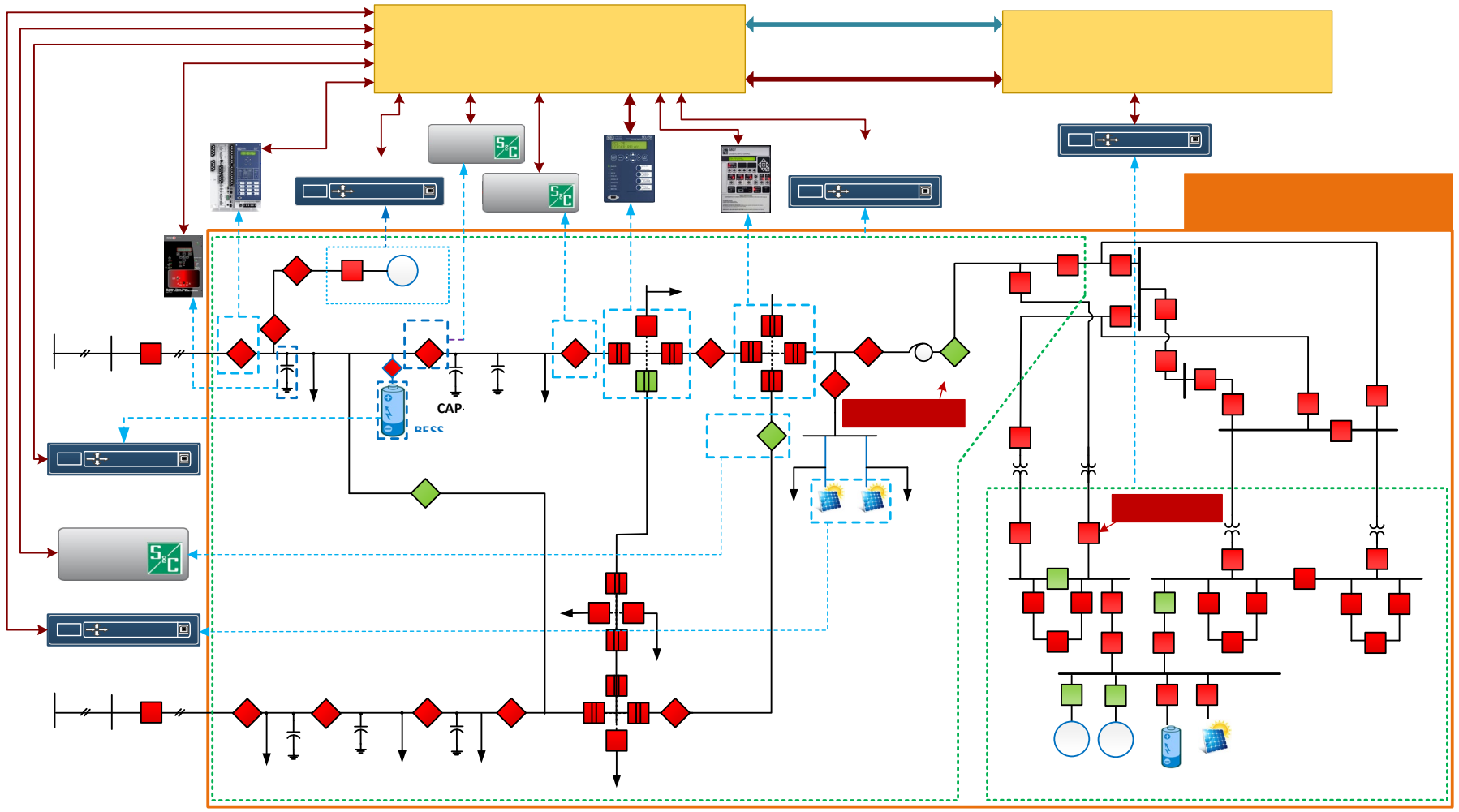
Hardware in the Loop Test Setup at GrIT Lab

BCM-ICM Cluster

- Both BCM and ICM should be in islanded mode
- SW N1: Primary point of clustering (POC) and de-clustering

Testbed

- Dynamics of the microgrid is modeled in RTDS
- Selected intelligent electronic devices (IEDs) are incorporated that communicate with RTDS and MMC
- MGMS is BCM MMC while ICM MMC is incorporated with IIT RTDS model



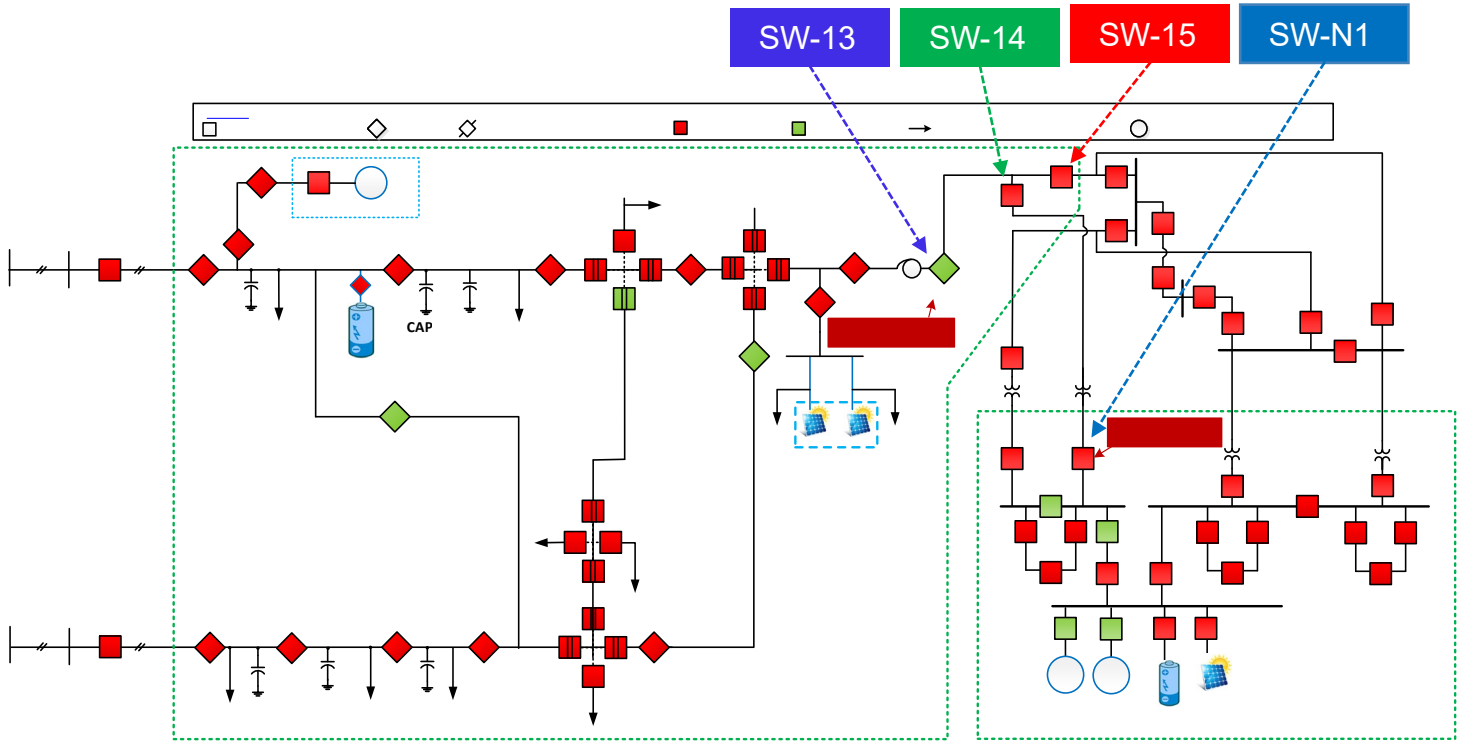
BCM-ICM Cluster/De-cluster Process Flow

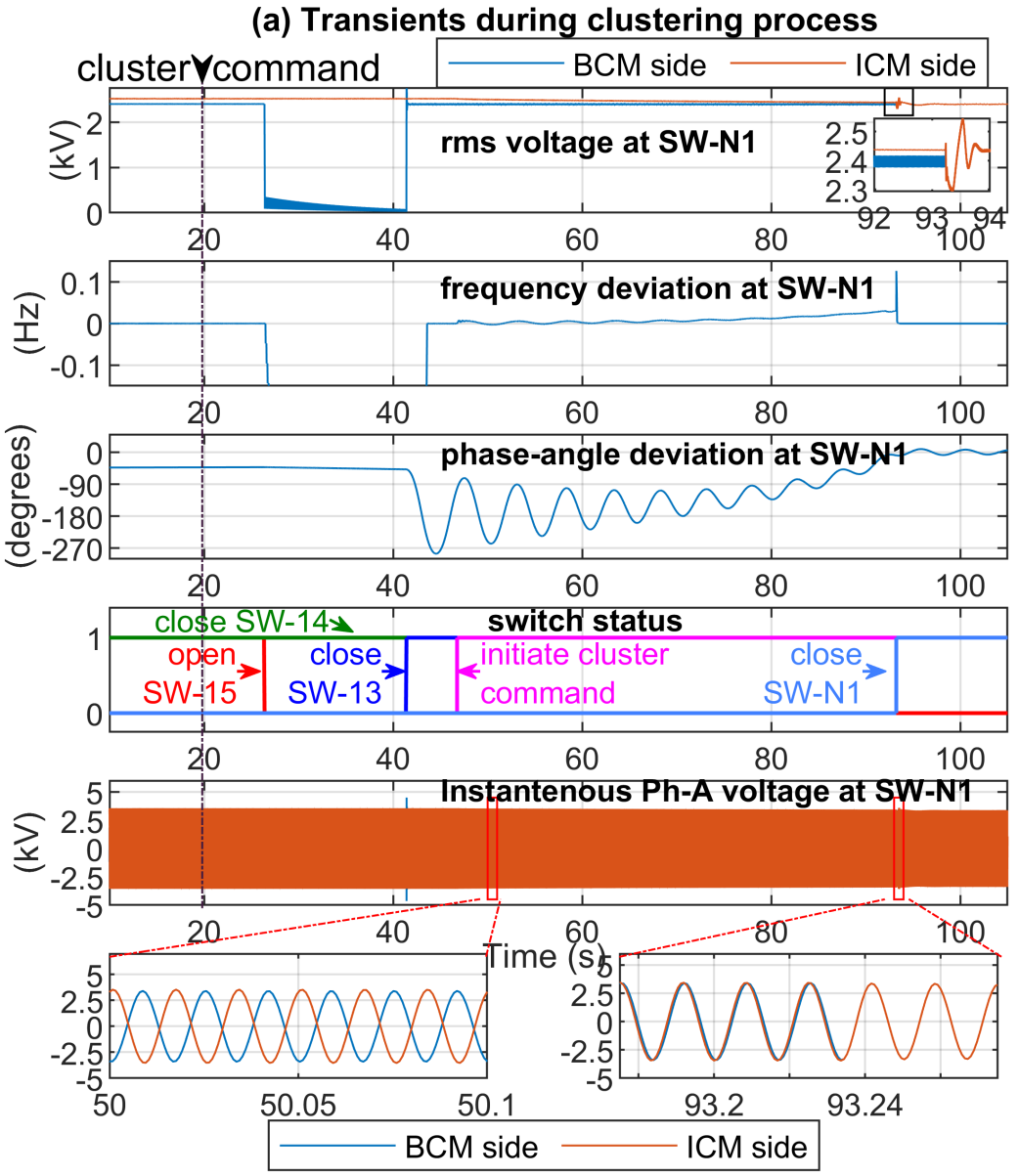
1. BCM MMC notifies ICM MMC with the emergency request via web services
2. ICM MMC submits bids via web services in response to BCM MMC's request
3. BCM MMC notifies ICM MMC of the award via web services
4. At the start of the award, BCM MMC notifies ICM MMC via DNP communication to initiate the clustering process and sends the import power setpoint from ICM as agreed via web services
5. Steps are taken by BCM MMC and ICM MMC to close the primary point of clustering
6. BCM and ICM are in clustering mode of operation where ICM MMC follows the power import setpoints it receives from BCM MMC via DNP communication
7. At the end of clustering, BCM MMC notifies ICM MMC via DNP communication to initiate de-clustering
8. Steps are taken by BCM MMC and ICM MMC until ICM MMC opens the primary point of de-clustering between BCM and ICM
9. BCM and ICM return to their islanded mode of operation

RTDS-HIL Test Results: *Transient Responses during Clustering*

Clustering SOO

- Open SW-15
- Close SW-14 if open
- Close SW-13
- Initiate cluster command
- ICM MMC synchronizes ICM with BCM by adjusting voltage and frequency of the ICM Gas Generator
- Synchronization check and close SW-N1

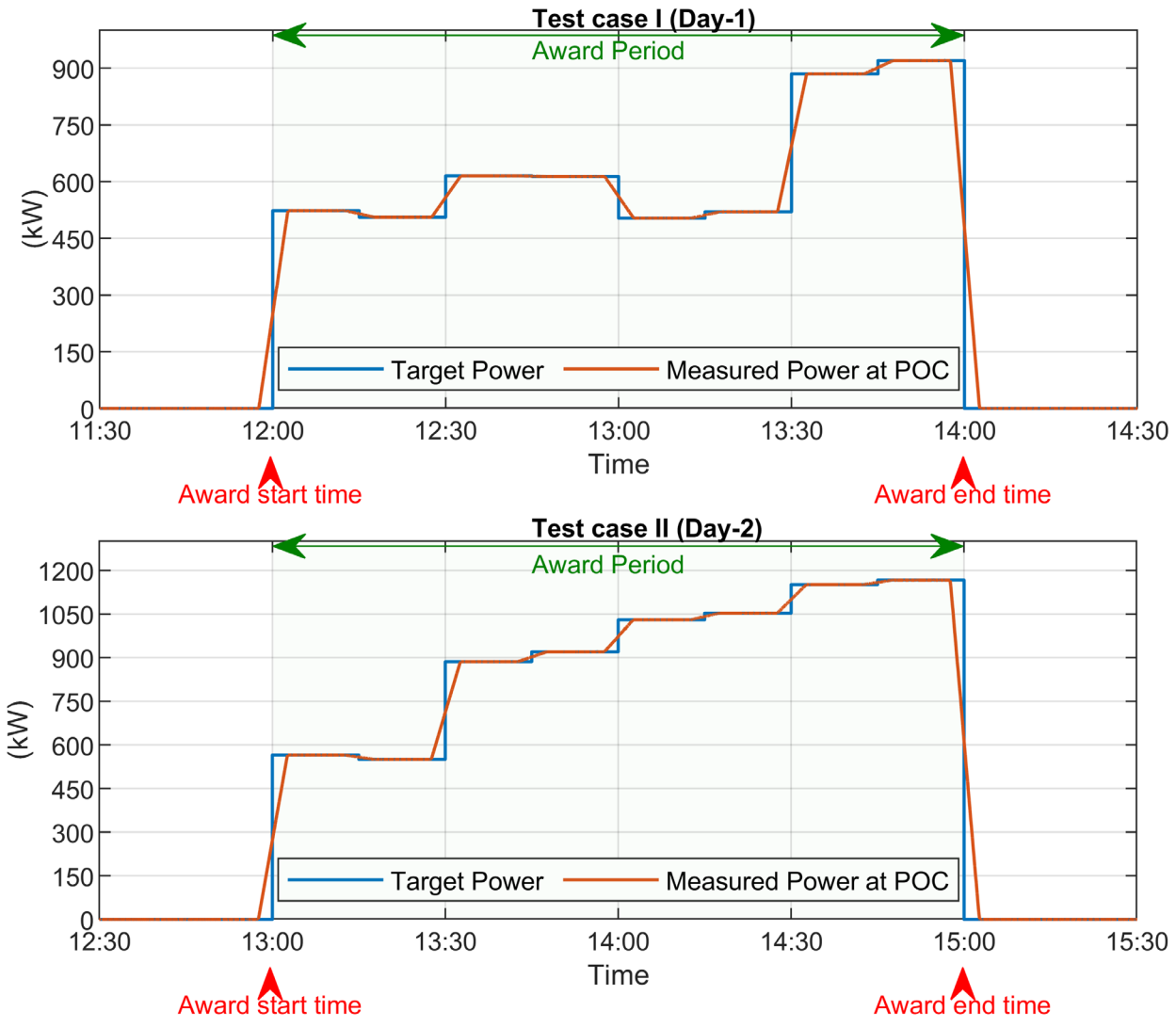




RTDS-HIL Test Results: *Power Import at POC*

- Two test Cases
- During testing, artificial shortage is created on BCM by imposing limit on the BCM gas generator power
- During clustering, the power import at POC respects the awarded values.

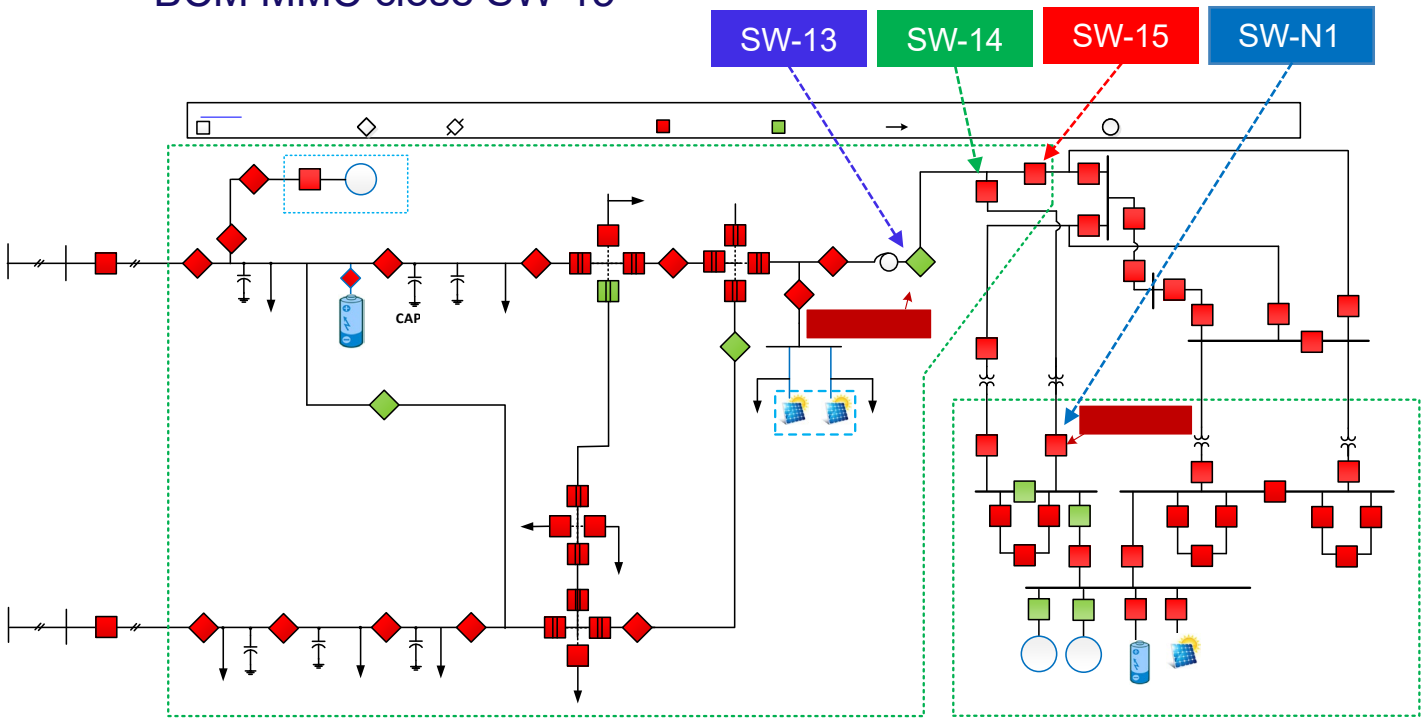
SN	Test Case I (Day-1)			Test Case II (Day-2)		
	Start time	End time	Cleared kW	Start time	End time	Cleared kW
1	12:00	12:15	523.16	13:00	13:15	565.08
2	12:15	12:30	506.00	13:15	13:30	550.20
3	12:30	12:45	615.04	13:30	13:45	885.89
4	12:45	13:00	513.59	13:45	14:00	920.15
5	13:00	13:15	503.31	14:00	14:15	1029.90
6	13:15	13:30	520.33	14:15	14:30	1053.02
7	13:30	13:45	884.78	14:30	14:45	1150.88
8	13:45	14:00	920.15	14:45	15:00	1166.43

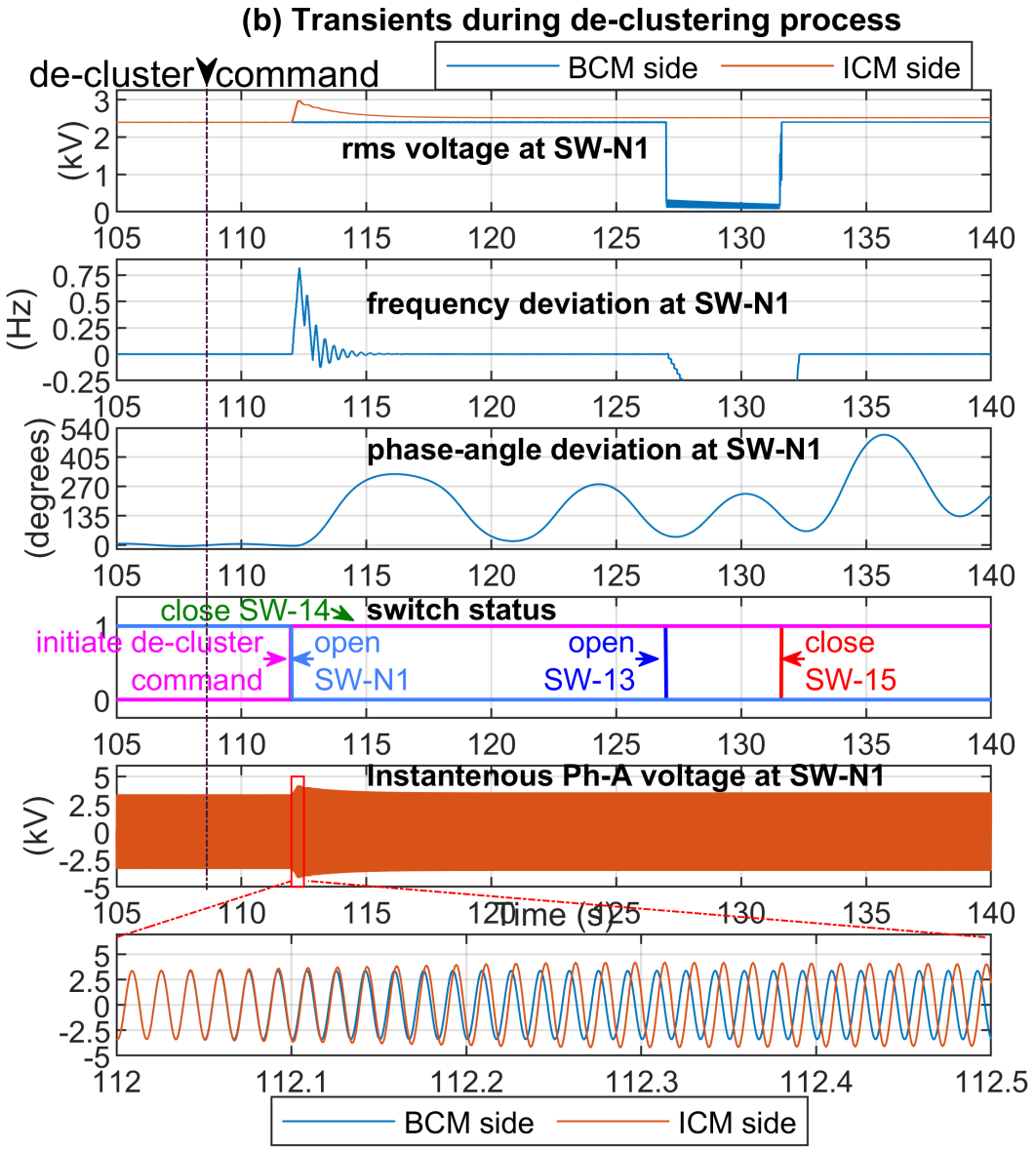


RTDS-HIL Test Results: *Transient Responses during De-clustering*

De-clustering SOO

- BCM MMC sends signal to ICM MMC to zero power at POC (SW-N1)
- ICM MMC adjusts power of ICM gas generator to zero out the power at POC
- BCM MMC issues de-cluster command to ICM MMC
- ICM MMC opens SW-N1
- BCM MMC opens SW-13
- BCM MMC close SW-15





Challenges in Microgrid Cluster Implementation

While operation of microgrids in cluster has the benefit of sharing additional resources for enhanced resiliency and flexibility, the operation of multiple microgrids in network/cluster comes with challenges:

- **Microgrid Infrastructure**
  - DERs should have capability to operate in grid following mode and/or grid forming mode
  - DA switches/breakers should be capable of remote control
  - High speed communication for real time operation specially to ensure stability following transition of modes

- **Control and coordination between MMCs and DERs:**
  - Proper coordination between MMCs and individual DERs especially during clustering/de-clustering procedures is required to maintain frequency/voltage

- **Protection Challenges:**
  - Protection schemes of networked microgrids primarily depend on DER type and microgrid operation modes. The operation of microgrids with additional DERs/microgrid cluster re-design of protection coordination schemes.

- **Cyber-physical security:**
  - In networked microgrids, the participating MMCs interact with each other. These MMCs/microgrids are owned by different parties. Cyber-physical security measures need to be carefully evaluated.

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Thank you