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Benefits of Grid-Forming Distributed Energy Resources in Grid-Connected Scenarios

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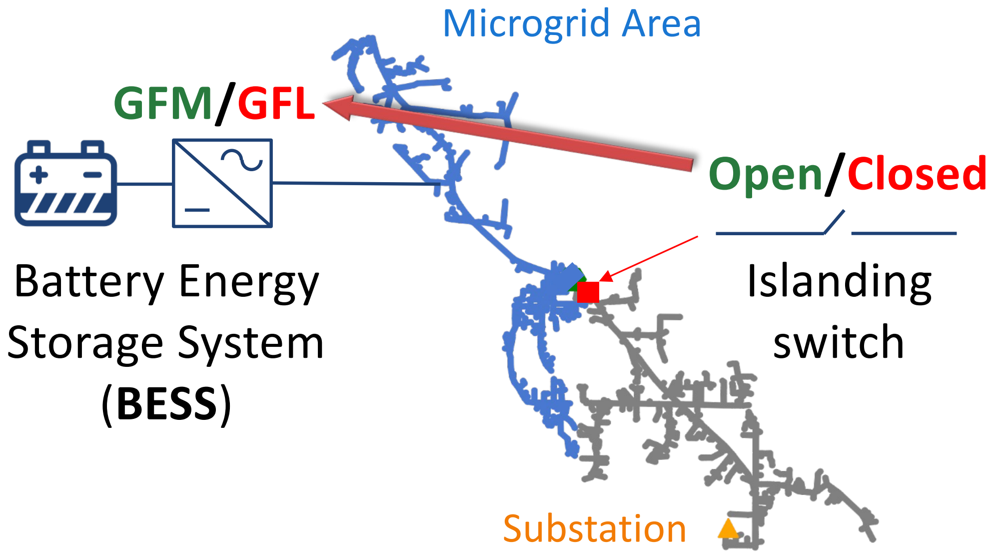
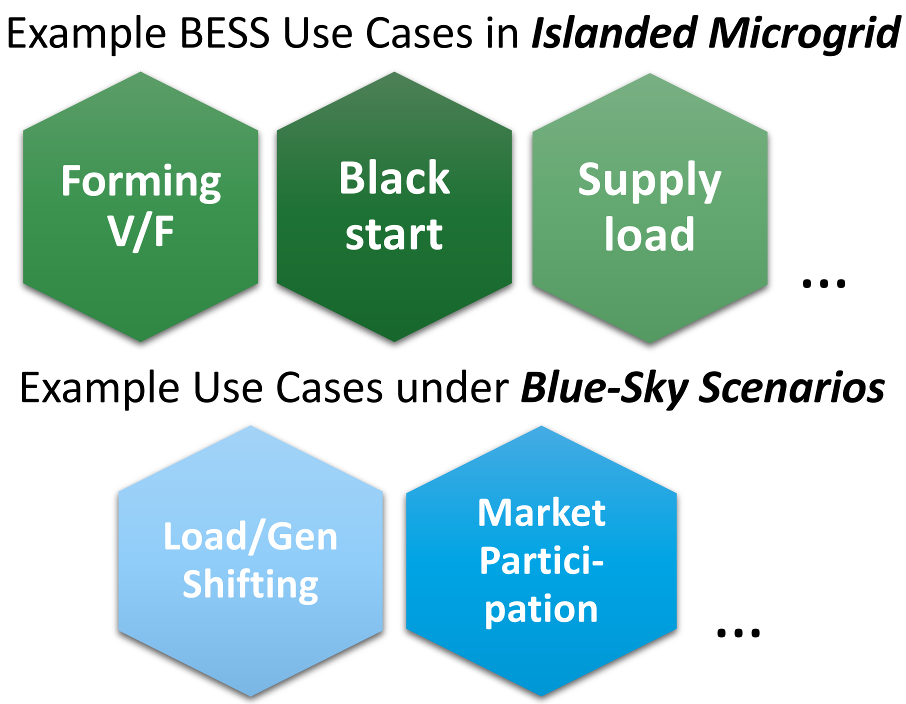
Research questions

- With high penetration of inverter-based resources (IBR) in both transmission and distribution, will today's grid-following (GFL) distributed energy resource (DER) control remain stable?
- If DERs face stability challenges, can it be effectively resolved by transmission-connected grid-forming (GFM) resources alone?
- Will GFM DER become necessary in power systems with high renewable penetrations?

Use cases of utility-scale BESS in Dx grid — today's perspective



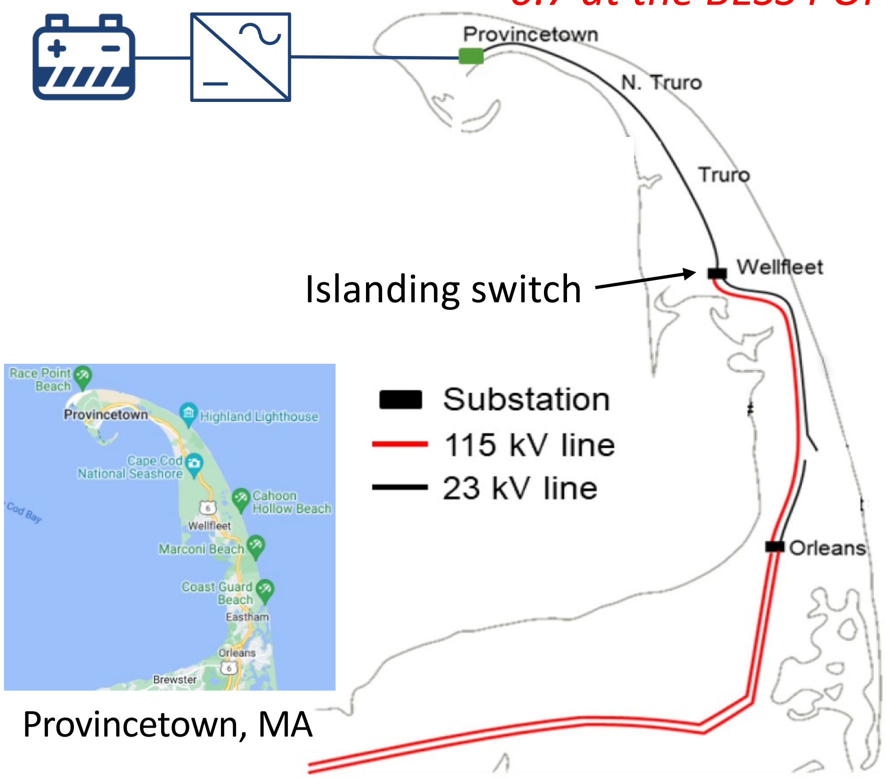


- Presently, BESS operates in grid-forming (**GFM**) mode in microgrid and typically switches to grid-following (**GFL**) when grid-connected

Real-world example of BESS in <u>GFM mode</u> under blue-sky scenarios — is this going to be the trend for tomorrow?

Always GFM

short circuit ratio (SCR) = 0.7 at the BESS POI

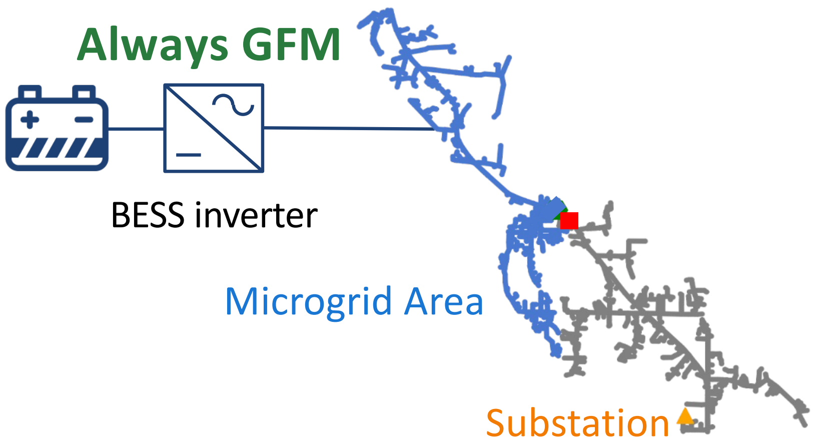


Provincetown, MA

- 25 MW/38MWh/57.6MVA BESS connected to the 23 kV system
- **The BESS inverter operates in GFM mode under both grid-connected and islanded conditions**
- GFM inverters can operate stably under ultra-weak grid conditions unlike GFL inverters

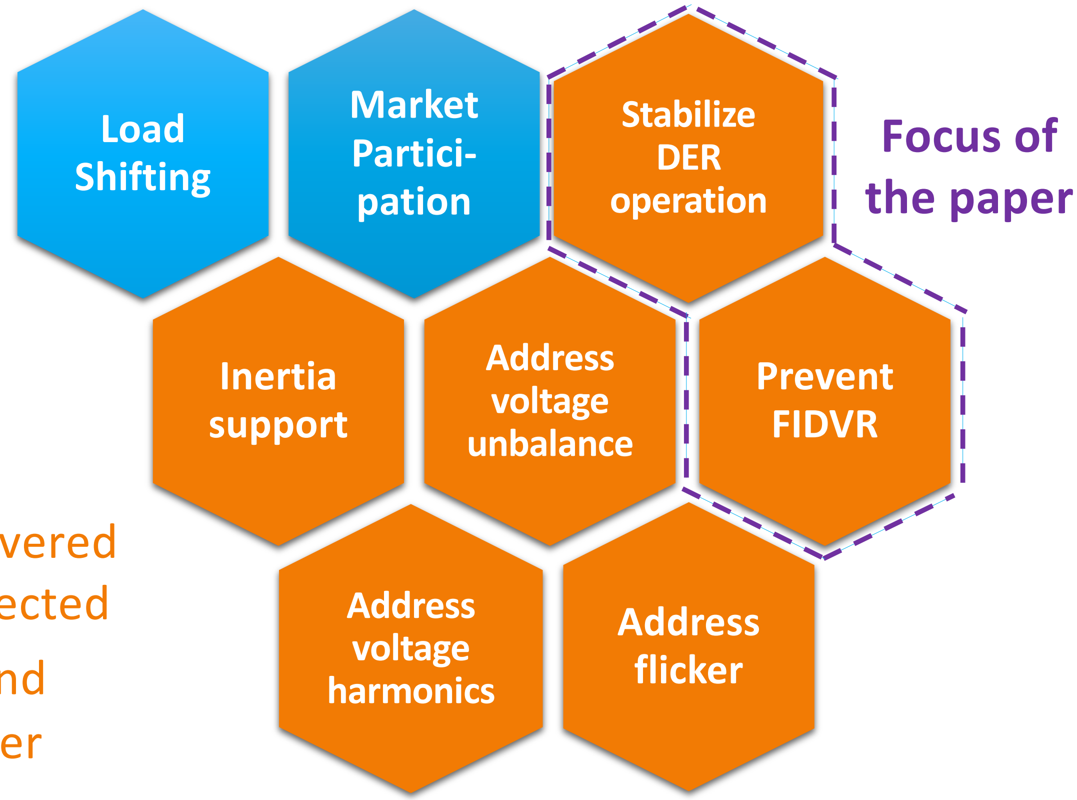
Ref: "Analysis and Application of Grid-Forming Battery Energy Storage System for Reliability Improvement on the Eversource Distribution System in Cape Cod Massachusetts," 2022 Grid of the Future Symposium

Can GFM control bring more use cases for BESS in Dx grid-connected operation?



Potential BESS Use Cases under

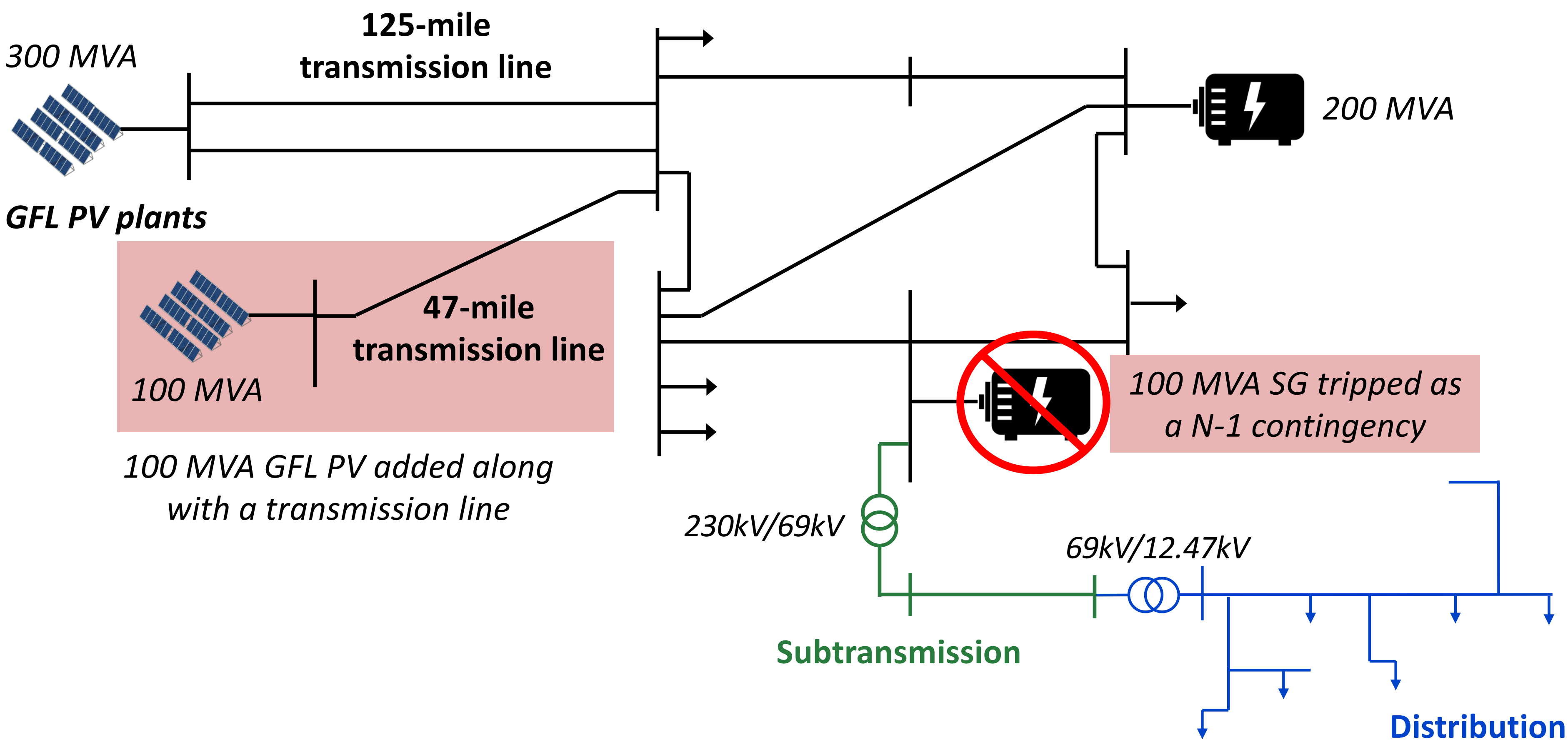
Blue-Sky Scenarios



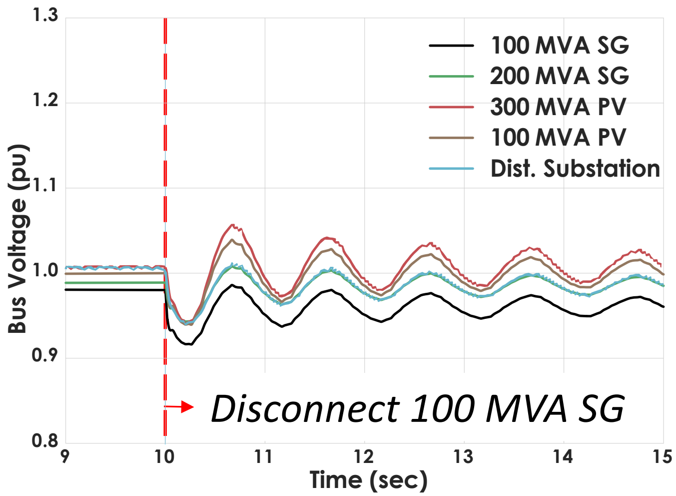
- Additional use cases of BESS may be delivered by utilizing GFM control when grid-connected
- Use cases on stabilizing DER operation and addressing FIDVR is the focus of this paper

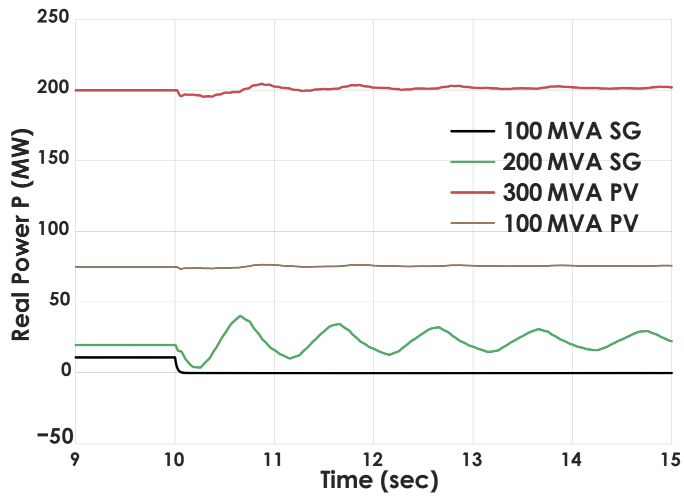
Are Transmission-Connected GFM IBRs Sufficient for System Stability with High Renewable Penetration?

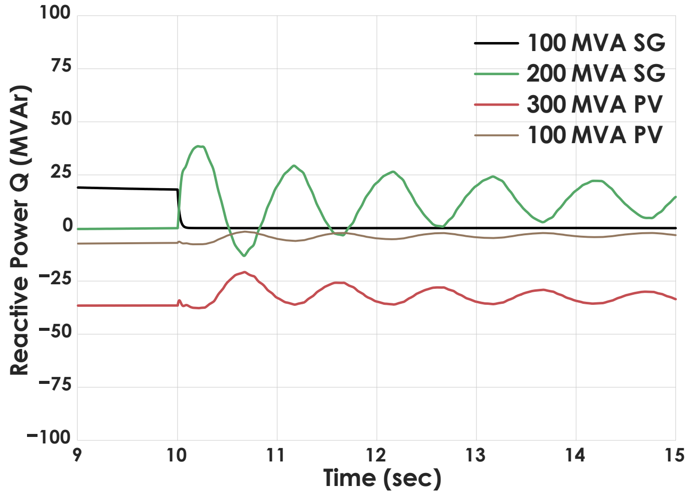
Case study: 67% IBR penetration in Tx



System stability with increased IBR penetration



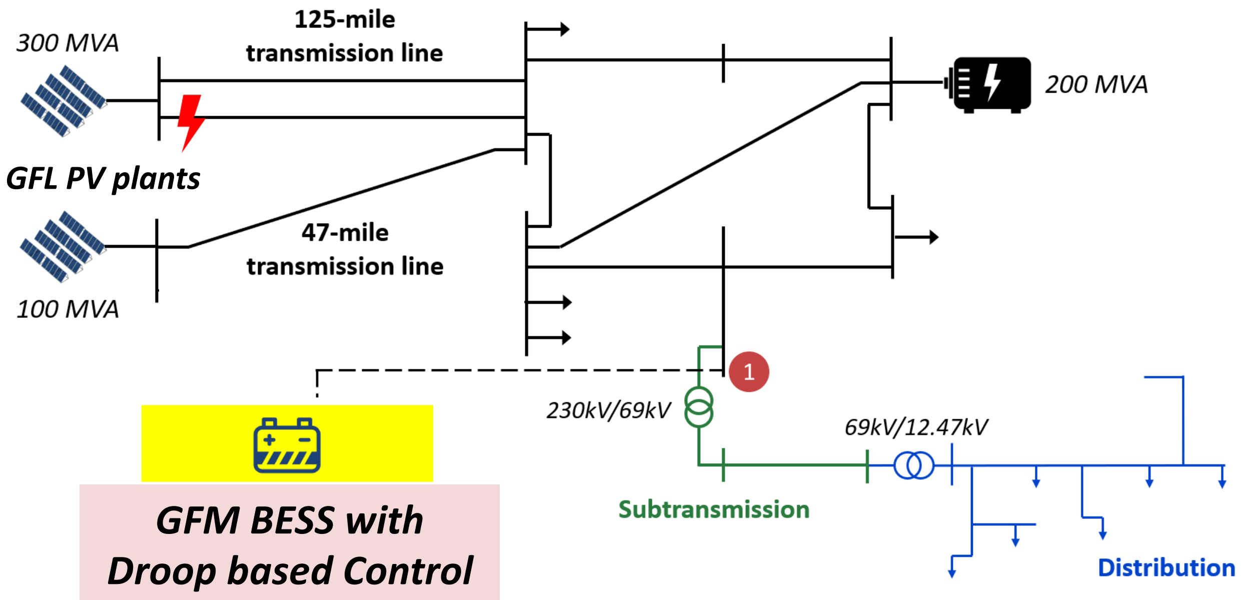




- Oscillations with insufficient damping occurs after disconnecting the 100 MVA SG
- This indicates that the remaining SG is not able to provide sufficient grid strength to accommodate the increased penetration of IBR

How much Tx-connected GFM BESS capacity is needed to stabilize the system?

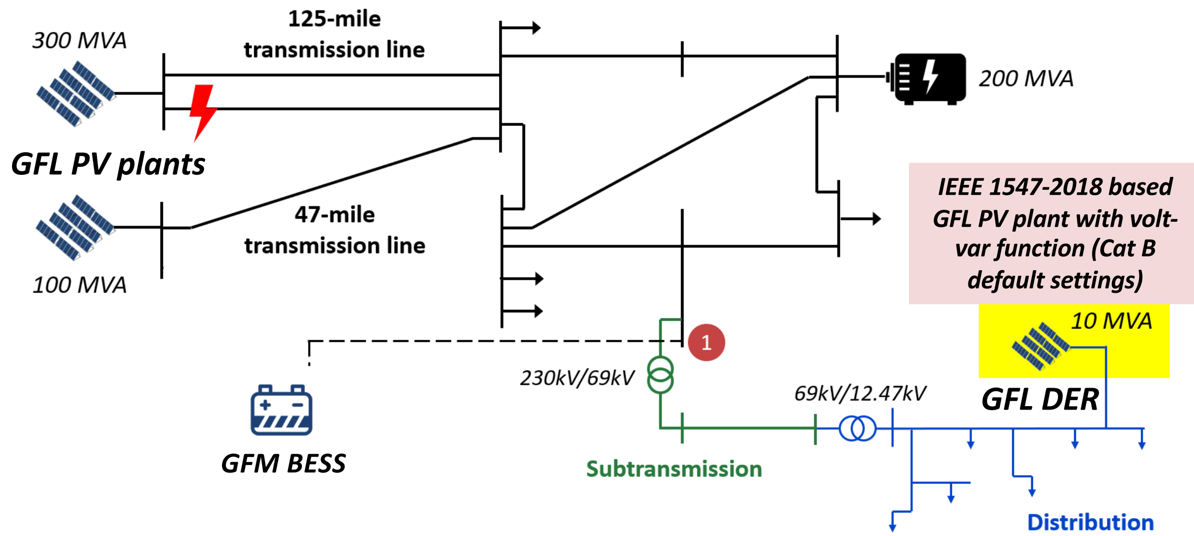
Location	Minimum GFM BESS Capacity Needed
1	45 MVA



- The transmission system can be stabilized by Tx-connected GFM BESS
- The GFM BESS capacity needed to stabilize the system depends on the location

Will the same BESS solutions work when additional large DER is connected in Dx?

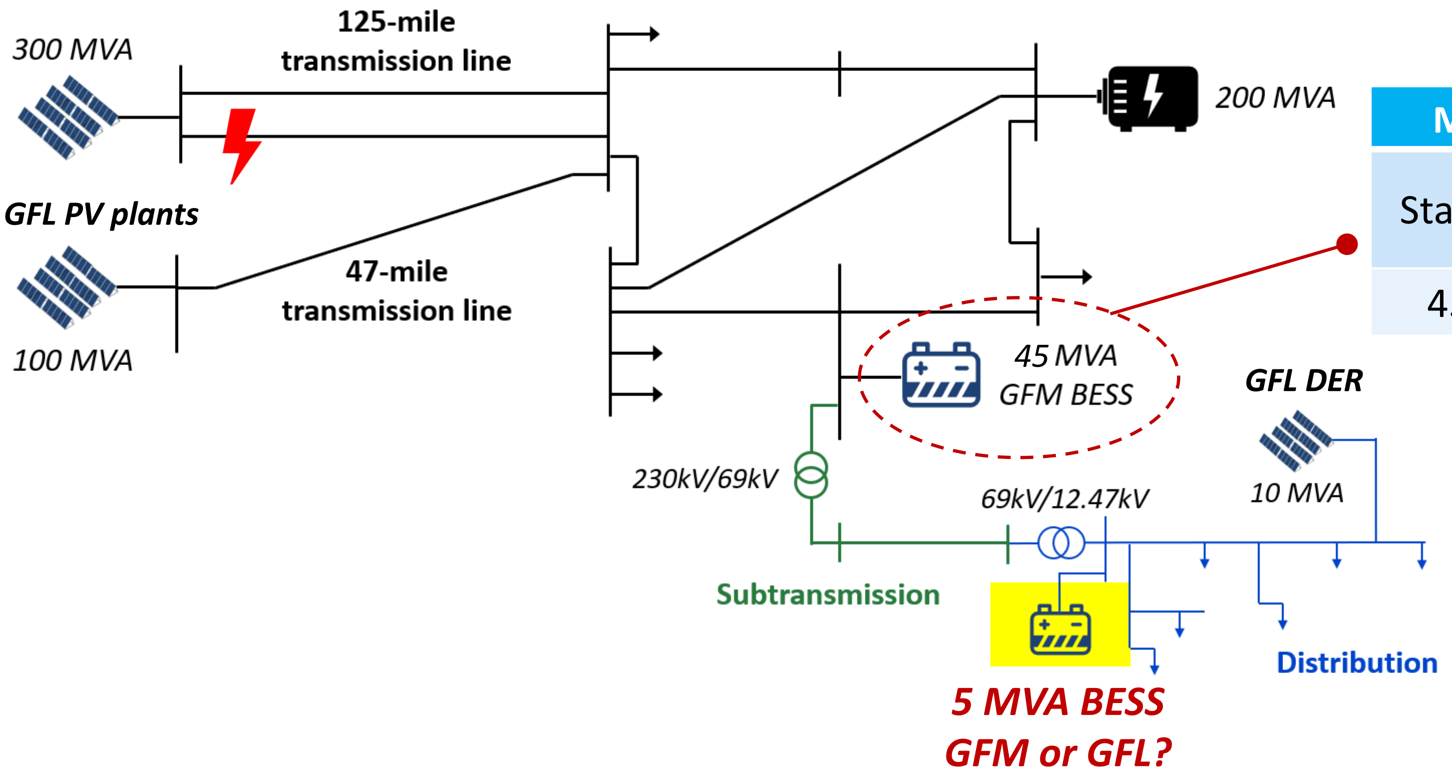
Location	Minimum GFM BESS Capacity	
	Stabilize Tx	Stabilize Tx & Dx
1	45 MVA	90 MVA



- The Tx-connected GFM BESS capacity required to stabilize both Tx and Dx is much greater than the capacity required to stabilize Tx itself
- Increasing hosting capacity of renewable DERs is critical to reach net-zero emissions but relying solely on Tx-connected GFM resources may not be a cost-effective solution

Can GFM DER Share the Responsibility to Maintain System Stability?

Simulation case study to evaluate the impact of GFM BESS

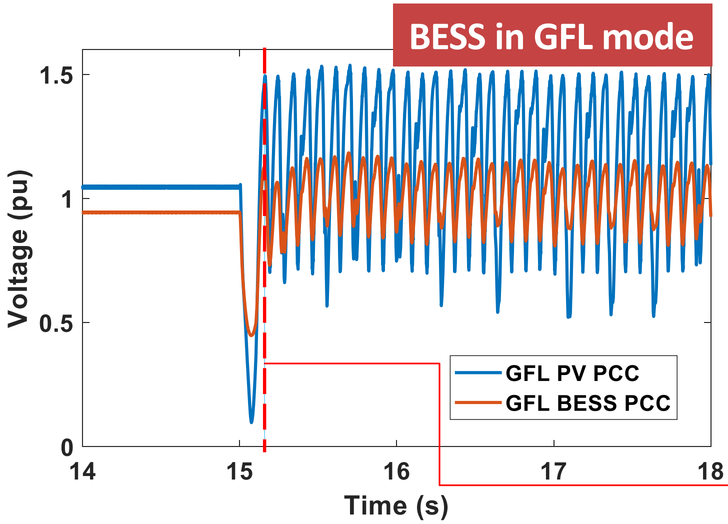


Minimum GFM BESS Capacity	
Stabilize Tx	Stabilize Tx & Dx
45 MVA	90 MVA

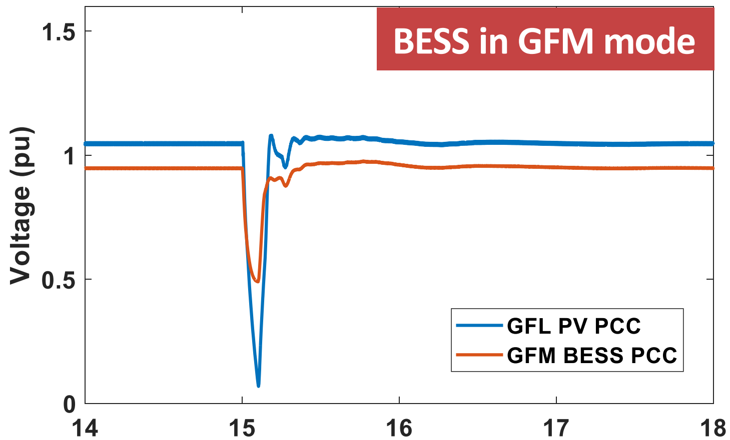
If a 5MVA BESS is installed at the Dx substation, does it benefit system stability by operating in GFM mode rather than GFL mode?

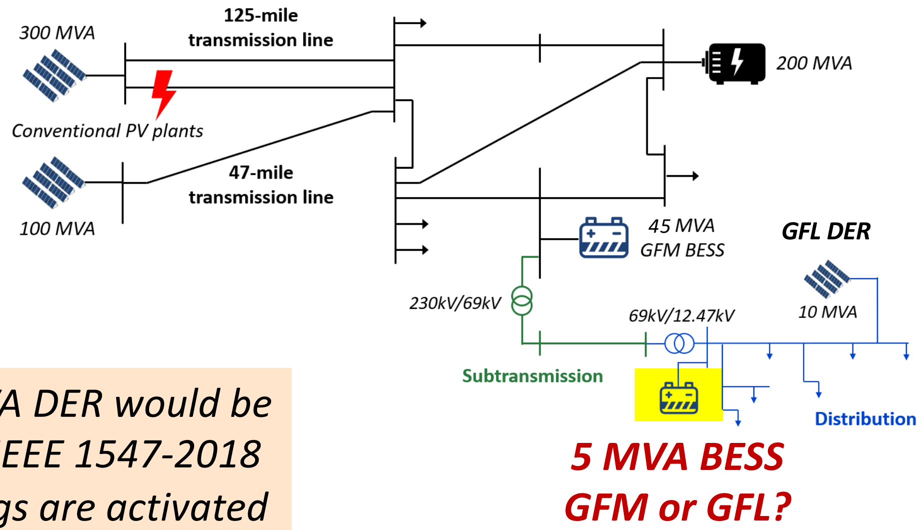
EPRI

Example results – beneficial impact of GFM BESS on DER stability



The 10MVA DER would be tripped if IEEE 1547-2018 trip settings are activated





- Operating the BESS in GFM mode can stabilize the GFL PV for the 0.1s fault event considered
- Compared to Tx-connected BESS, less GFM BESS capacity is needed in the Dx to stabilize the GFL DER

Can GFM DER Improve Power Quality of the Distribution System?

What is fault induced delayed voltage recovery (FIDVR)?

1
- Transmission or distribution fault occurs
- Single-phase induction motors (in HVAC) stall due to severe voltage dip
- Fault is cleared

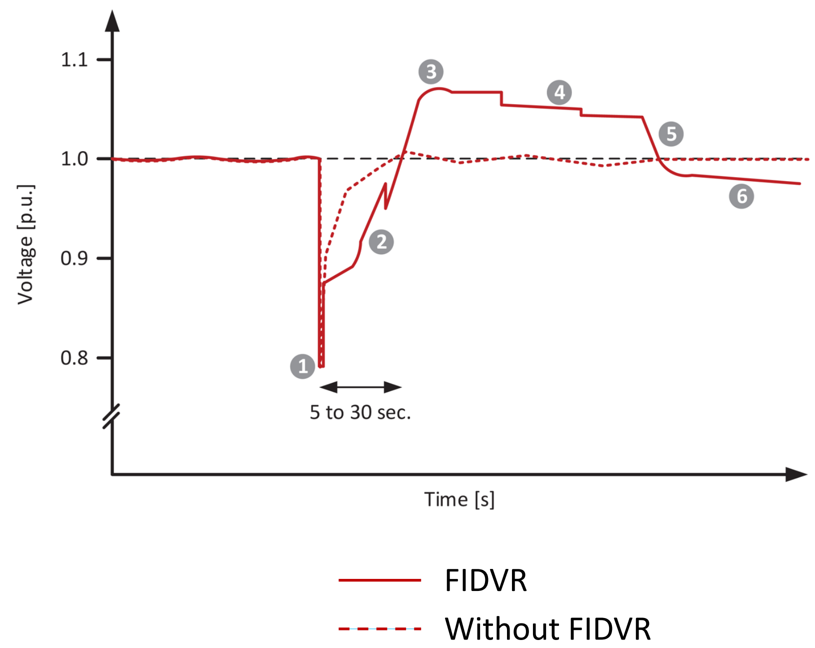
2
- Stalled motors keep drawing huge amount of reactive power; feeder voltage remains low
- More capacitors are switched on
- Feeder voltage starts to recover as stalled motors are tripped by thermal protection

3
- Overvoltage due to capacitors still online

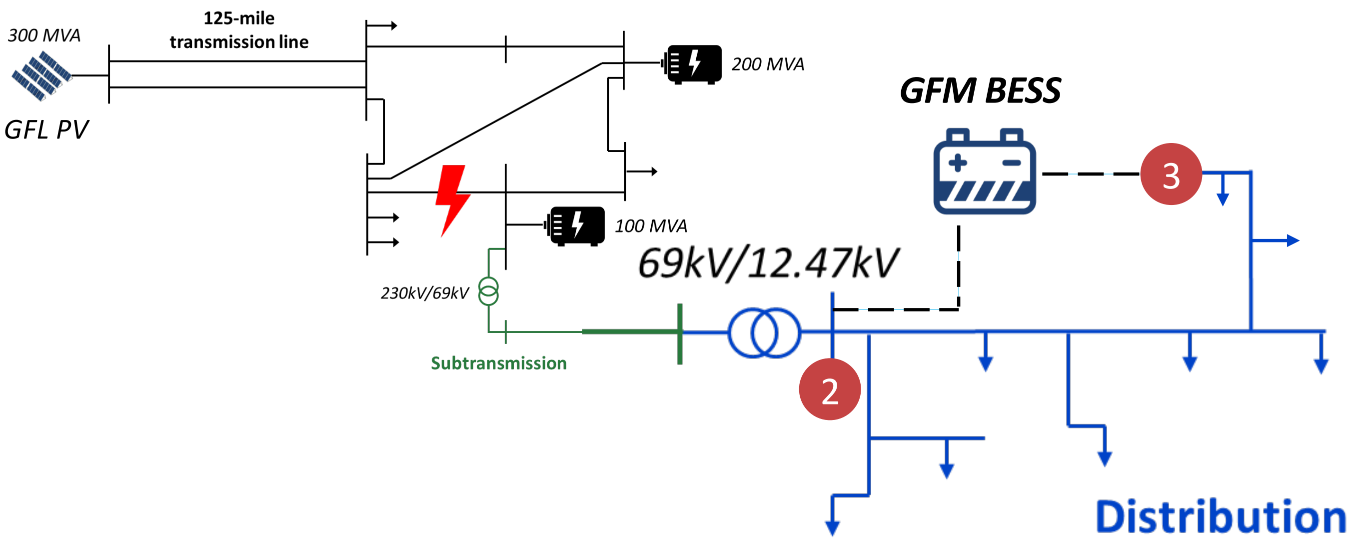
4
- Capacitors switch off due to over voltage

5
- HVAC loads come back

6
- Undervoltage due to higher load and capacitors offline



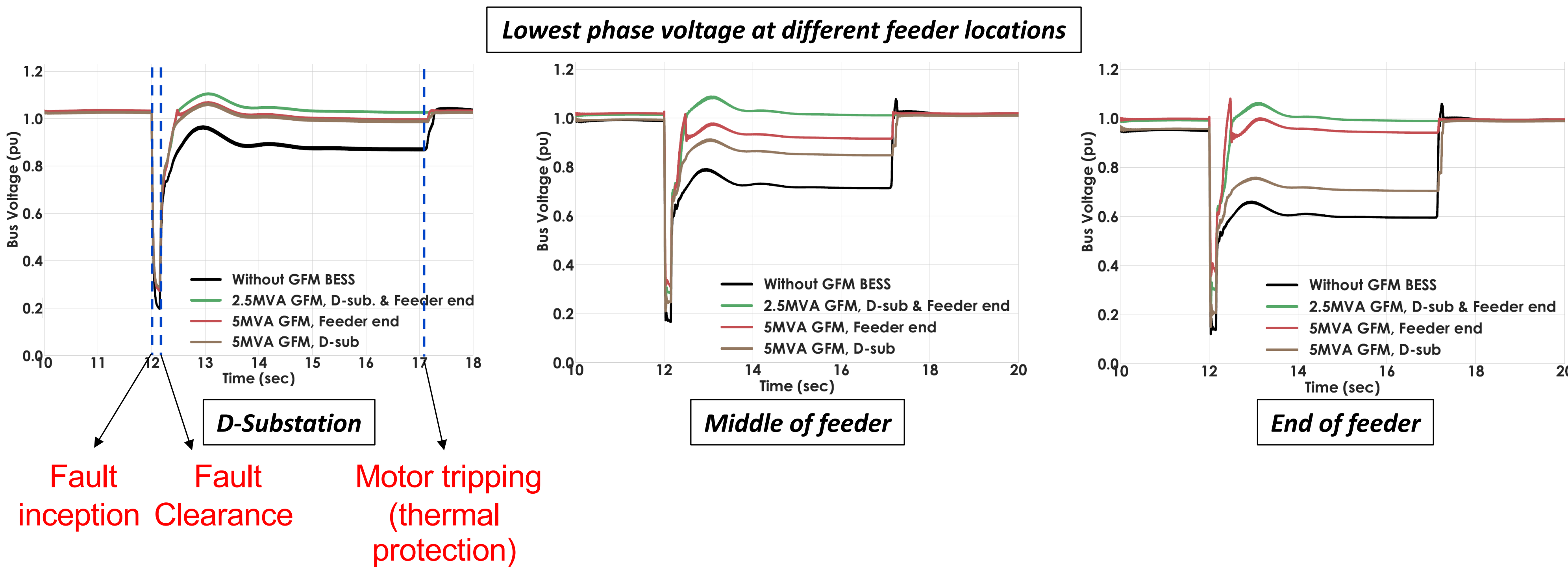
System and Scenarios Studied for GFM DER Impact on FIDVR



Scenario #	GFM BESS Size	GFM BESS Location
1	5 MVA	2
2	5 MVA	3
3	2.5 MVA	2&3

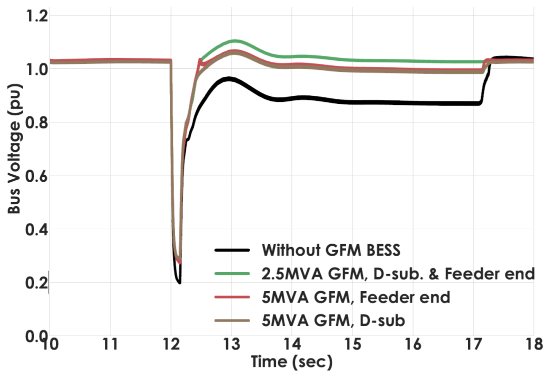
- Loads on the distribution feeder are modeled as single-phase loads with 50% HVAC motor and 50% constant impedance
- Following a 0.15s transmission three phase fault, FIDVR is observed on the distribution feeder and the impact of GFM BESS at different feeder locations is examined

Simulation case study– GFM DER impact on FIDVR

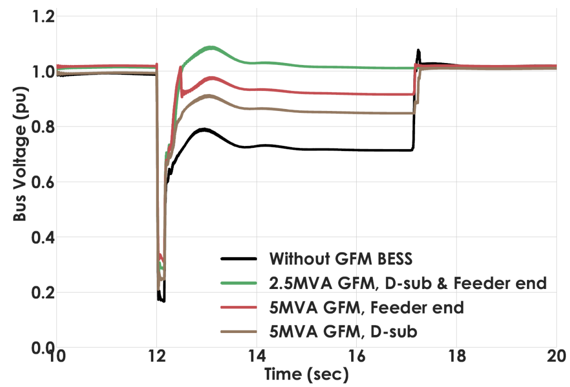


- Results indicate that GFM DER can reduce the percentage of motor stalling and improve the feeder voltage during FIDVR, or prevent FIDVR
- The level of voltage improvement depends on location and size of the GFM DER(s)

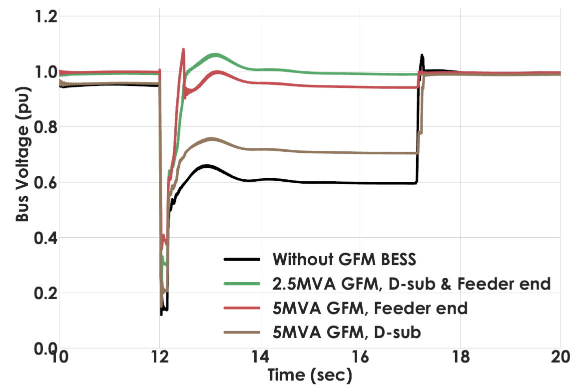
Case Study Results – Impact on the Percentage of Motor Stalling



D-Substation



Middle of feeder



End of feeder

Scenarios	w/o GFM	5MVA GFM at D-SUB	5MVA GFM at Feeder End	2.5MVA GFM at D-SUB and Feeder End
Estimated % of Motor Stalling	83.3	26.6	18.5	0

- Results indicate that GFM DER can effectively reduce the percentage of motor stalling and improve the feeder voltage during FIDVR, or prevent FIDVR

Conclusion

Conclusions based on simulation case studies

- High penetration of DERs/IBRs and retirement of SGs can cause instability in distribution systems
- Transmission connected GFM IBRs can help increase distribution hosting capacity of DERs but the capacity required might be high (cost prohibiting)
- GFM DER may be an effective way to resolve the potential stability challenges in weak distribution grids and to increase hosting capacity
- GFM DER also has the potential to improve power quality of the distribution system

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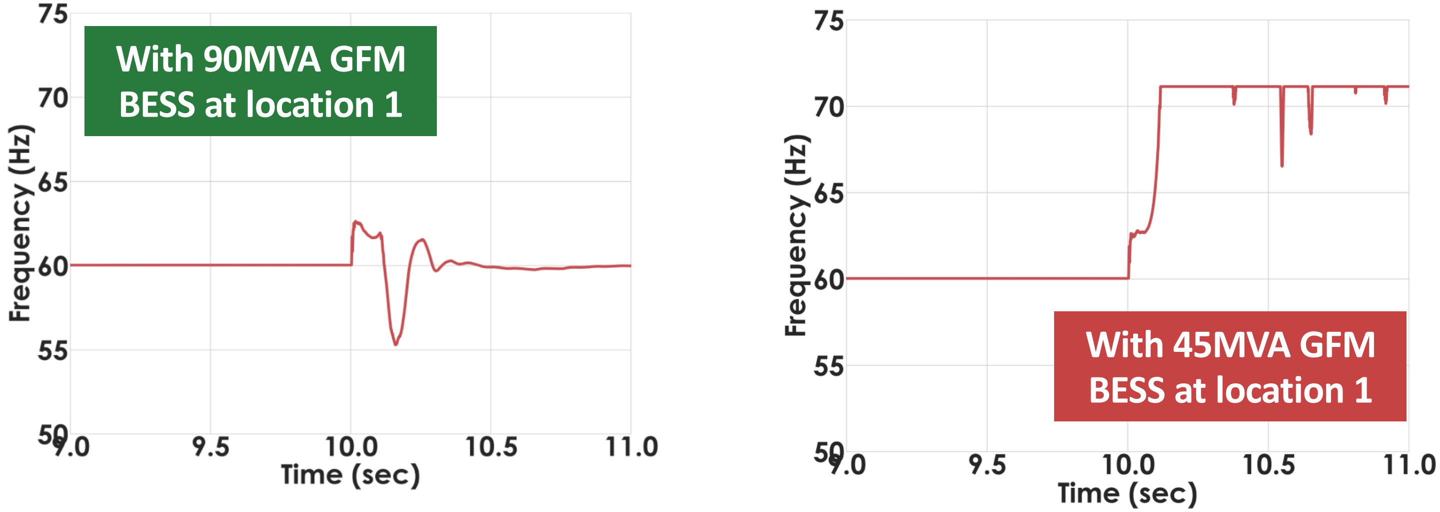
What’s causing the DER instability?

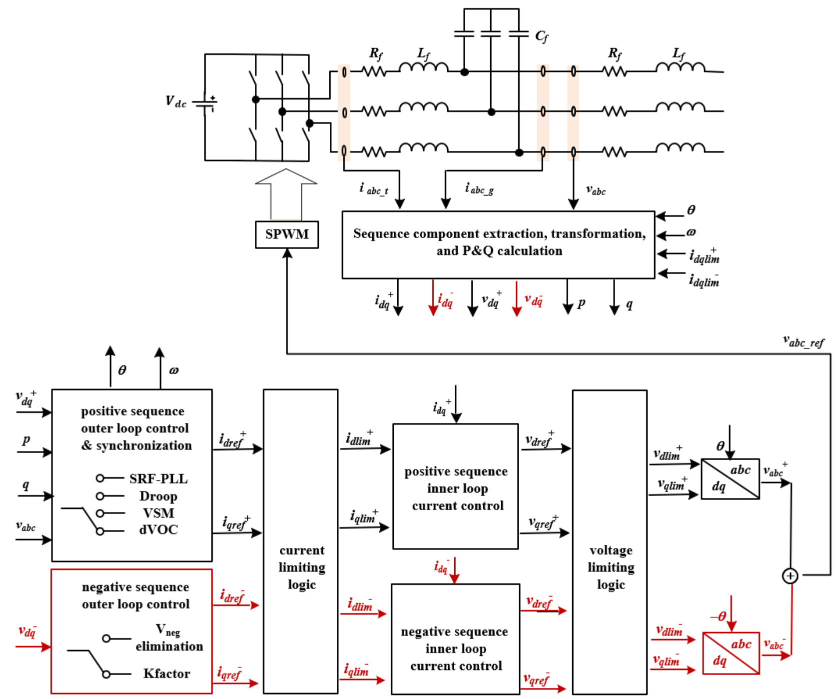
PLL Measured Frequency of 10 MVA DER



- For most present-day inverters, the control is designed to work properly when the grid voltage is relatively insensitive to inverter current injection
- At a weak system location, the PLL may fail to lock onto the grid frequency following a disturbance, resulting in inverter injecting current at incorrect phase
- GFM BESS improves the grid strength so that the conventional DER control can be stabilized

Modeling of Inverter Based Resources in PSCAD

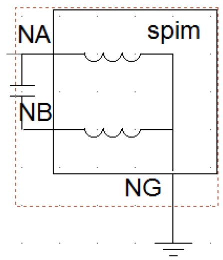
- The EPRI developed generic inverter model (shown on the right) is used to simulate GFM IBRs in both transmission and distribution and for GFL IBRs in transmission
- The transmission GFL IBR model utilizes a plant controller to carry out plant level voltage and frequency control
- For GFL DER, another EPRI developed generic model with IEEE 1547-2018 functions is leveraged ([3002025896](3002025896))
- For all the simulations presented, the GFL DER has volt-var function enabled with IEEE 1547-2018 Category B default settings

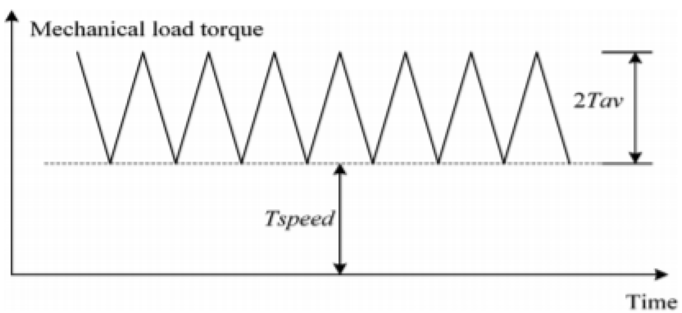


This PSCAD model is publicly available on PSCAD's knowledge base [link]

More details in the paper

HVAC Motor Modeling In PSCAD





- A HVAC motor model previously developed by EPRI is leveraged in the study
- The motor dynamics as well as the load torque characteristics are designed to closely represent a single-phase induction motor driving a reciprocating compressor
- EMT model of the HVAC load has been verified with lab testing results*
- It is also planned to include motor models with scroll compressor in later studies
- Scroll compressor is more common for new HVAC units to improve energy efficiency

* *Tech Update on Load Modeling.* EPRI, Palo Alto, CA: 2017. 3002010754.