Value of GFM DER in High Penetration Scenarios

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- The views expressed herein do not necessarily represent the views of the U.S. Department of Energy or the United States Government

Overview of EPRI's GFM research

Model Development

- Develop generic white-box model for GFM inverter in EMT and phasor domain
- Work with software vendors to make the models available
- Identify when to use each type of model
- Develop tests to identify if blackbox model showcases GFM behavior

Lab Testing

- Characterizing commercial GFM inverters
- Inform model development

Controls & Stability

- Identify stability characteristics and improvements
- Identify impact of source behind inverter

Transmission Analysis

- Identify need and location to deal with reduced grid strength and inertia
- Evaluate impact of various resources

Distribution Analysis

- Grid-connected analysis to identify the value and impact
- Microgrid analysis to establish performance requirements

Standardization

- Develop performance requirements
- Identify gaps in existing standards
- Engage the industry through working groups

Education

- Yearly GFM inverter tutorial

Terminology for evolution of services from IBRs

Legacy IBR

- Injects active power at unity power factor
- Provides no grid support services

Conventional IBR

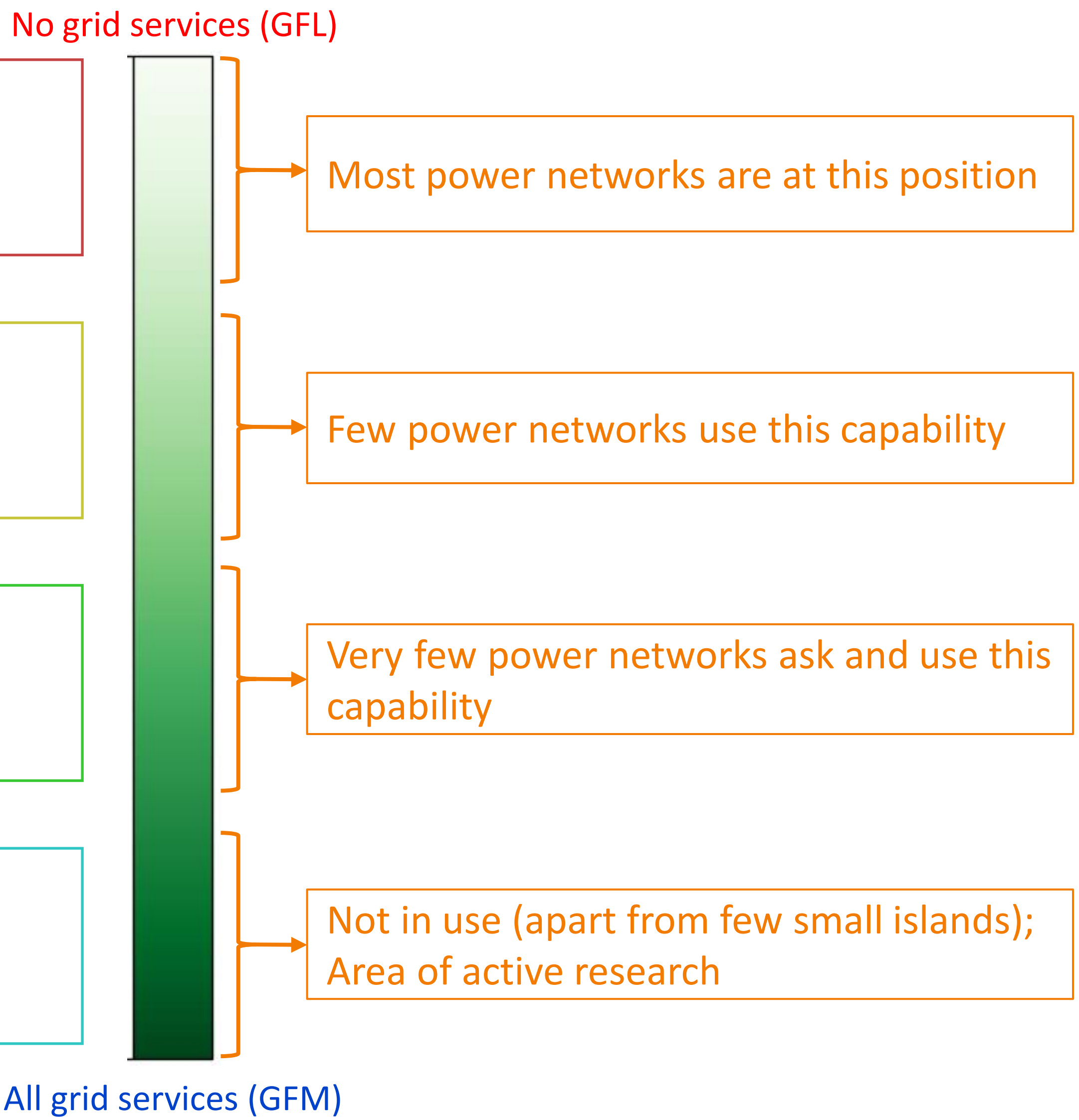
- Has capability to provide both frequency and voltage response
- Typically, full delivery of response over multiple seconds

Enhanced IBR

- Delivers full frequency and voltage response within 1s of event
- As a group, could survive loss of last synchronous machine

Future IBR

- Is capable of blackstart
- A single IBR could ride through extreme load-gen mismatch



Questions being evaluated

- How does transmission system stability get impacted by DERs?
- What role does load dynamics play?
- If DERs face stability challenges, can it be effectively resolved by transmission-connected enhanced/future IBR resources alone?
- Will increased robustness of DER become necessary in power systems with high renewable penetrations?

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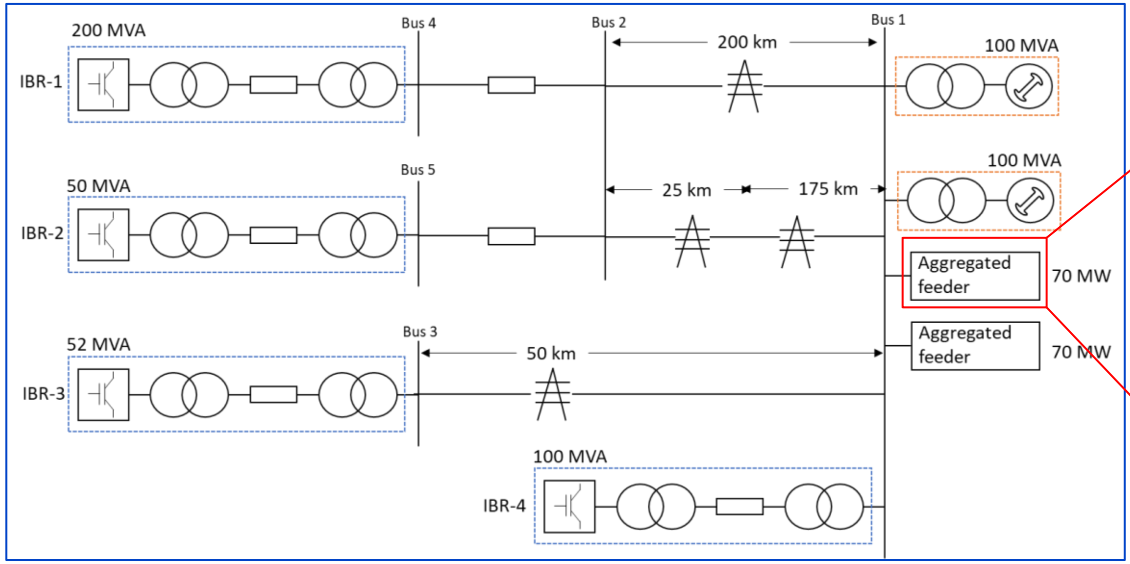
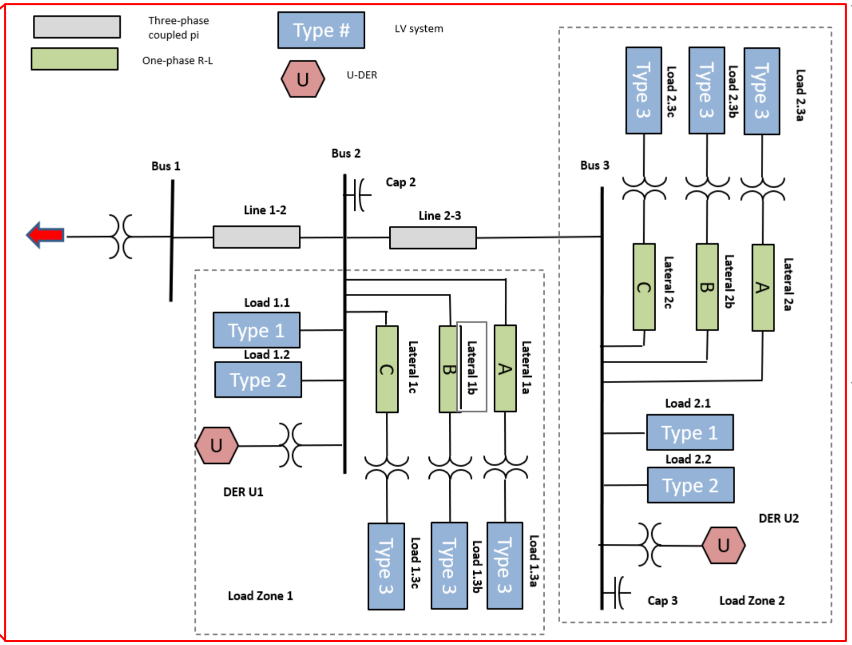
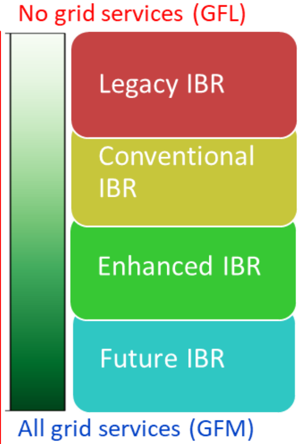
Impact of DER and load on microcosm Tx dynamics







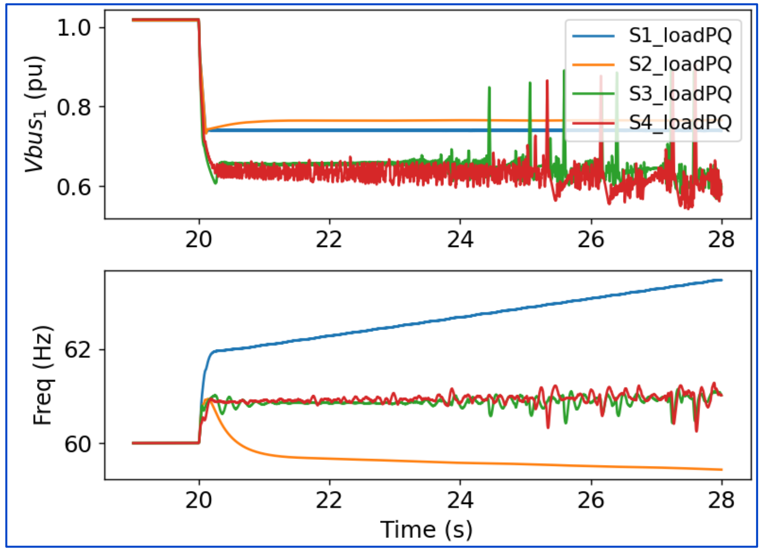
- Four IBR configuration scenarios are studied:
  - S1 –> Only IBRs 1, 2, 3 as conventional IBRs
  - S2 –> Only IBRs 1,2, 3 as enhanced IBRs
  - S3 –> S1 + IBR 4 as enhanced IBR
  - S4 –> S2 + IBR 4 as enhanced IBR

- Three load scenarios are studied:
  - LoadPQ –> Static constant PQ
  - LoadIPZQ –> Static constant I and Z
  - LoadDyn –> Aggregated composite feeder

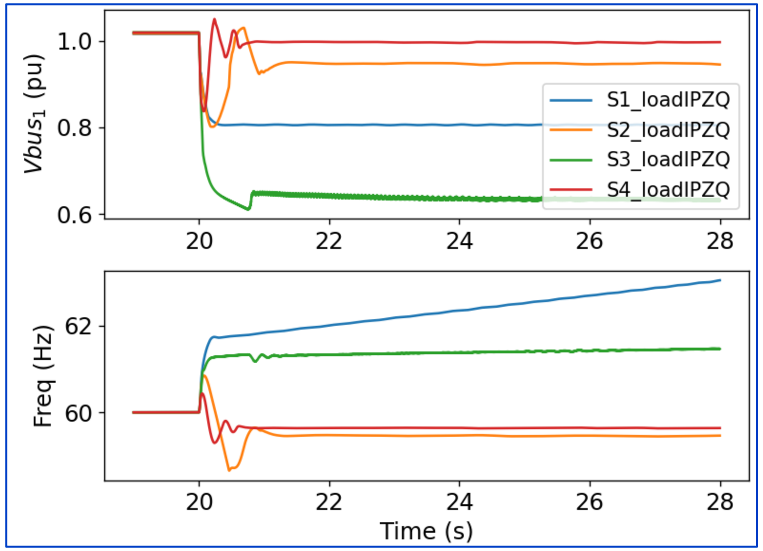
References:
- IBR model: https://www.epri.com/research/products/000000003002025889 [Public]
- Aggregate feeder: https://www.epri.com/research/products/000000003002021940 [Public]

Importance of distribution system dynamics

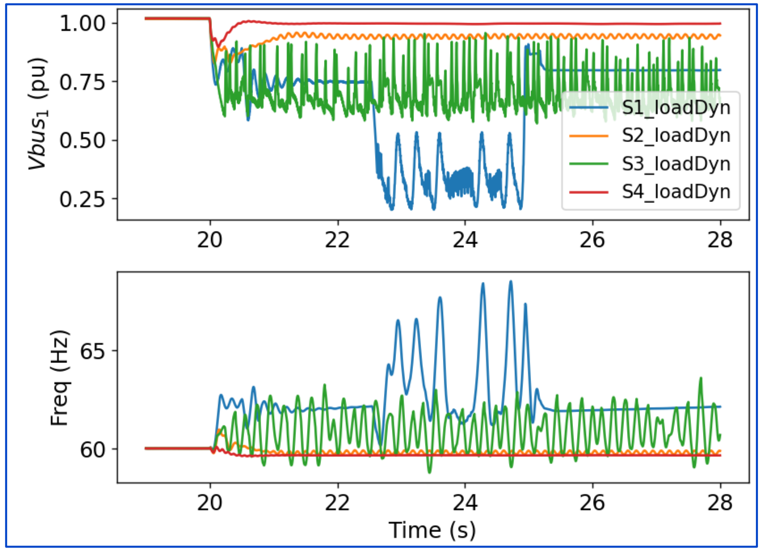
Trip of both synchronous machines to form 100% IBR network



Static constant power load



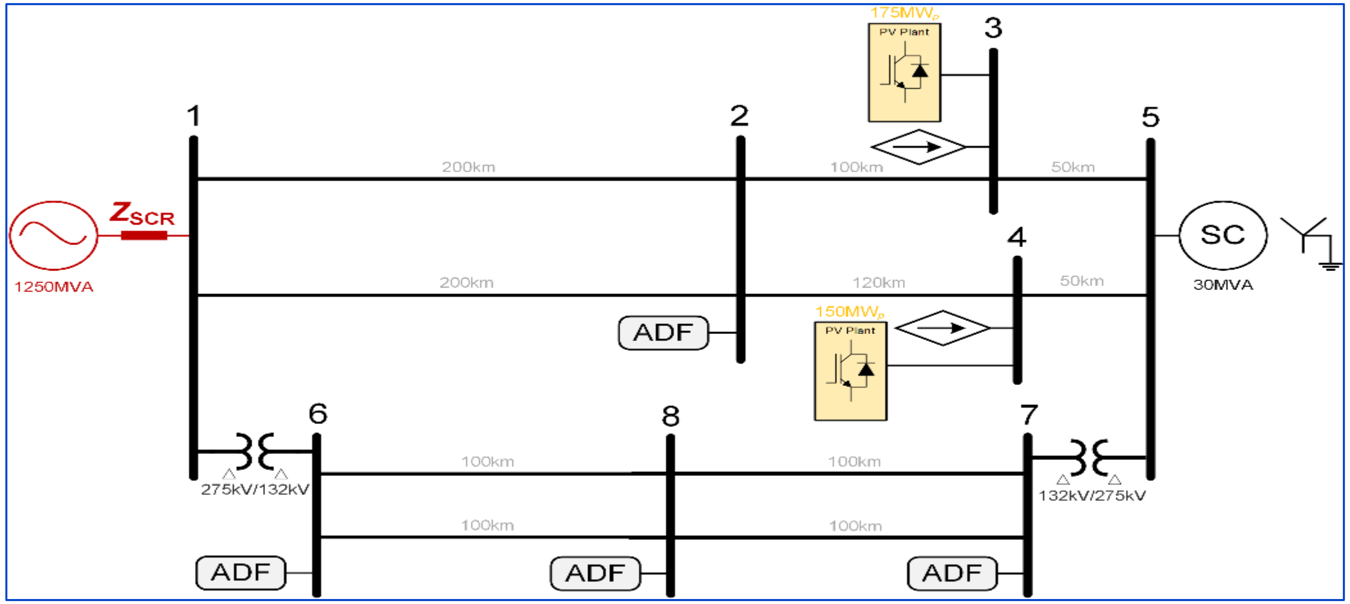
Static constant I-Z load

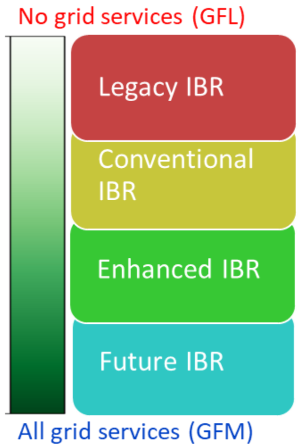


Dynamic composite load

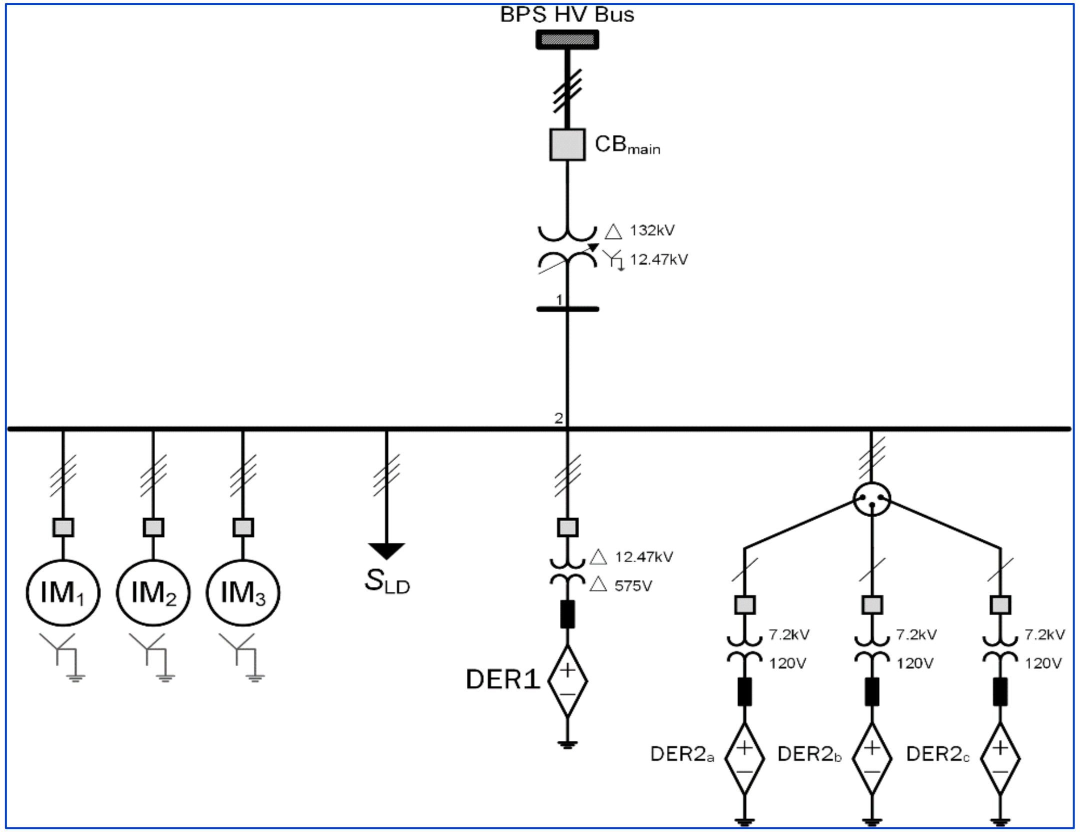
- Using static models to represent net load in distribution can provide either very conservative or very optimistic results
- Detailed distribution network representation is not required
  - Dynamic behavior should however be realistically represented

Impact of DER on real utility transmission network





- Portion of network with composite active distribution feeder (ADF)
- Transmission connected resource
  - Conventional IBRs
- Distribution connected resource
  - Legacy IBR/DER



References:

- Ali Arzani, Deepak Ramasubramanian, Parag Mitra, "Impact of Dynamic Load on IBR-Based Transmission-Distribution Network Operation: A Case Study," IEEE ISGT North America 2024 [under review]
- Yi Zhou, Deepak Ramasubramanian, Parag Mitra, Manjula Dewadasa1, Sachin Goyal, "Impact of Distributed Photovoltaic System on System Strength," 2023 CIGRE Cairns Symposium, Cairns, Australia

DER Impact

- Increase in DER can cause instability with reduction of system strength
- Increase in dynamic load characteristics improves stability
- DER and load dynamic characteristics have varied impact

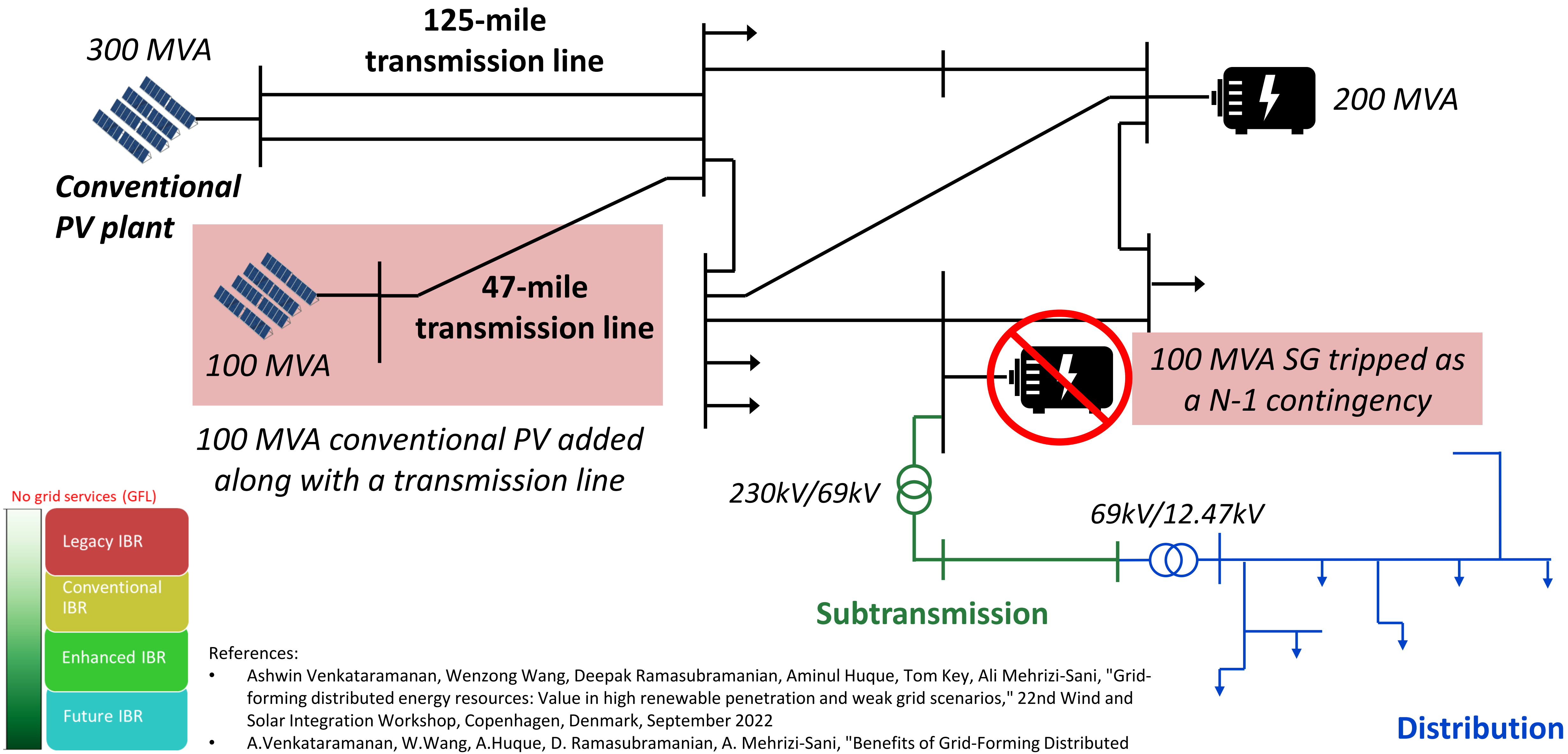
DER_MW GrossLD_605	IM_MW share (%)	ΔSCC (%) 0	-10	-20	-30	-40	-50	-60	-70	-80	-90	Unstable Cases per IM_MW	Unstable Cases per DER_MW
0	0											6	27
	10.4											6	
	20.8											6	
	31.2											5	
	41.6											4	
50	0											6	27
	10.4											6	
	20.8											5	
	31.2											5	
	41.6											5	
100	0											6	24
	10.4											5	
	20.8											5	
	31.2											4	
	41.6											4	
150	0											6	22
	10.4											5	
	20.8											4	
	31.2											4	
	41.6											3	
200	0											6	20
	10.4											5	
	20.8											4	
	31.2											3	
	41.6											2	
250	0											6	20
	10.4											5	
	20.8											4	
	31.2											3	
	41.6											2	
300	0											7	23
	10.4											6	
	20.8											5	
	31.2											3	
	41.6											2	
350	0											8	26
	10.4											6	
	20.8											5	
	31.2											4	
	41.6											3	
400	0											8	31
	10.4											7	
	20.8											6	
	31.2											5	
	41.6											5	
Unstable Cases per ΔSCC		0	0	2	4	16	29	42	50	50	50		

References:

- Ali Arzani, Deepak Ramasubramanian, Parag Mitra, "Impact of Dynamic Load on IBR-Based Transmission-Distribution Network Operation: A Case Study," IEEE ISGT North America 2024 [under review]

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

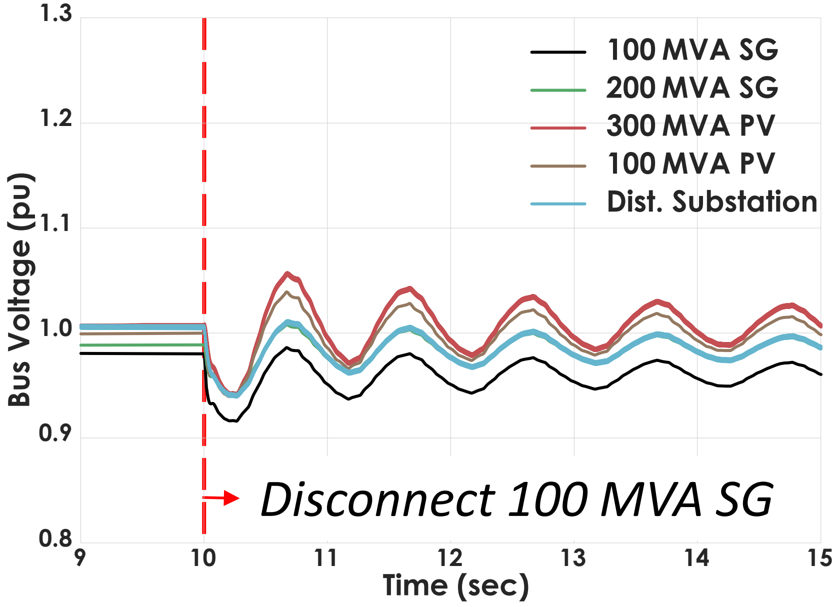
Case study: 67% IBR penetration in transmission

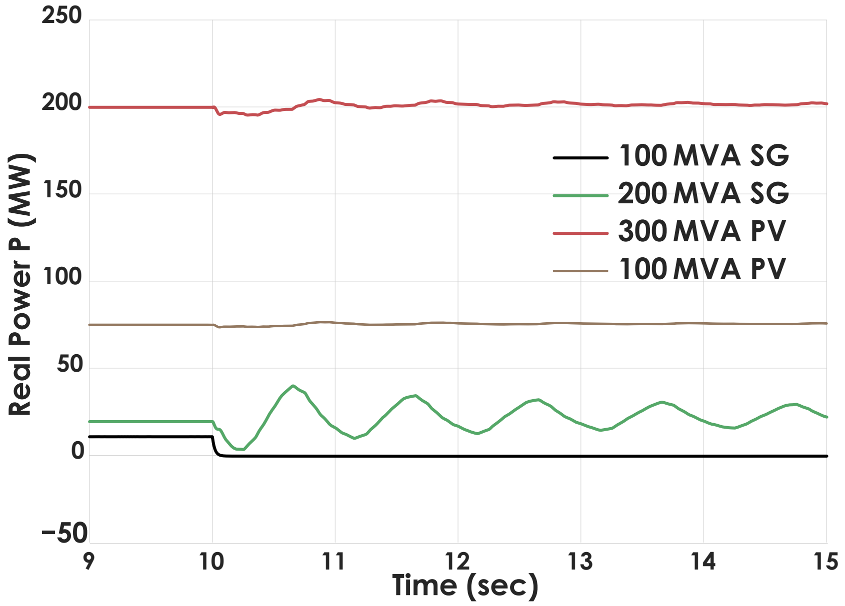


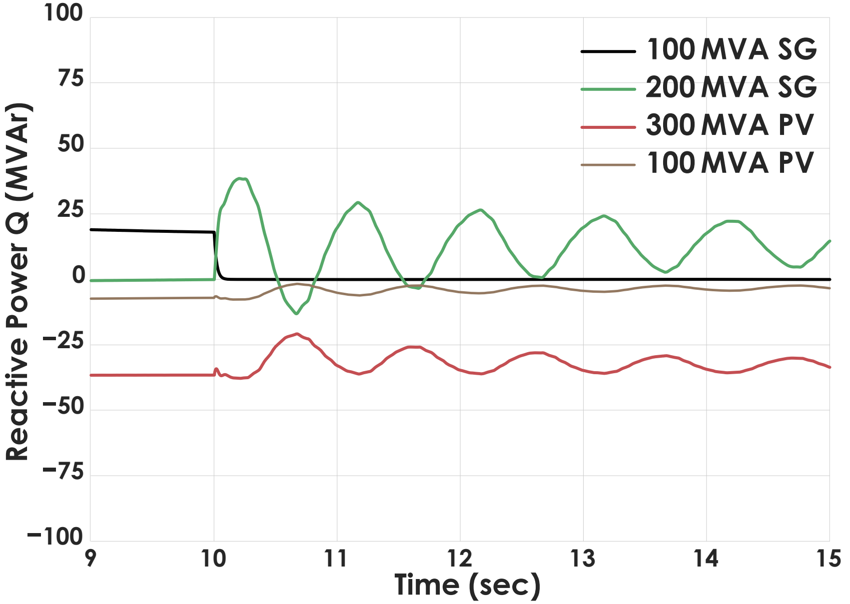
References:

- Ashwin Venkataramanan, Wenzong Wang, Deepak Ramasubramanian, Aminul Huque, Tom Key, Ali Mehrizi-Sani, "Grid-forming distributed energy resources: Value in high renewable penetration and weak grid scenarios," 22nd Wind and Solar Integration Workshop, Copenhagen, Denmark, September 2022
- A.Venkataramanan, W.Wang, A.Huque, D. Ramasubramanian, A. Mehrizi-Sani, "Benefits of Grid-Forming Distributed Energy Resources in Grid-Connected Scenarios," CIGRE USNC Grid of the Future, Kansas City, MO, October 2023

System performance with increased IBR penetration



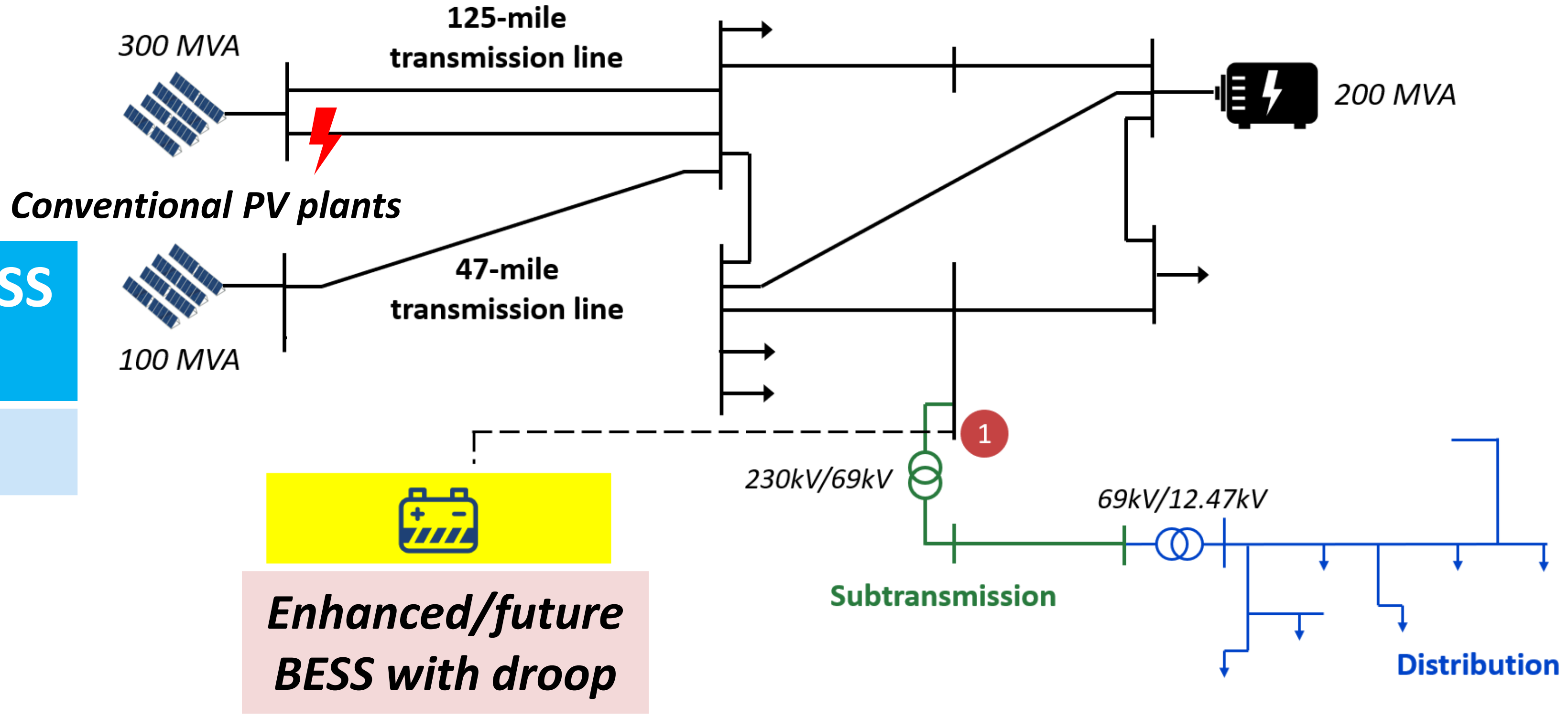


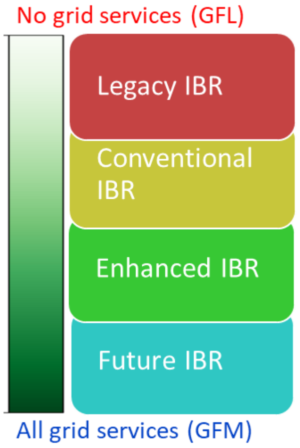


- Oscillations with insufficient damping occurs after disconnecting the 100 MVA SG
- This could indicate that the remaining SG is not able to provide sufficient grid strength to accommodate the increased penetration of IBR
  - Additional interesting insight on this during ESIG Services Task Force meeting on Thursday

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

Location	Minimum future BESS Capacity Needed
1	45 MVA



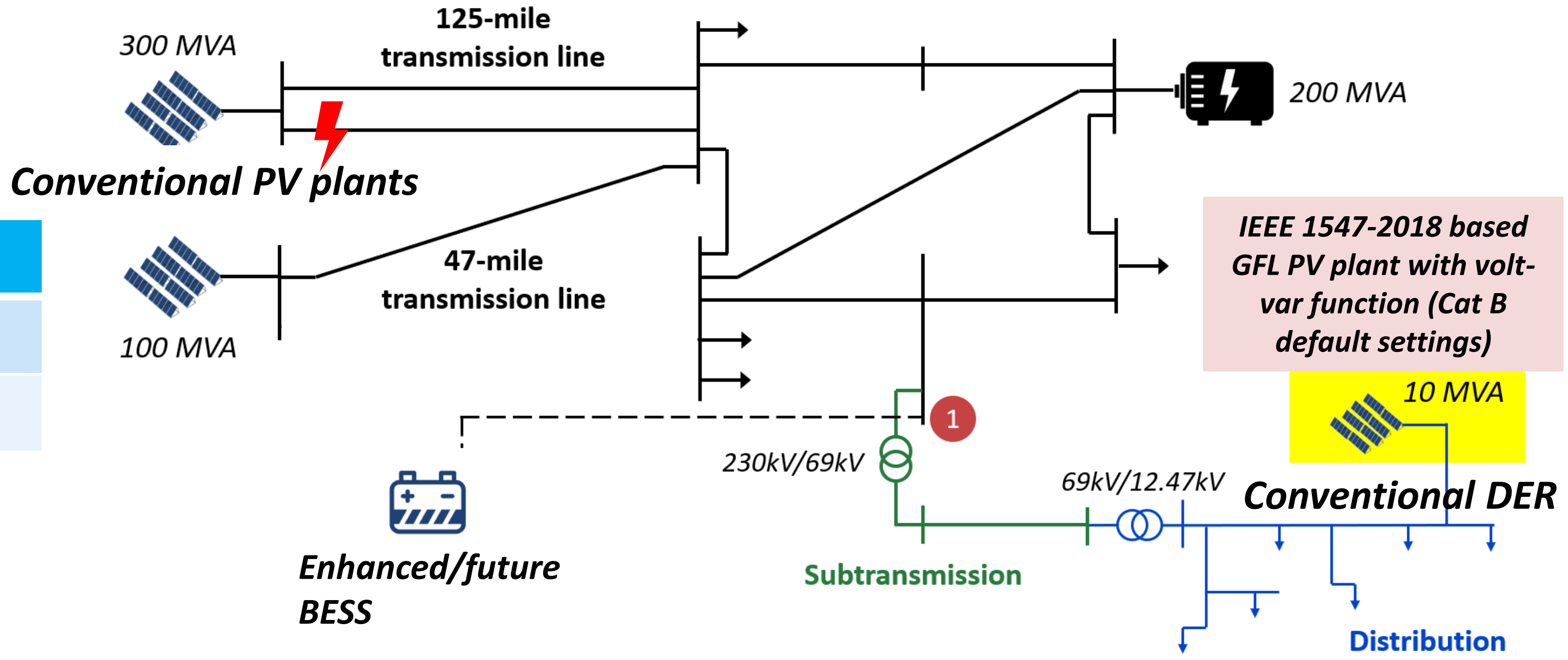


- The transmission system can be stabilized by Tx-connected enhanced/future BESS
- The BESS capacity needed to stabilize the system depends on the location

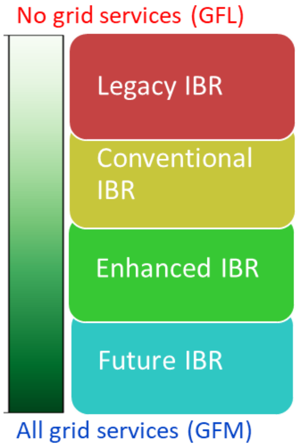
References:

- Wenzong Wang, Deepak Ramasubramanian, Aminul Huque, Arun Kannan, and Diana Strauss-Mincu, "Benefit of Fast Reactive Power Response from Inverters in Weak Distribution Systems," 2022 IEEE Rural Electric Power Conference, Savannah, GA, USA, 2022

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



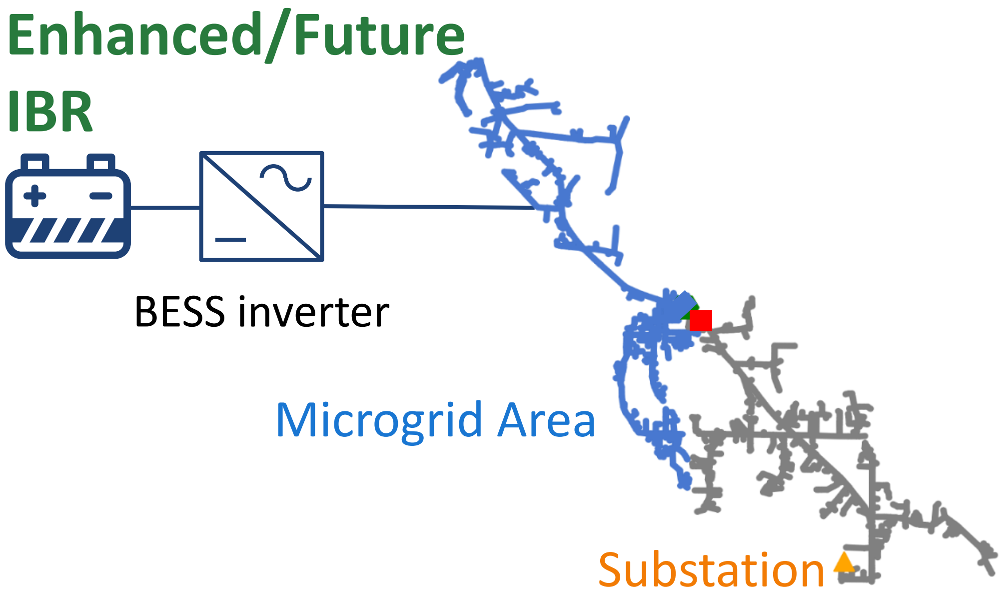
Location	Minimum future BESS Capacity	
	Stabilize Tx	Stabilize Tx & Dx
1	45 MVA	90 MVA



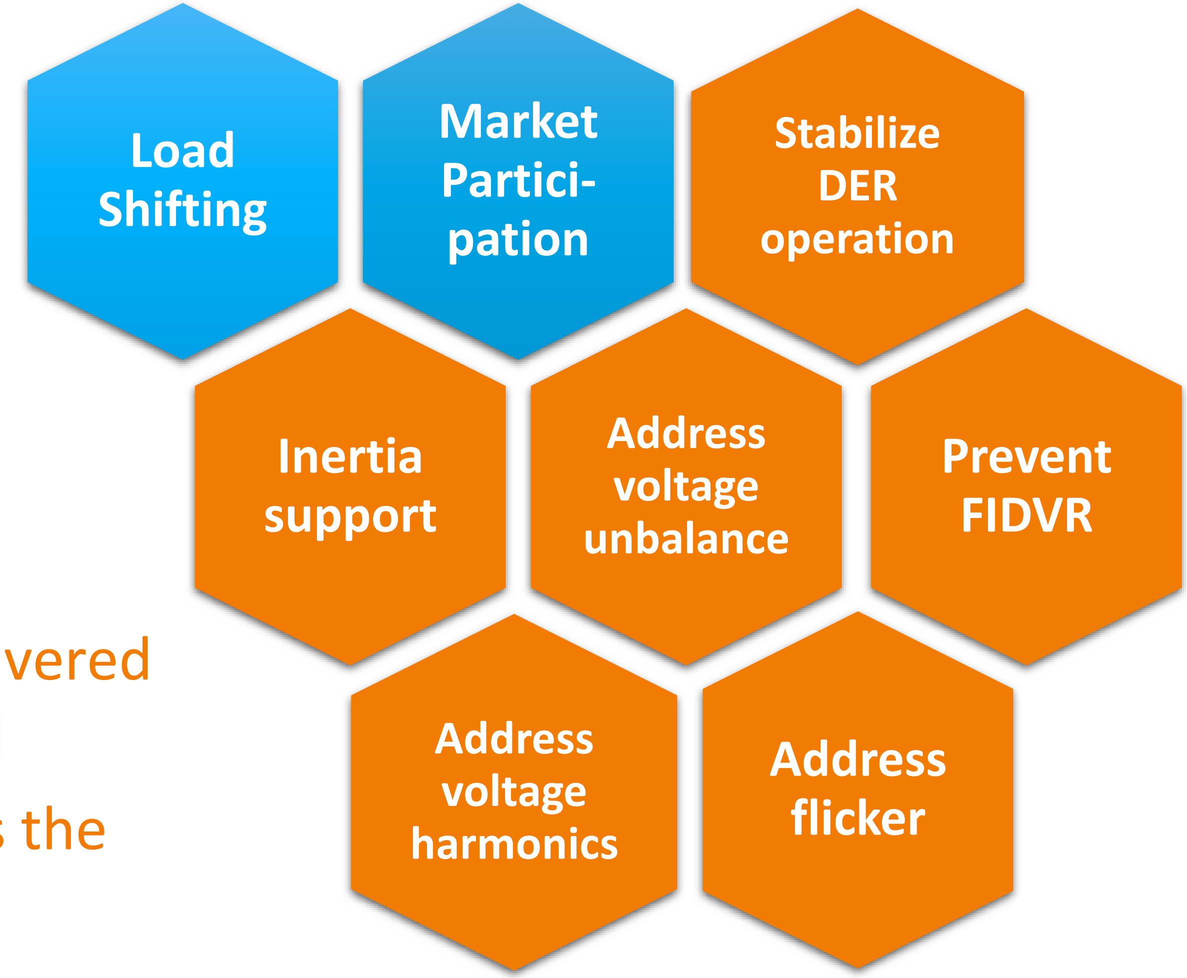
- The Tx-connected BESS capacity required to stabilize both Tx and Dx is much greater than the capacity required to stabilize Tx itself
- Increasing hosting capacity of renewable DERs is critical to reach net-zero emissions but relying solely on Tx-connected resources may not be an efficient solution

Can Enhanced/Future DER Share the Responsibility to Maintain System Stability?

Can enhanced/future IBR 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 control when grid-connected
- Use cases on stabilizing DER operation is the focus

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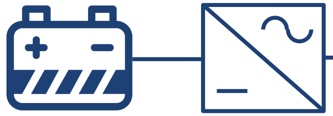
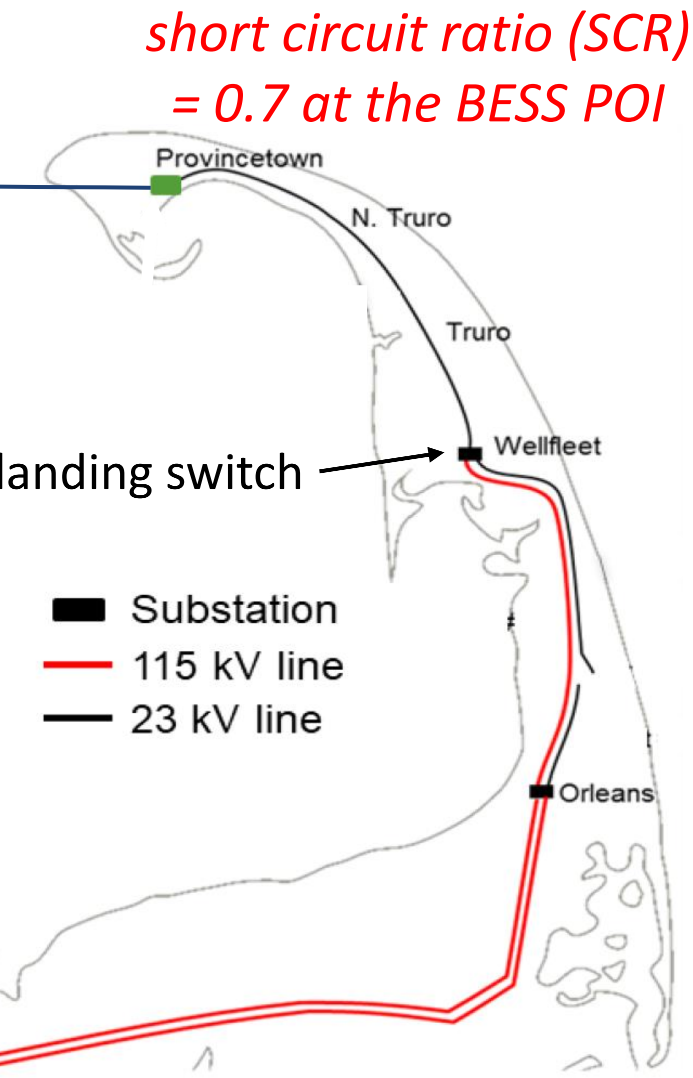
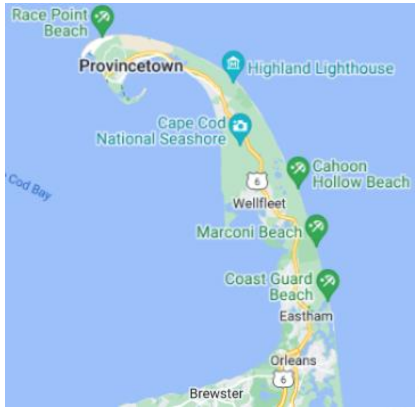
Real-world example of Distribution BESS in <u>Future IBR mode</u> under blue-sky scenarios

Future IBR







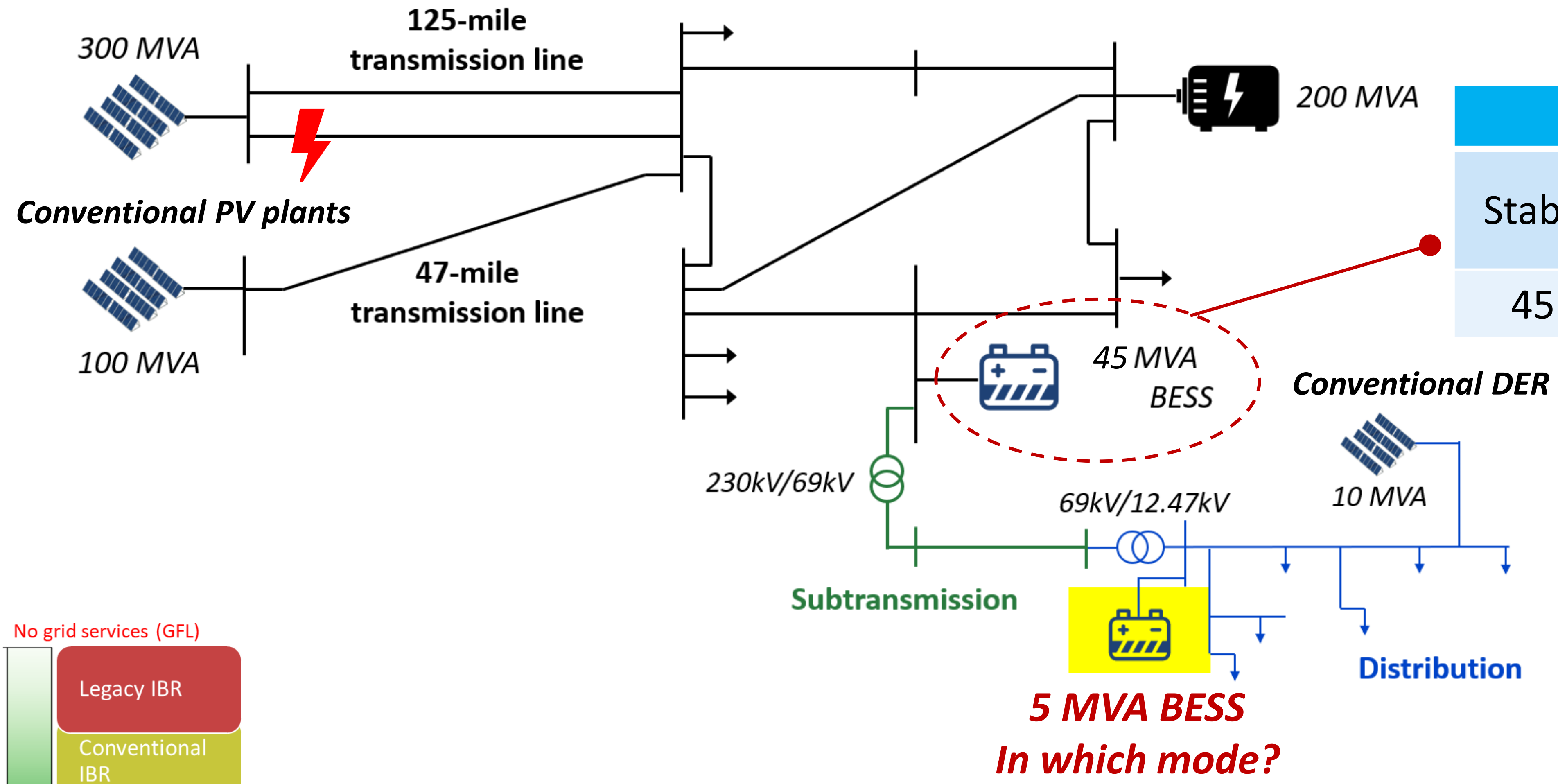
Provincetown, MA

- 25 MW/38MWh/57.6MVA BESS connected to the 23 kV system
- **The BESS inverter operates as a Future IBR under both grid-connected and islanded conditions**
- The Future IBR is potentially also capable of blackstart and being the single balancing resource in the islanded system.

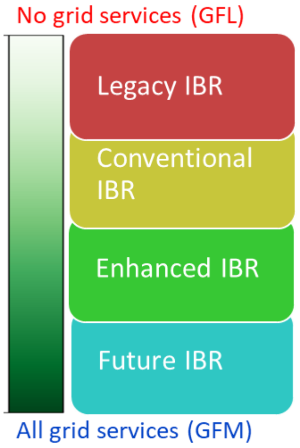
References

- "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

Simulation case study to evaluate the impact of BESS

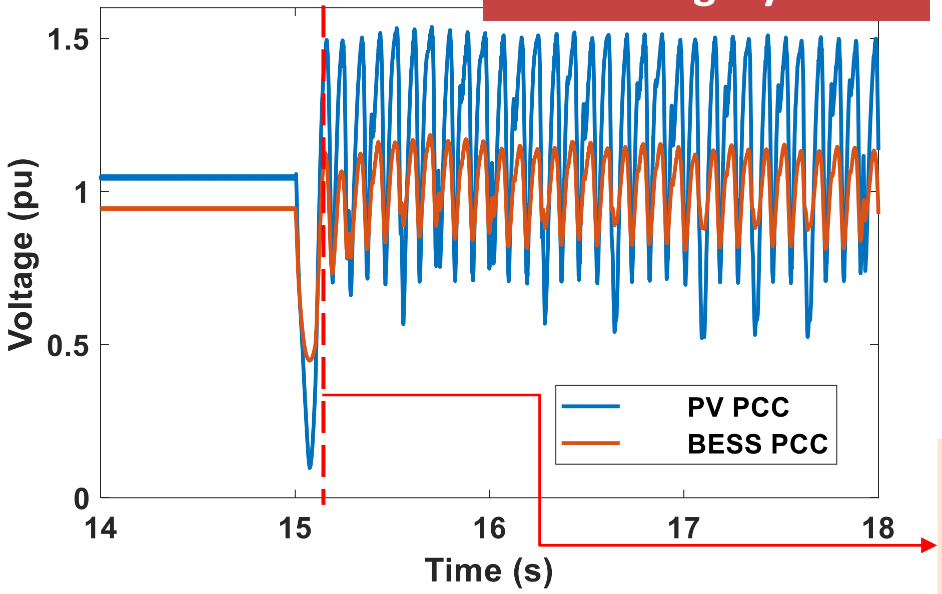


Minimum BESS Capacity	
Stabilize Tx	Stabilize Tx & Dx
45 MVA	90 MVA

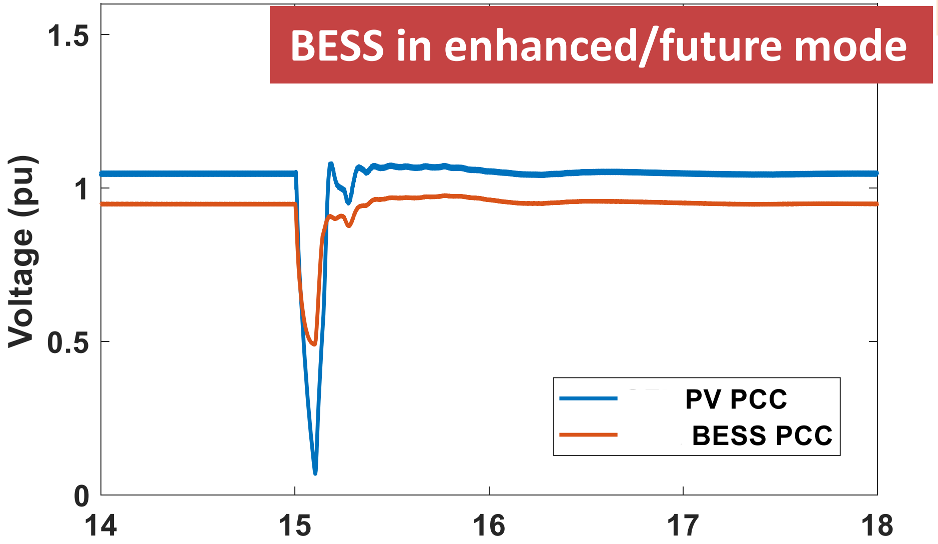


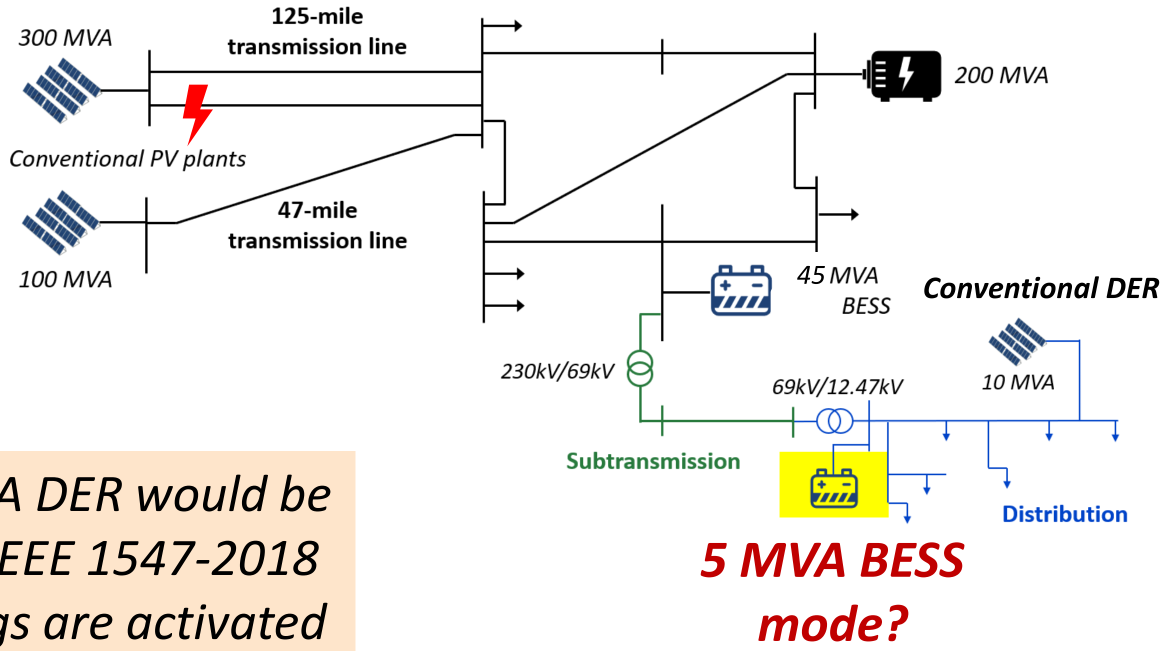
If a 5MVA BESS is installed at the Dx substation, does it benefit system stability by operating in which mode?

Example results – beneficial impact of enhanced/future BESS on DER stability



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





- Operating the BESS in enhanced/future mode can stabilize the conventional PV for the 0.1s fault event considered
- Compared to Tx-connected BESS, ***less BESS capacity*** is needed in the Dx to stabilize the conventional DER

No grid services (GFL)

- Legacy IBR
- Conventional IBR
- Enhanced IBR
- Future IBR

All grid services (GFM)

Summary

Conclusions based on simulation case studies

- High penetration of DERs/IBRs and retirement of SGs can cause instability in distribution systems and transmission networks
- Load dynamics are important to be considered in an appropriate manner
- Transmission connected enhanced/future IBRs can help increase distribution hosting capacity of DERs but the capacity required might be high (lower efficiency)
- Enhanced/future DER may be an effective way to
  - resolve the potential stability challenges in weak distribution grids and to increase hosting capacity
  - improve power quality of the distribution system

EPRI Annual grid forming inverter tutorial

https://www.epri.com/research/products/000000003002028090 [Slides – Public]

Roadmap for adoption of enhanced/future IBRs

- Step wise approach to provide a more informed picture of:
  - required ability of IBRs in a future network,
  - the expected services that can be required from these devices
- Overall improvement in the stability, security, and reliability of the network.

https://www.epri.com/research/products/000000003002028365 [Public]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