Benefits of Advanced Grid Support in Stability Constrained Areas

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Characterization of Advanced Grid Support (AGS) from IBRs

- An IBR is said to provide AGS if:
  - Voltage and frequency control is prioritized in sub-transient and transient time scales
  - In Q vs V frequency scan, between 4 to 40Hz around nominal:
    - near constant gain,
    - phase closer to 180 degrees
  - In ω vs P frequency scan:
    - up to a cutoff frequency
      - near constant gain,
      - phase between ± 45 degrees
    - above cutoff frequency
      - low gain

Network support functionality in time domain

Network support functionality in frequency domain

Stability and robustness property in frequency domain

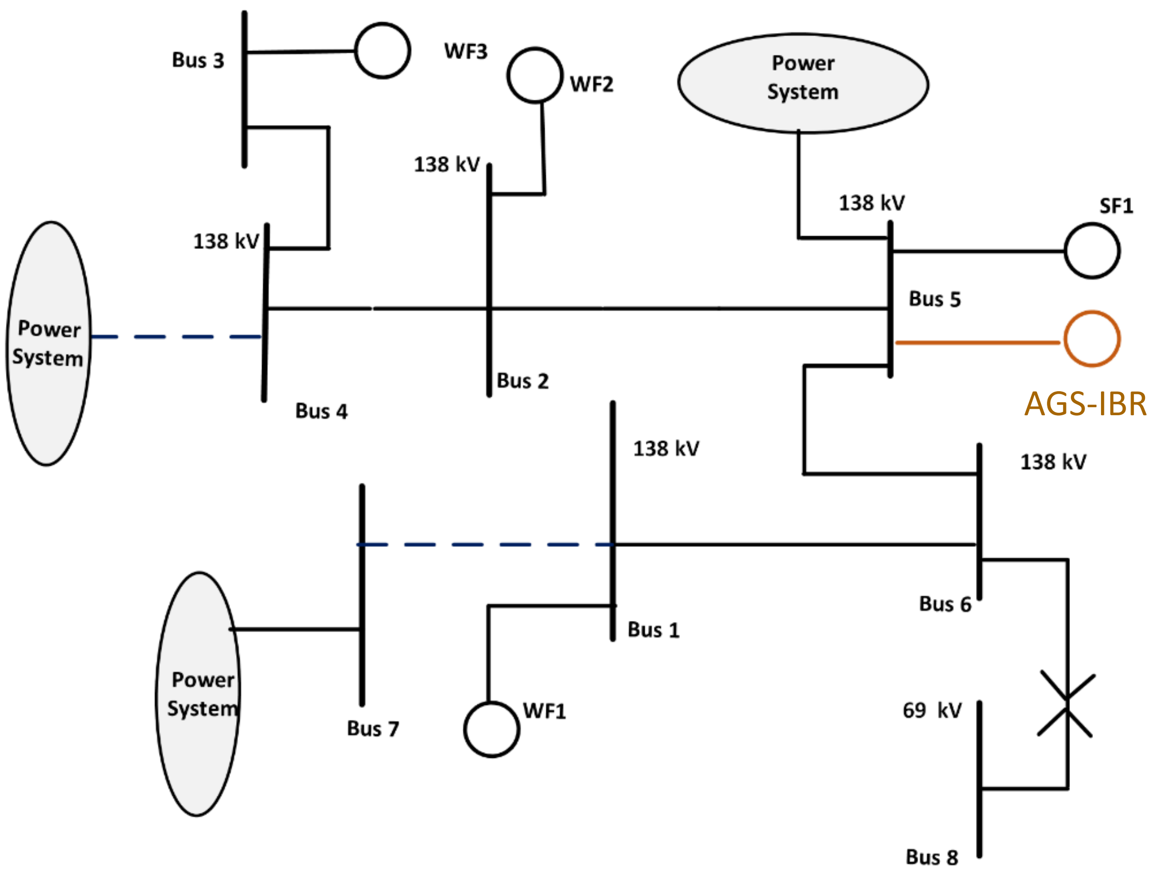
The exact control architecture used within the inverter unit does not matter when characterizing AGS capability

Ask me about EPRI, ESIG, and UNIFI work on these topics

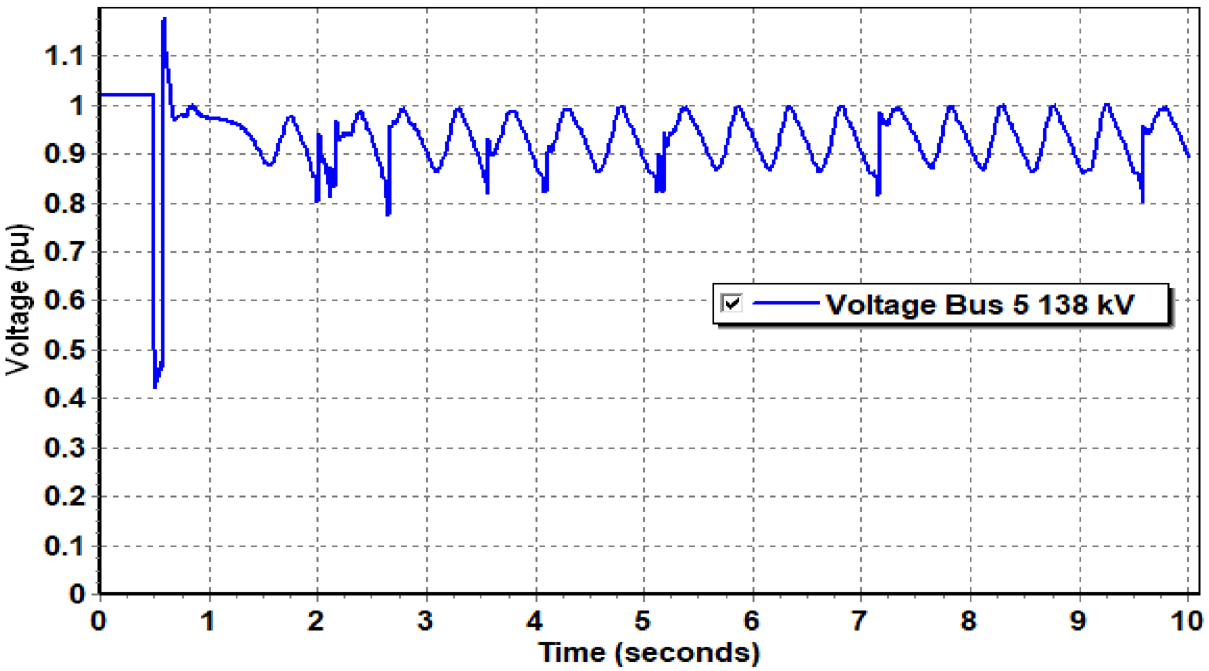
EPRI

Deploy AGS – IBR to help relieve stability constraint

Example 1: Potential use of AGS – IBR in ERCOT Area

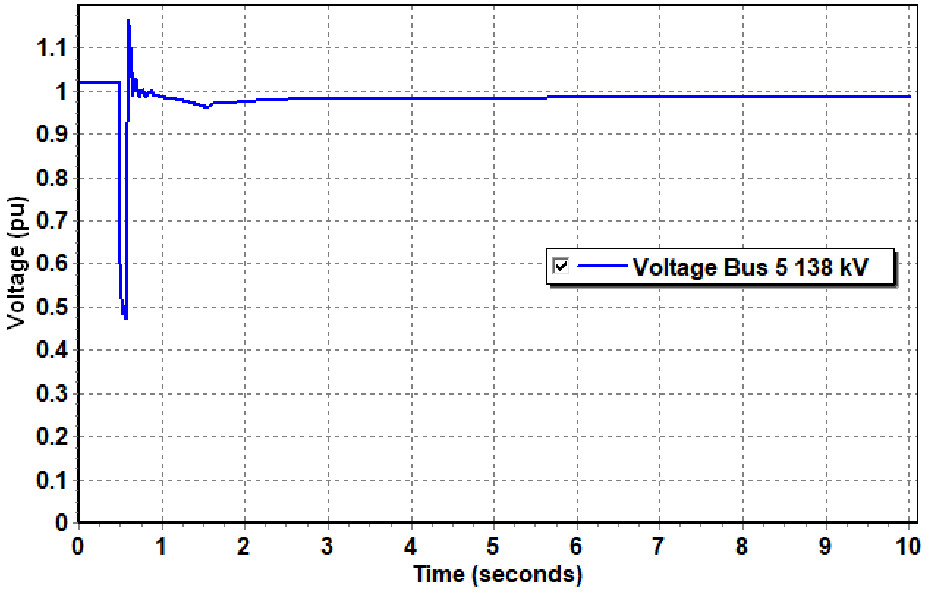


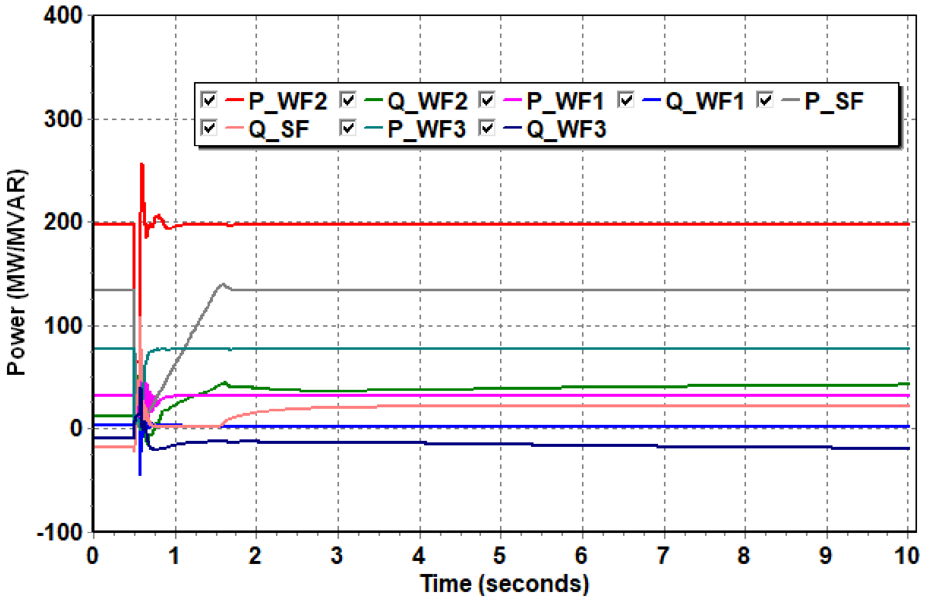
- Three wind farms and a solar farm are connected to 138 kV system
- N-1-1 contingency (marked by dashed lines) disconnect all farms from the power system leaving only one exit path
- Total generation capacity is nearly 440 MW



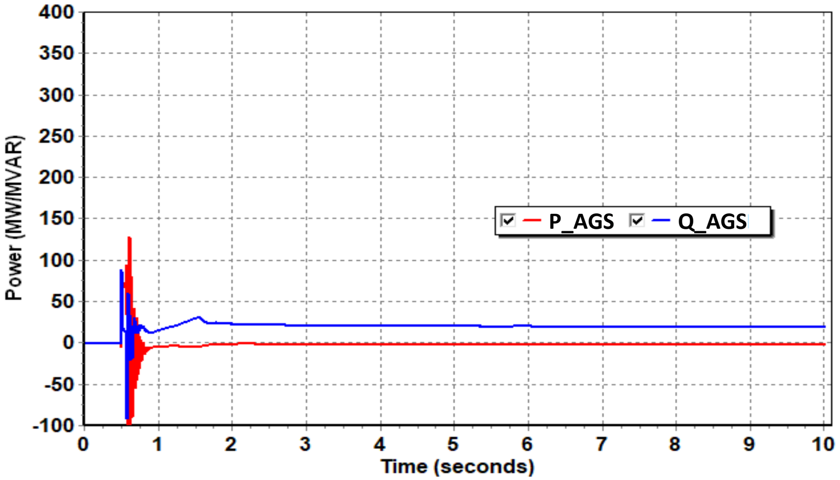
N. Ekneligoda, R. O'Keefe, and D. Ramasubramanian, "Case Studies of the Stability Benefit of Grid Forming Inverters on Energy Storage Facilities," *2023 Grid of the Future Symposium, CIGRE US National Committee*, Kansas City, MO, 2023

Example 1: Potential use of AGS – IBR in ERCOT Area (cont'd)





- AGS – IBS provides transient damping capability
- It also provides reactive power support both during and after the event to help stabilize the network



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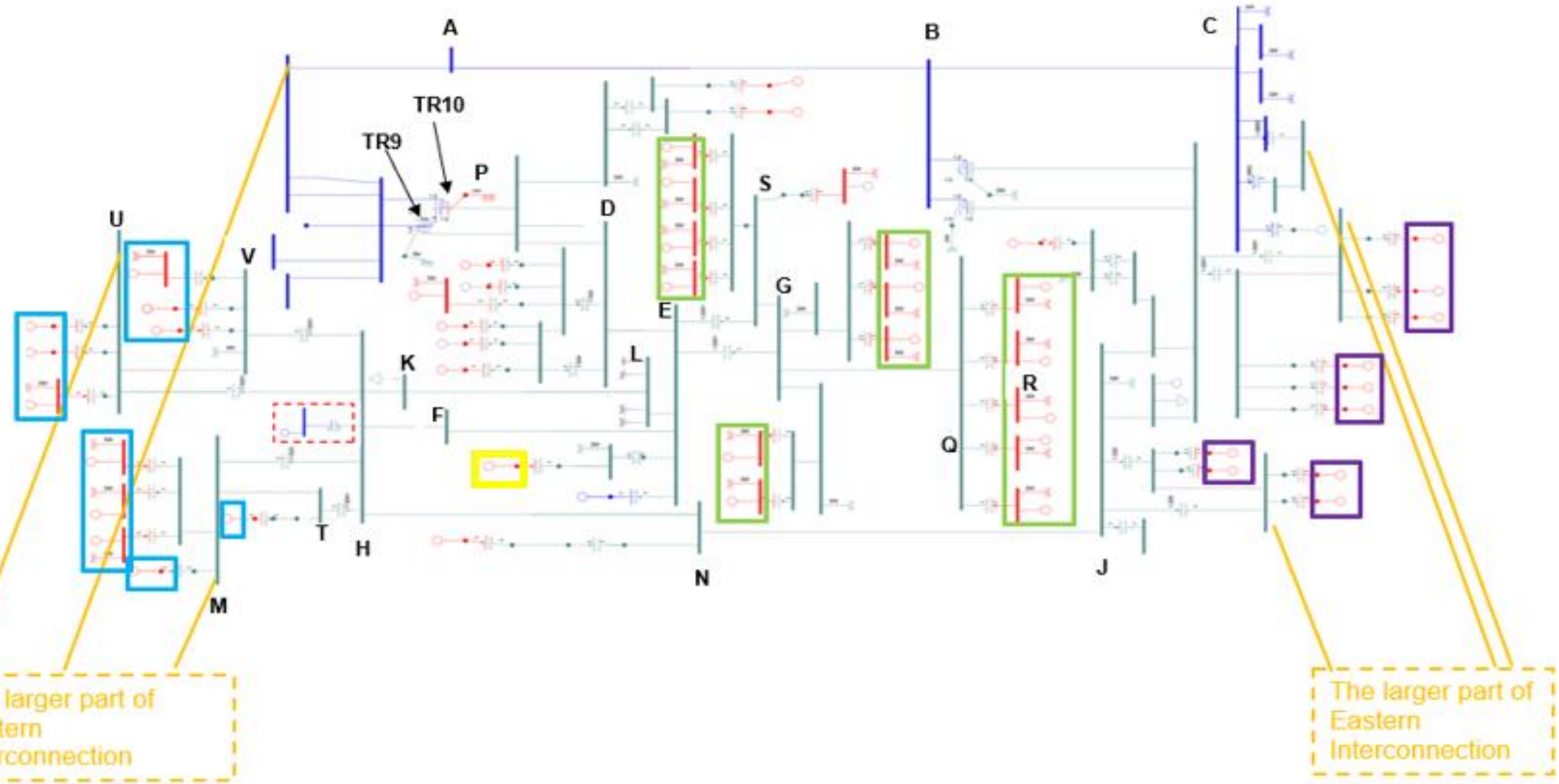
Locate AGS – IBR to help relieve stability constraint

Example 2: Where to place AGS – IBR in the Midwest?

- A region has high levels of wind generation which subsequently leads to stability constrains during N – x events.

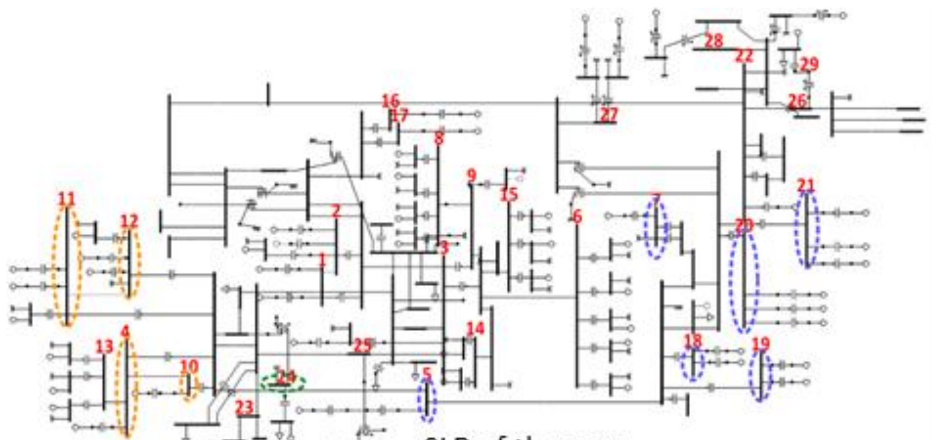


- The interconnection queue near the region has numerous BESS that could potentially be used for AGS capability.
- Would these BESS be able to provide benefit?

Example 2: Where to place AGS – IBR in the Midwest?

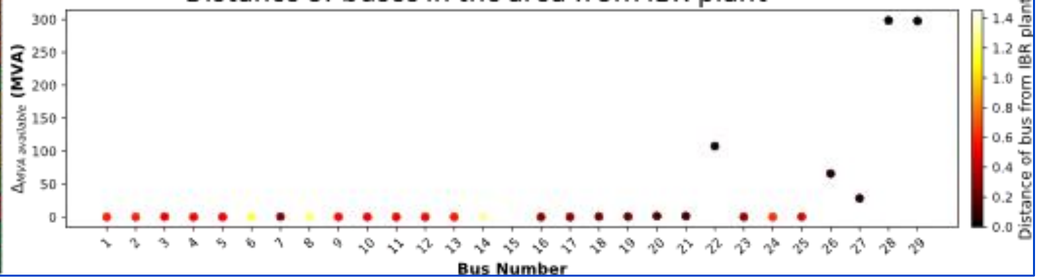
Remaining available MVA matrix for Contingency A

Bus	MW	No IBR	IBR 1	IBR 11	IBR 17	IBR 18	IBR 19	IBR 26	All IQ
1	123.42	590.84	590.89	590.84	590.9	590.84	590.85	590.84	592.496
2	122.38	589.56	589.61	589.56	589.6	589.56	589.56	589.56	591.2201
3	115.81	268.67	268.86	268.66	268.9	268.67	268.69	268.67	274.5928
4	27.62	-6.5181	-6.4868	-6.519	-6.488	-6.5186	-6.515	-6.519	-5.61028
5	168	-716.24	-716.19	-716.2	-716.2	-716.24	-716.2	-716.2	-714.84
6	71.43	289.36	289.39	289.36	289.4	289.36	289.36	289.36	290.3645
7	278.2	-364.47	-364.46	-364.5	-364.5	-364.47	-364.5	-364.5	-364.113
8	78.81	249.24	249.26	249.24	249.3	249.24	249.24	249.24	249.8403
9	56.87	262.29	262.38	262.29	262.4	262.29	262.3	262.29	264.9973
10	104.65	-25.379	-25.348	-25.38	-25.35	-25.379	-25.38	-25.38	-24.4774
11	120.21	-47.408	-47.375	-47.41	-47.38	-47.408	-47.4	-47.41	-46.4603
12	156.02	-148.7	-148.67	-148.7	-148.7	-148.7	-148.7	-148.7	-147.752
13	54.83	85.513	85.53	85.512	85.53	85.512	85.514	85.512	86.0147
14	51.23	205.52	205.53	205.52	205.5	205.52	205.52	205.52	205.8851
15	55.19	89.717	89.722	89.717	89.72	89.717	89.718	89.717	89.86301
16	114.24	326.38	326.4	326.38	326.4	326.38	326.39	326.38	326.9872
17	116.44	324.46	324.48	324.46	324.5	324.46	324.46	324.46	325.0615
18	113.85	-274.58	-274.56	-274.6	-274.6	-274.58	-274.6	-274.6	-274.051
19	112.2	-269.28	-269.26	-269.3	-269.3	-269.28	-269.3	-269.3	-268.755
20	125.78	-387.76	-387.75	-387.8	-387.7	-387.76	-387.8	-387.8	-387.388
21	129.5	-389.71	-389.69	-389.7	-389.7	-389.71	-389.7	-389.7	-389.337
22	200	3727.1	3832.7	3727.6	3730	3727.5	3727.3	3727.1	4210.036
23	152	424.75	424.83	424.75	424.8	424.75	424.75	424.75	426.6204
24	107.42	13.806	13.82	13.806	13.82	13.806	13.808	13.806	14.23683
25	202.73	266.58	266.71	266.58	266.7	266.58	266.6	266.58	270.3957
26	160.38	3174.2	3245.2	3174.7	3176	3174.5	3174.3	3174.2	3497.439
27	243.2	-837.62	-837.6	-837.6	-837.6	-837.62	-837.6	-837.6	-837.063
28	167	4940.1	5242.1	4940.8	4944	4940.7	4940.4	4940.2	5558.031
29	167	4972.9	5275.2	4973.7	4977	4973.6	4973.3	4973	5600.253

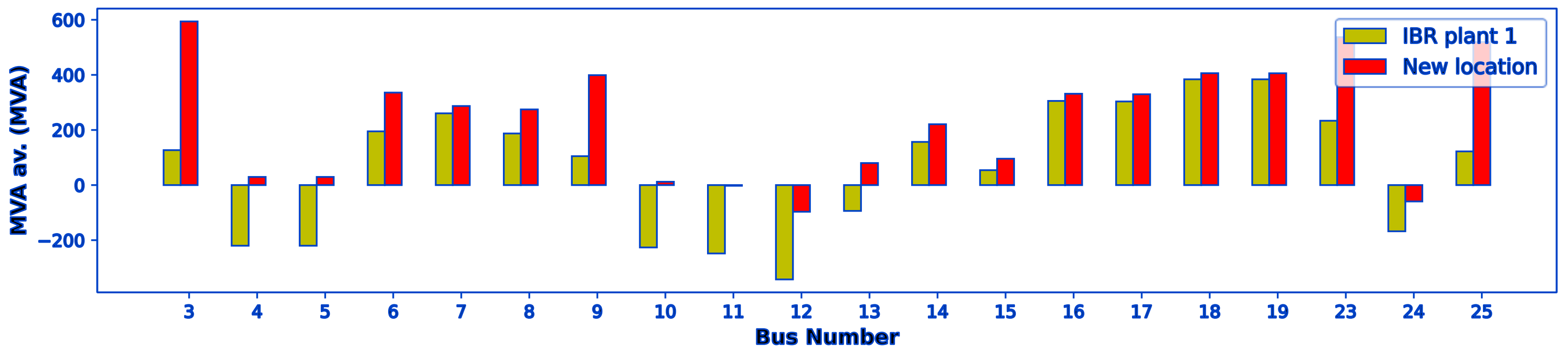


SLD of the area

Distance of buses in the area from IBR plant



- The BESS from the interconnection queue are not well positioned to provide support to this region
- Hence, even if AGS is enabled on these BESS, the stability constraint would persist
- Novel screening metrics are of great use here

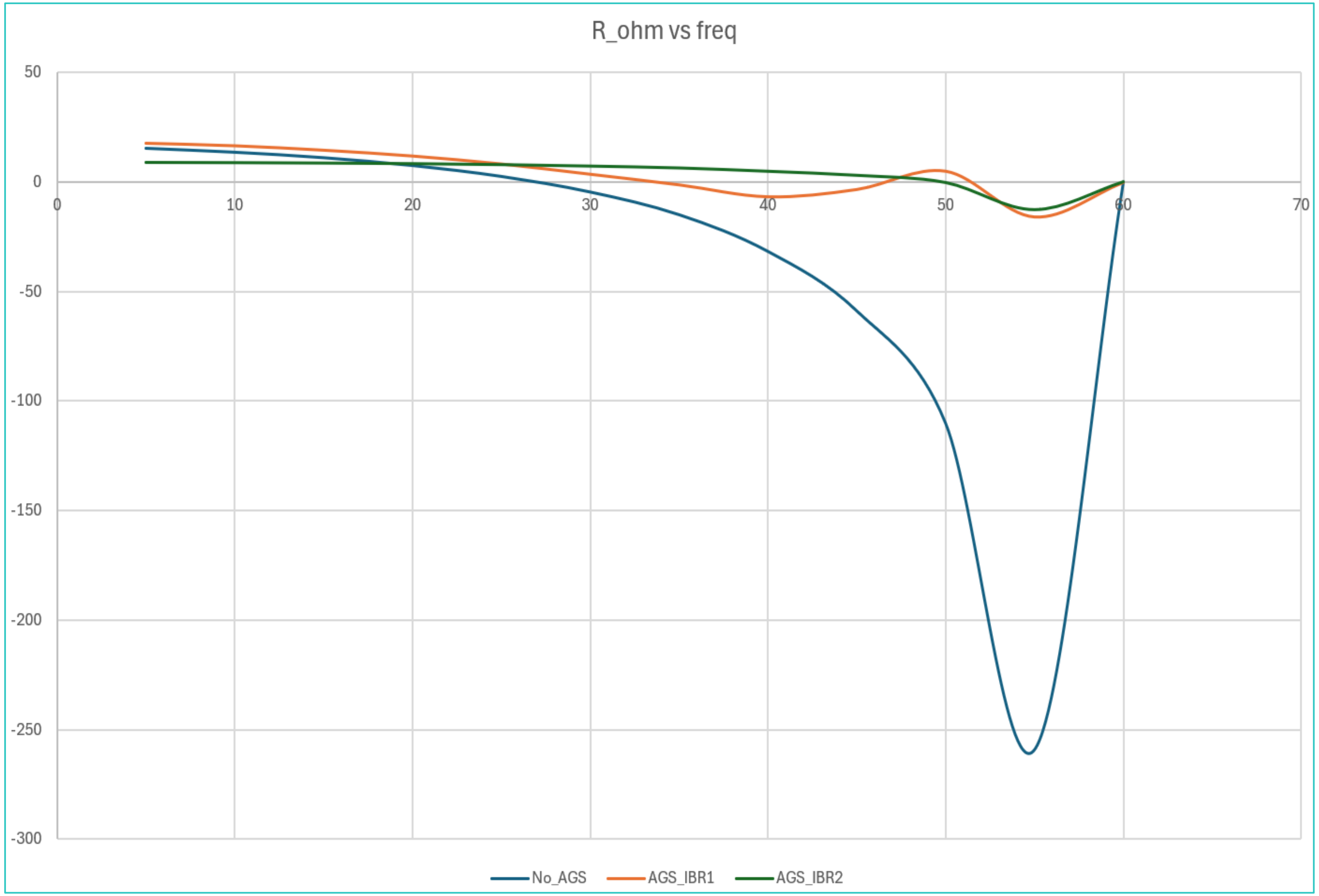


To obtain maximum benefit from AGS, a new location has to be chosen in the region, where the strength is improved

AGS – IBR and SSR damping

AGS – IBR having improved damping capability

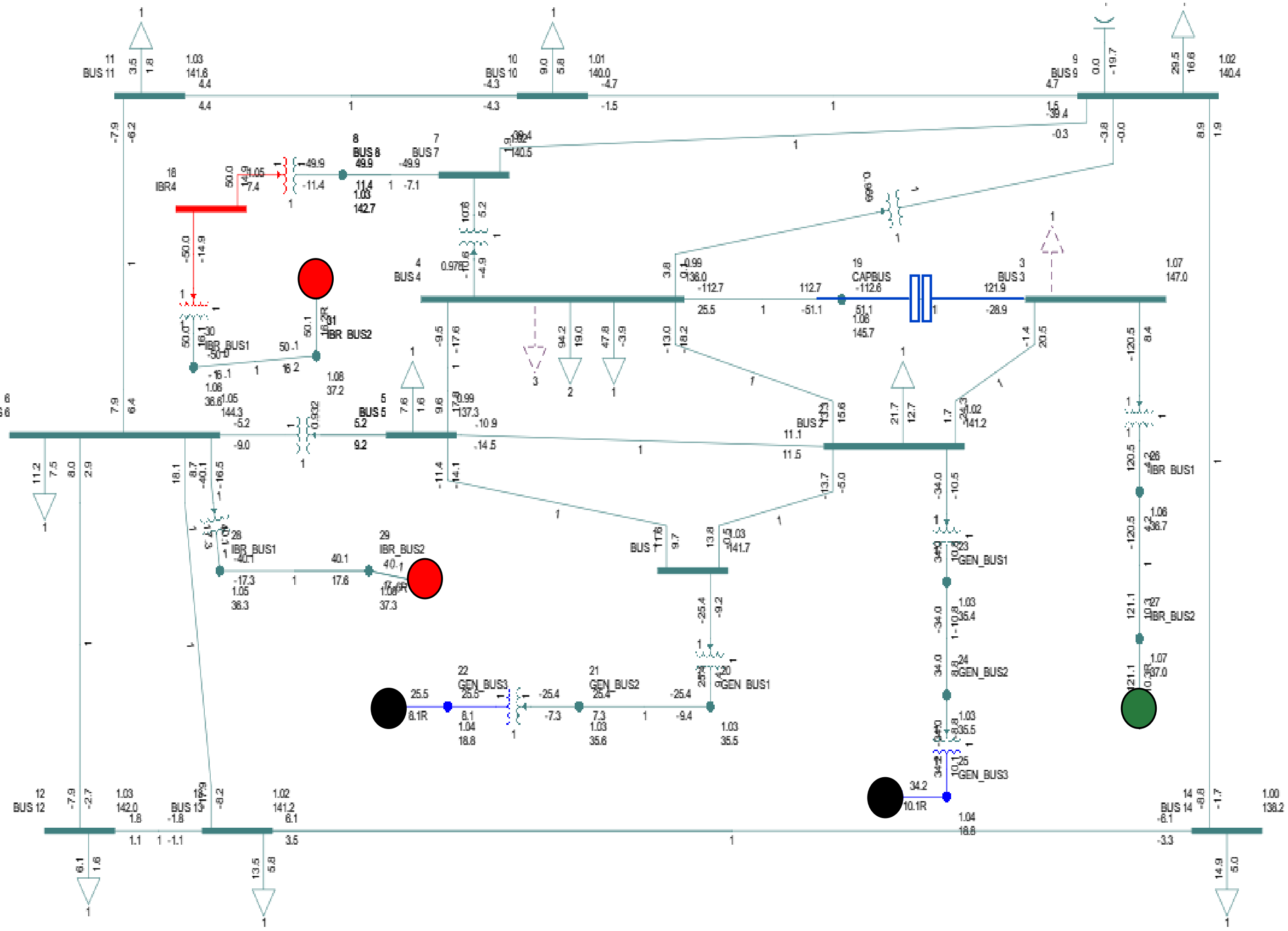
- Comparing three different OEM IBRs
  - Without AGS – potentially large negative damping
  - AGS_IBR1 – improved damping
  - AGS_IBR2 – further improved damping



Will a network with known SSR risk automatically benefit due to this IBR with AGS?

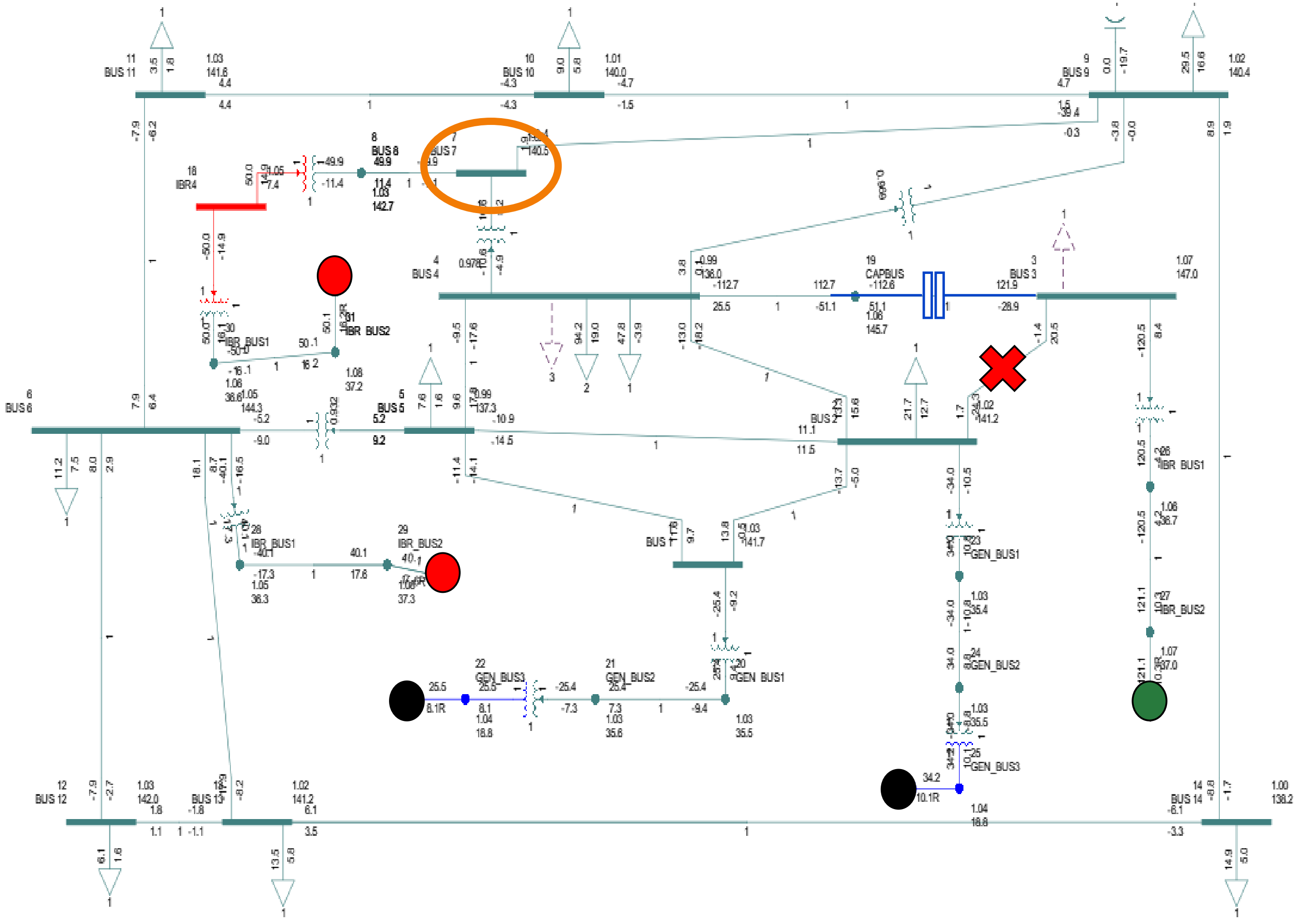
Single line diagram of a test network

- A test 18 bus network is used for the evaluation
- Network is set up with following key components:
  - Synchronous machines (●)
  - Series compensated line (—▯—)
  - Inverter based resources (IBRs)
    - Type III Wind (●)
    - Full converter (●)
  - Constant power load (conservative assumption)



Initiation of the oscillation and potential mitigation

- Oscillations are initiated when line between buses 2 – 3 is tripped (or is on outage). (✖)
- Let's assume that existing IBR at bus 7 (⬭) decides to add a co-located 100 MW BESS with AGS capability



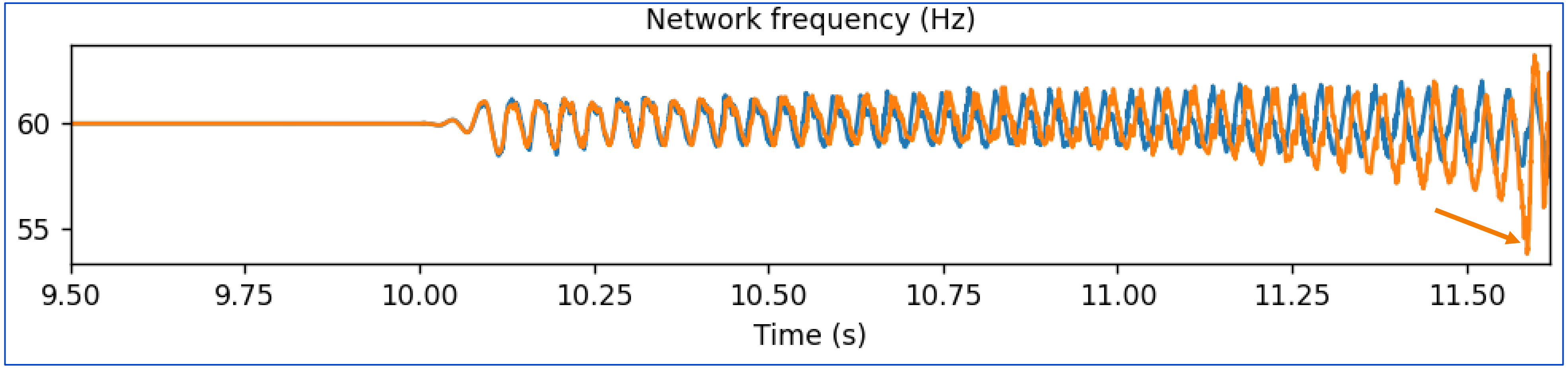
What does the Type III wind “see” with and without additional BESS?

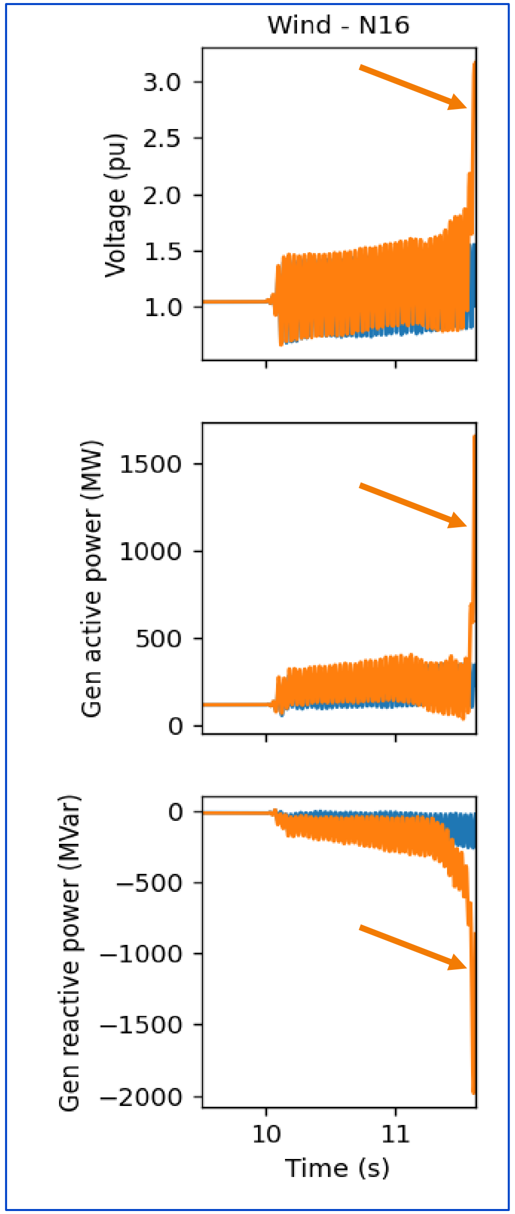
- Crossover frequency ≈ 46Hz (where the resonant mode appears)
- with AGS BESS, the Type III wind “sees” a lower value of resistance

Presence of IBR with AGS capability potentially lowers the damping of this mode

Time domain results with and without AGS BESS

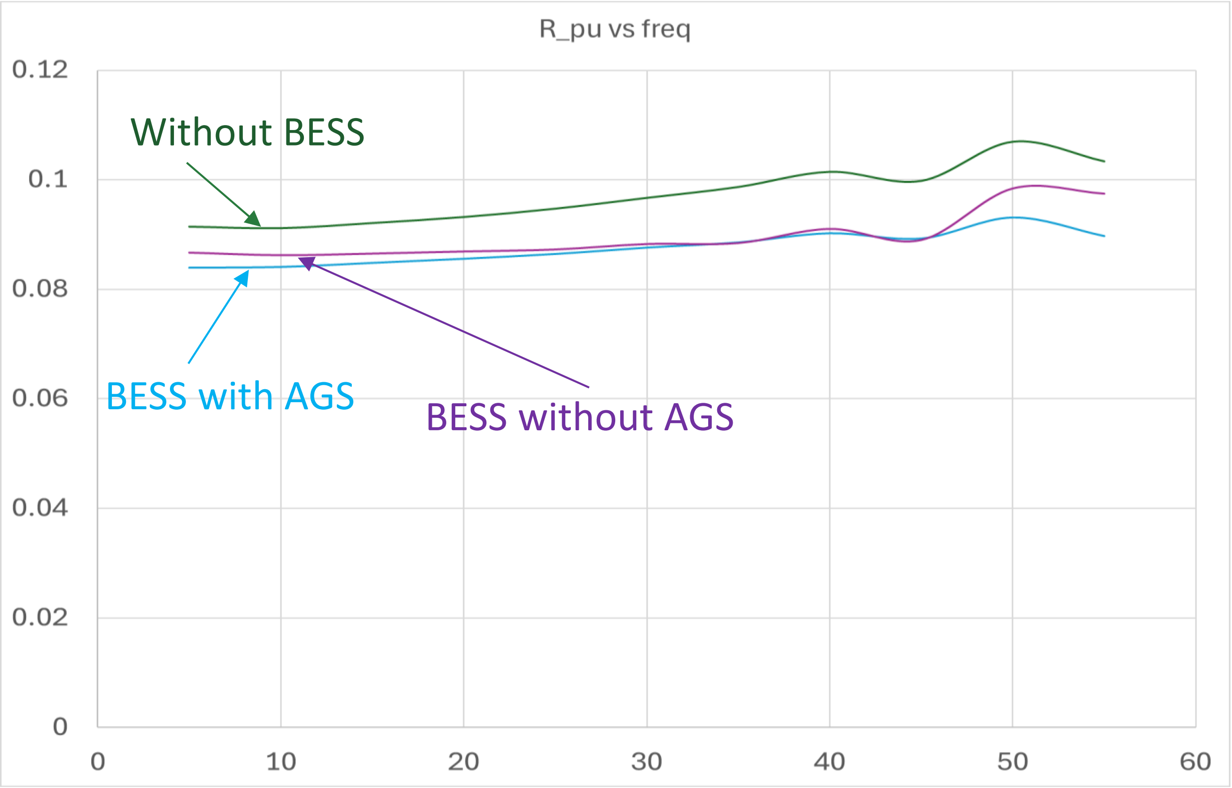
- With the AGS BESS in the network, a ‘run-away’ instability occurs (see pointer on orange curves)
- The presence of an IBR with AGS capability does not automatically imply increased damping in the network.

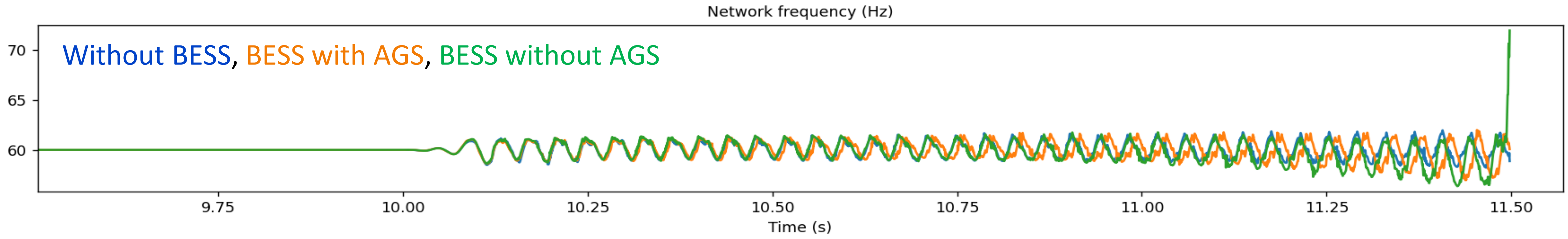




Time domain results with BESS, with and without AGS

- BESS with AGS can bring about improvement in damping compared to BESS without AGS
- But, BESS with AGS may not automatically always imply improvement in damping





Key takeaways

- Exact type of IBR control architecture is not important when defining AGS capability for an IBR
- An IBR with AGS can provide improvement in performance in local regions and pockets
- Exact location/bus where the IBR with AGS connects is important to ensure value proposition in the system
  - Automatic improvement of system dynamic performance, especially with existing challenges, are not always guaranteed

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