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EI Frequency Response Assessment with Inverter Based Resources

EI Changing Resource Mix Update

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RELIABILITY | ACCOUNTABILITY




Background and Study Purpose

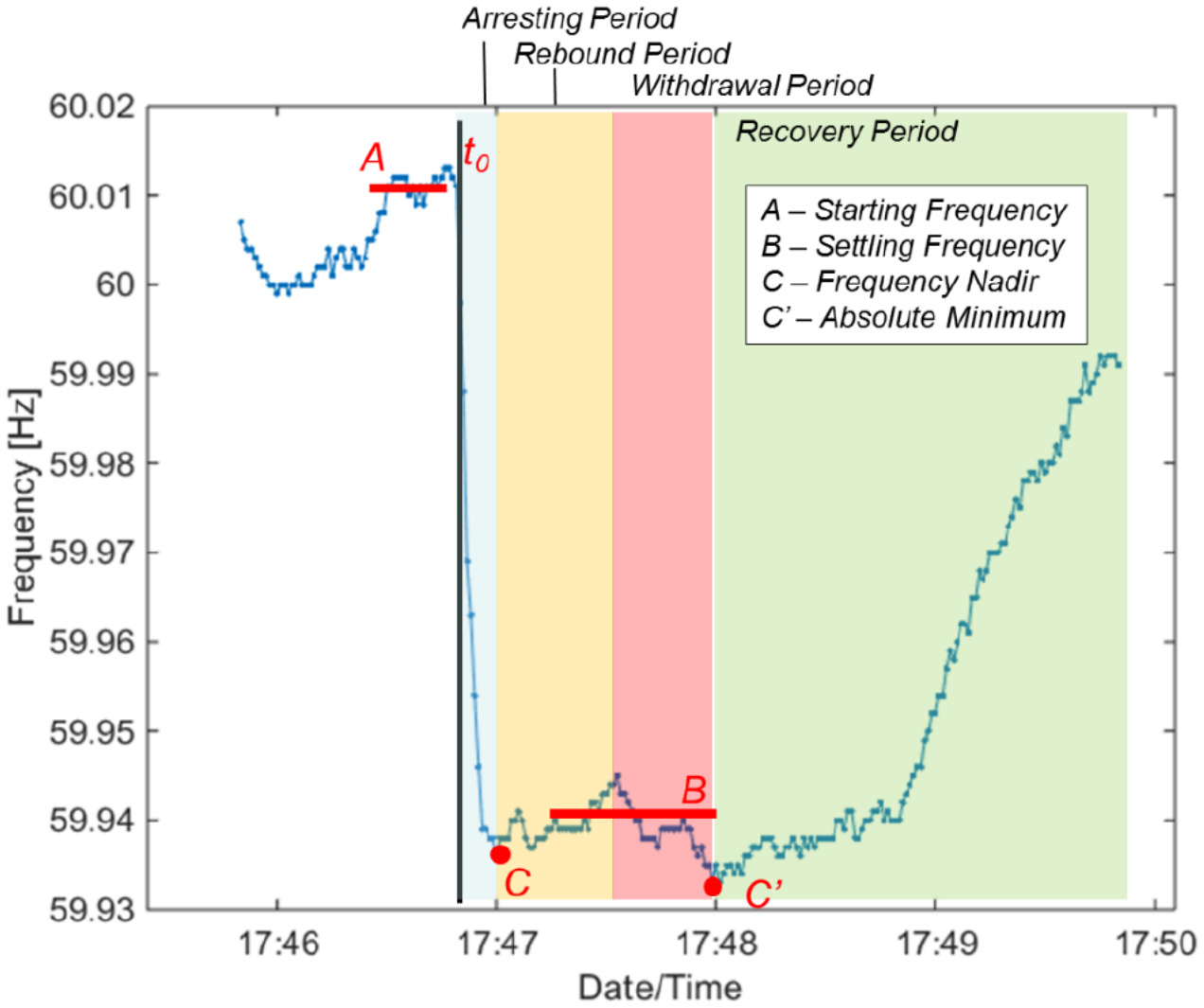
Study Purpose

- To evaluate potential impacts on Eastern Interconnection resource shift from synchronous generation to Inverter Based Resources (IBR)

Study Process

- Analysis was performed using the 2016 SERIES, ERAG/MMWG BASE CASE LIBRARY. CEII DATA 2021 Light Load Base Case
- Replace 20,000 MW of synchronous generation IEEEG1 governor type with wind IBR with and without Primary Frequency Response(PFR)
- Determined the frequency nadir and PFR impact of increasing levels of wind IBR penetration
- Compared the power response of wind IBR to synchronous generation under various contingency events

Primary Frequency Reponse



Spinning Reserve

$$Reserve_{Spinning} = \sum_{i=0}^{n} K_i * \left(P_{max,i} - P_{gen,i}\right)$$

- where n is the total number of online units in the case,
- KI is the status of unit i (Ki = 1 for online, Ki = 0 for offline),
- Pmax,I is the maximum active power output of unit i,
- Pgen,I is the active power output of unit i.

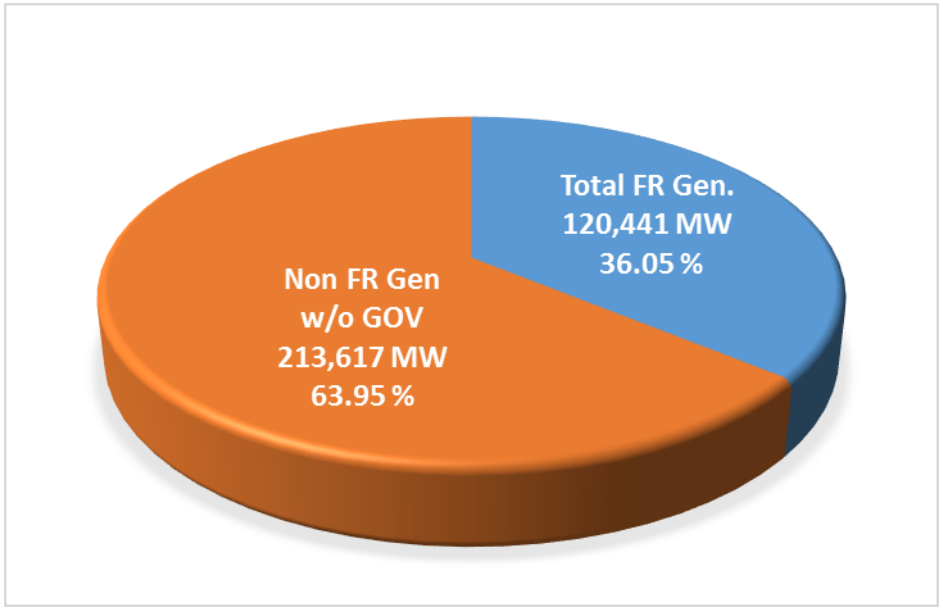
Online Frequency Responsive Reserves (FRR)

$$Reserve_{FrequencyResponsive} = \sum_{i=0}^{n} K_i * (1 - B_i) * \left(P_{max,i} - P_{gen,i}\right)$$

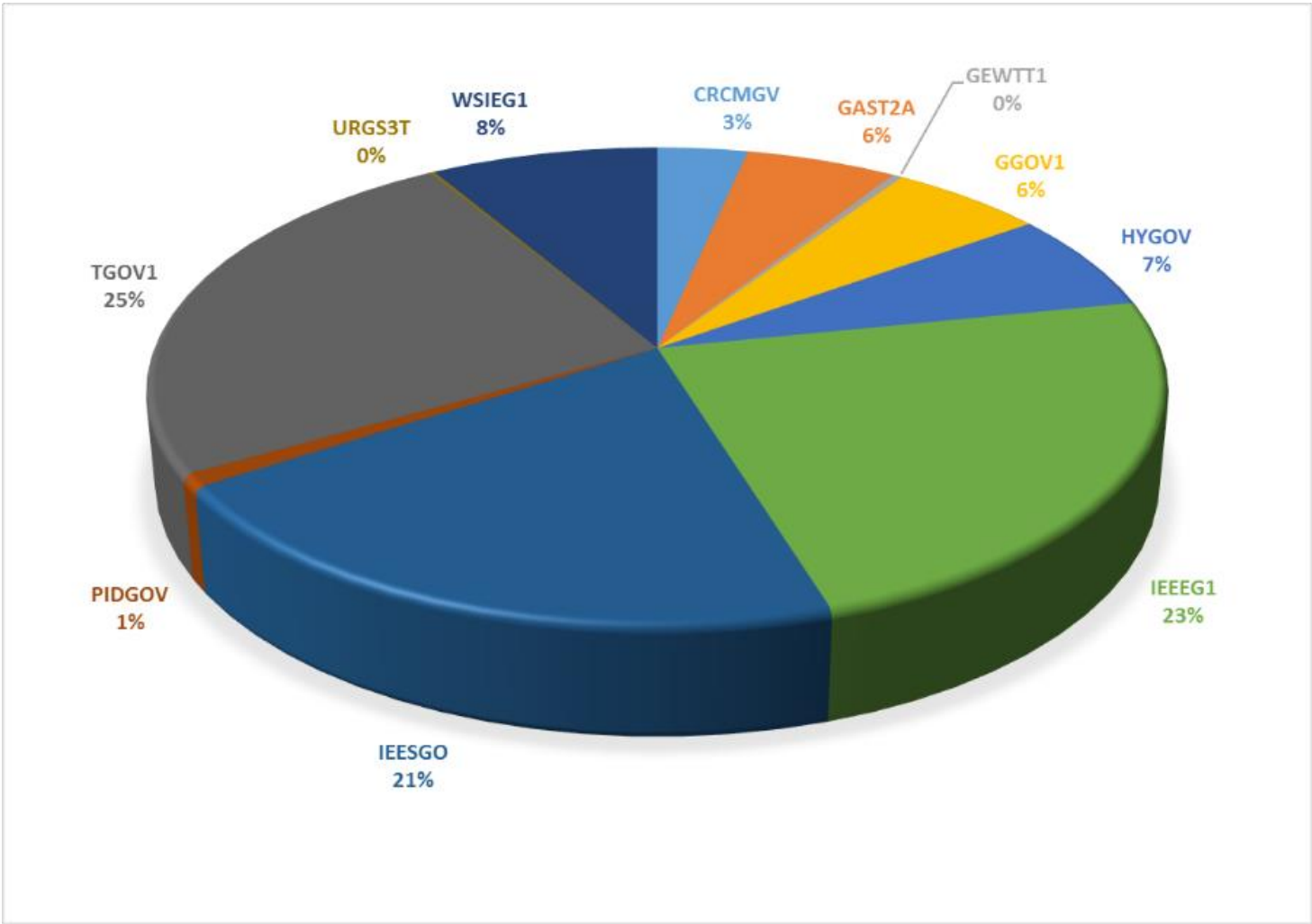
- where n is the total number of online units in the case,
- KI is the status of unit i (Ki = 1 for online, Ki = 0 for offline),
- BI is the “baseload flag” for unit i
- (Bi = 1 for non-frequency responsive, Bi = 0 for frequency responsive),
- Pmax,I is the maximum active power output of unit i,
- Pgen,I is the active power output of unit i.

2021 Light Load FR Modeling Overview

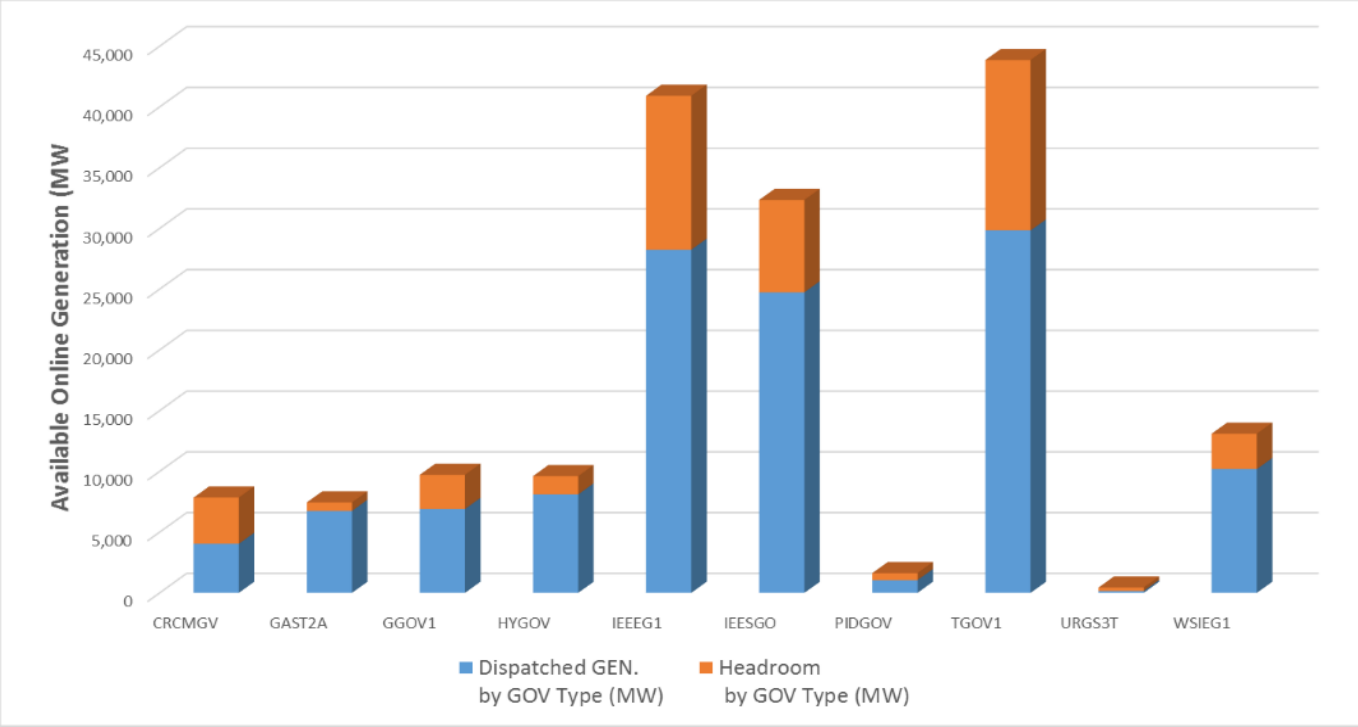
2021 Light Load FR Generation Modeling Summary



2021-LL Distribution of FRR by Governor Type



2021-LL FFR by Governor Type for Total FR Generation



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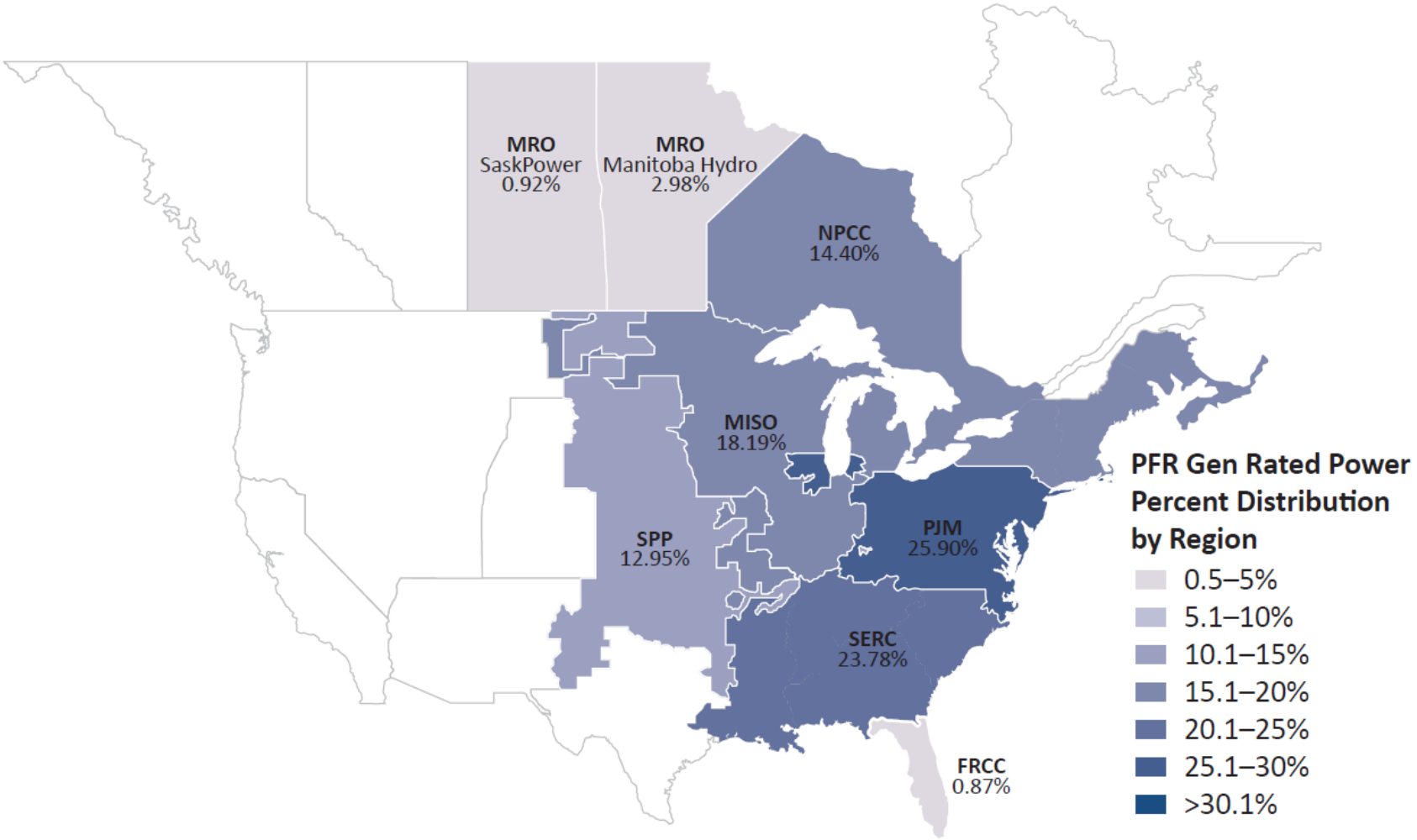
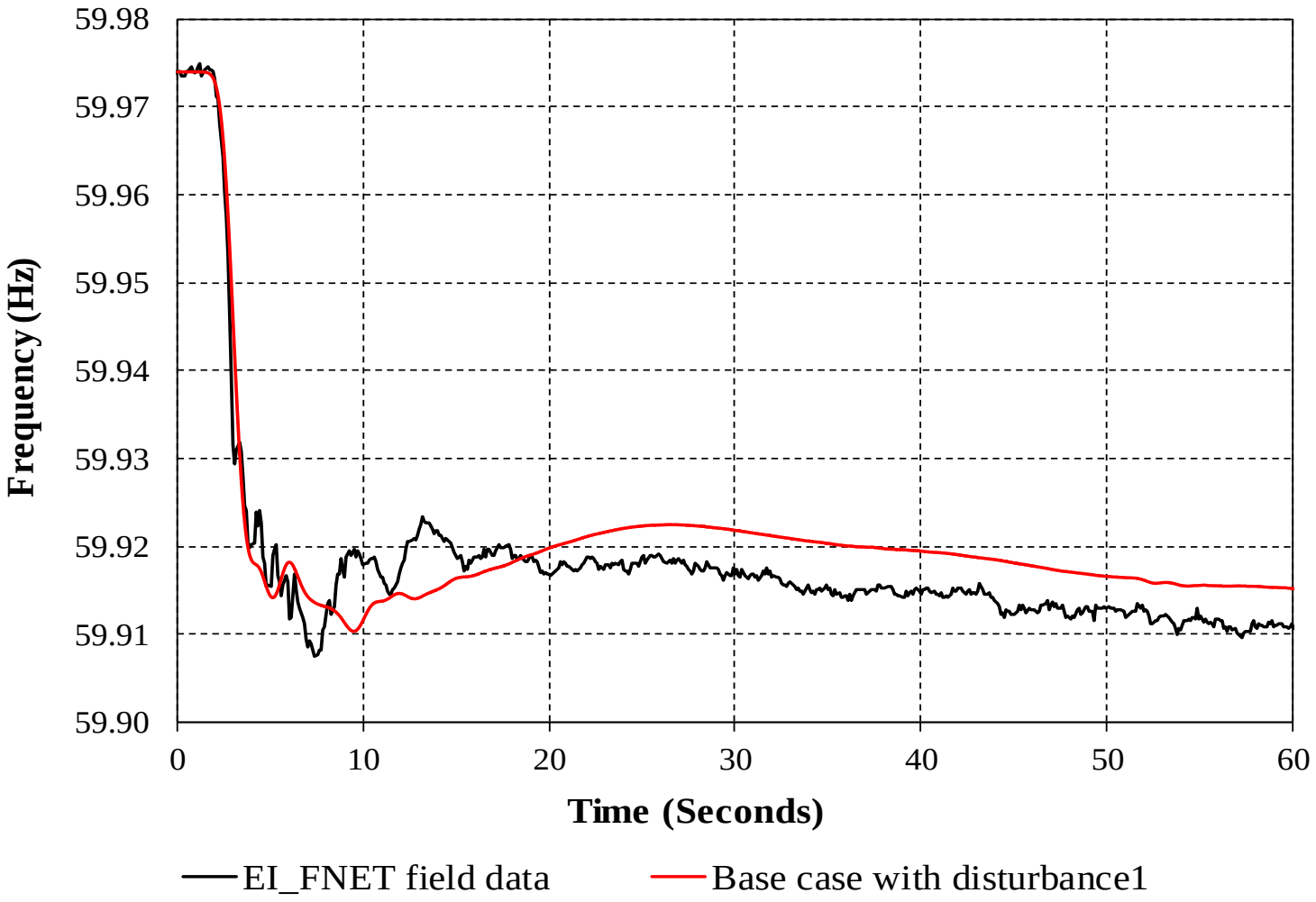
2021-LL Synchronous Generation PFR Percent Distribution by Region



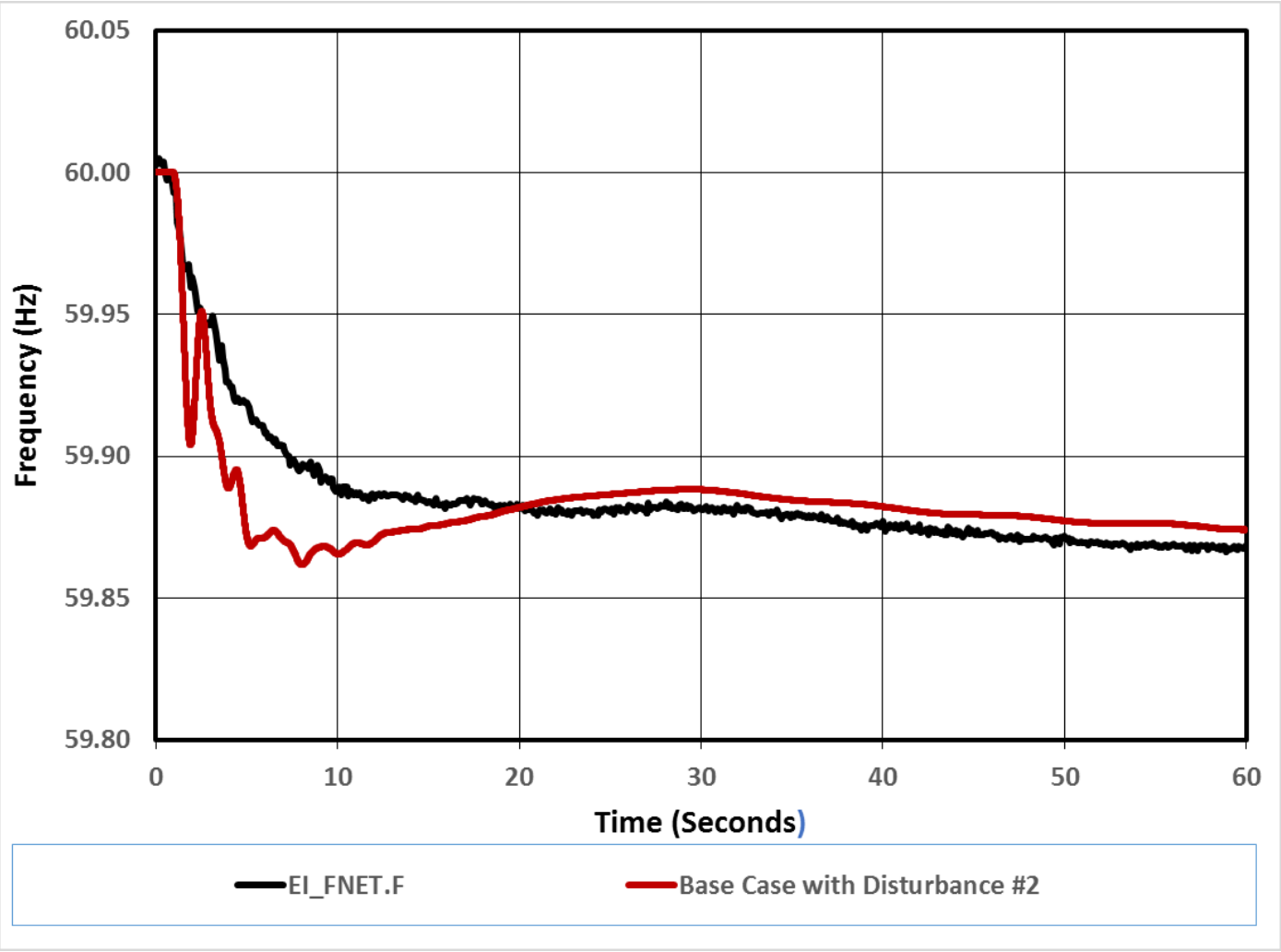
EI Model Benchmarked against Field Data

Model benchmarked against 2,100 MW resource loss



EI Model Benchmarked against Field Data

Model benchmarked against 4,500 MW resource loss



Inverter Based Resource Modeling

Inverter Based Resource

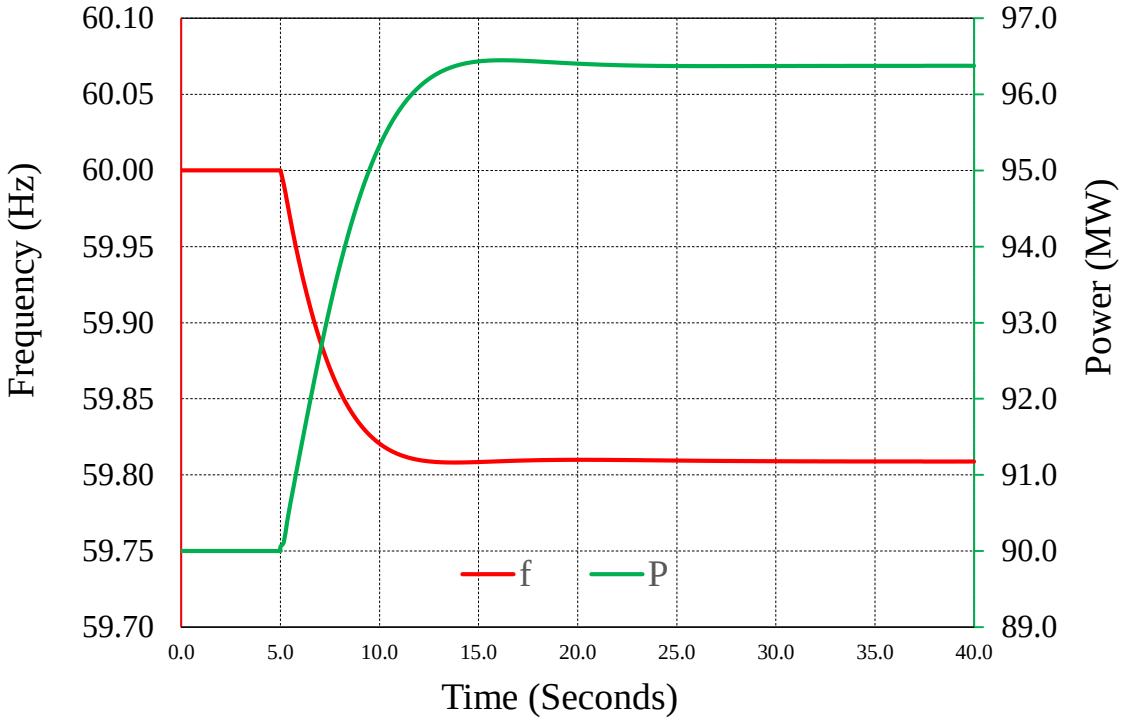
- Synchronous generator retired and Increasing penetration of IBRs from grid and distribution system
- Wind plant and Solar power plant are the main resources
- Battery Energy Storage System and STACTOM (FACTs) as the axillary resource
- Grid concerns on frequency/inertia stability, voltage/reactive stability
- FERC 827(0.95 power factory), NERC PRC-024 voltage/frequency protection, NERC Mod-032/033 model and validation

Type 3 Wind Plant Model as IBR

- WECC 2nd generation general model available in PSSE and PSLF
- NERC recommend to simulate real renewable power plant on :
  - Wind plant primary frequency response
  - Wind plant voltage/power factor control
  - Wind plant LVRT dynamic performance
- Type 3 wind models in PSSE V33.9 : REGCAU1, REECAU1, WTDTAU1, WTPTAU1, WTARAU1, WTTQAU1 and REPCTAU1

Wind Plant PFR Model Validation

Generic wind plant primary frequency response (PFR) model with 5% droop verified



Wind plant 5% frequency droop response

- Simplified benchmark system simulation
- $\Delta f=0.32\%$, $\Delta P=6.38\% \rightarrow$ Droop$=\Delta f/\Delta P=5\%$

Impact of Declining EI Synchronous FR Resources

Synchronous Generation Governors (PFR Disabled Level #2)

Synchronous Generation Governors (PFR Disabled Level #2)			
EI Governors with PFR Disabled	**PFR Generator Dispatch (Pgen) MW**	**PFR Generator Dispatched %**	**Total Headroom of Generators with PFR MW**
IEEEG1	20,532	25.7%	12,662
IEESGO	16,409	20.5%	7,600
TGOV1	18,386	23.0%	14,031
Total FR Gen. with PFR Disabled	**55,237**	**69.24%**	**34,294**
Total FR Gen. with PFR	79,905		

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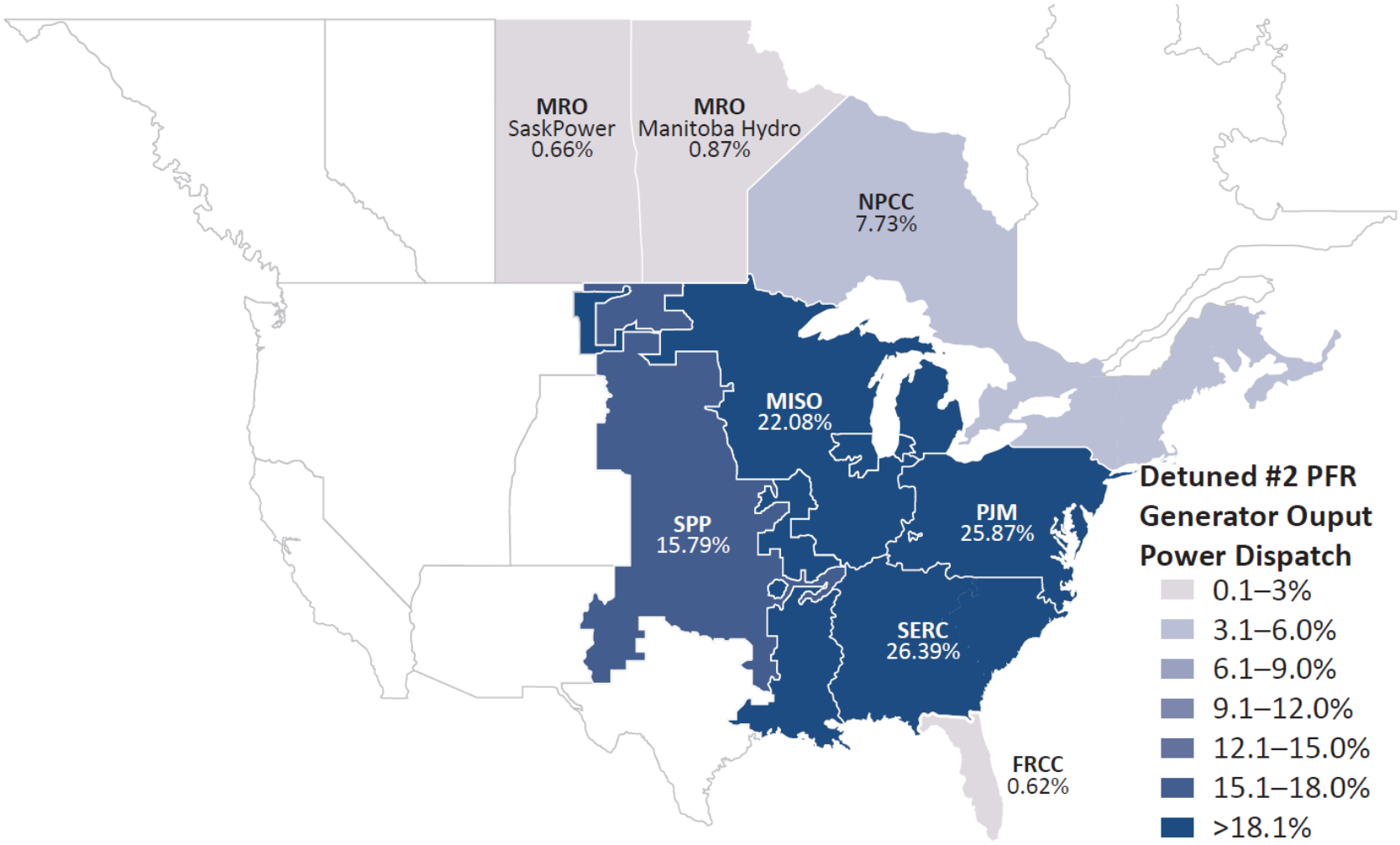
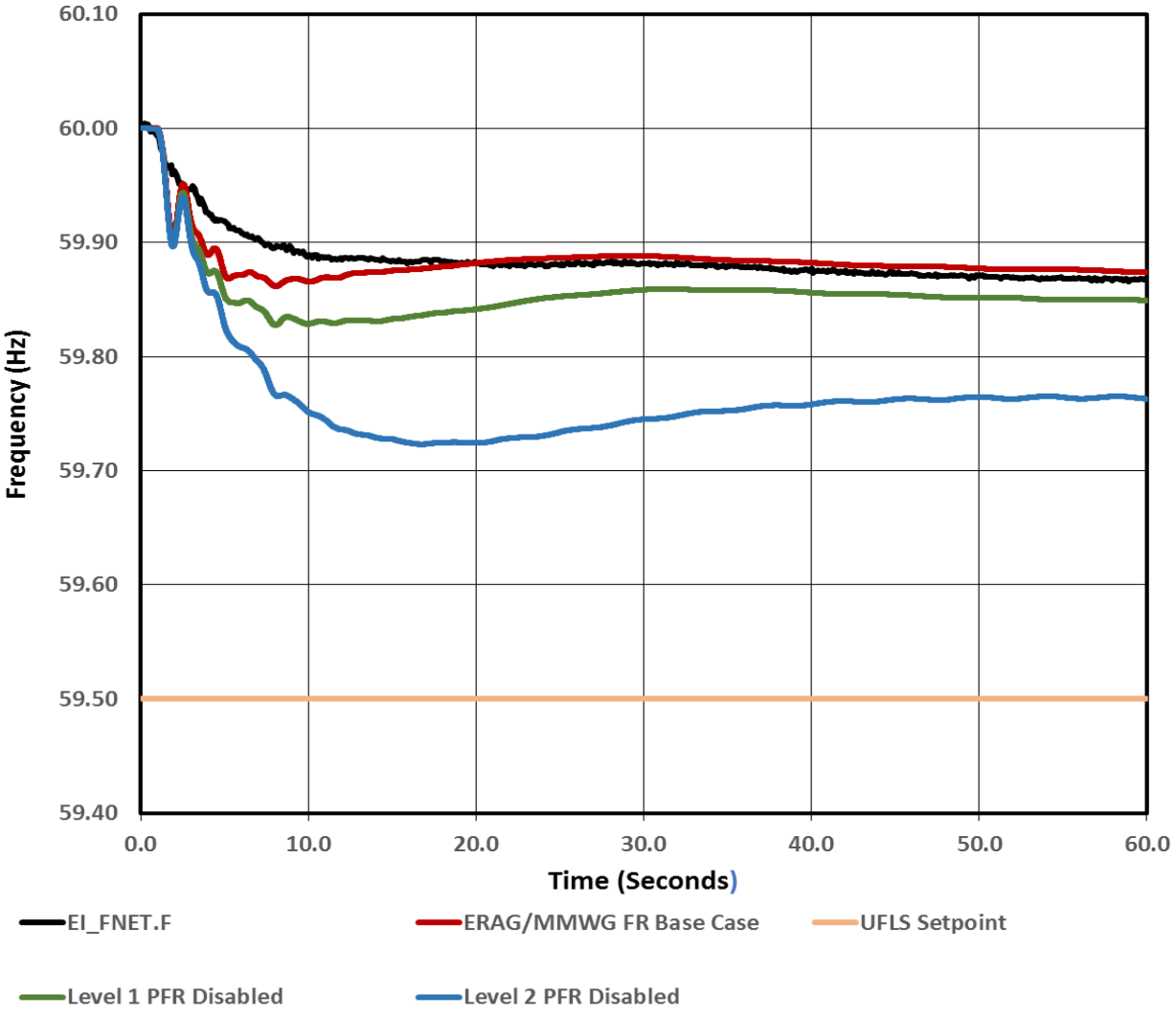
Synchronous Generation Governors (PFR Disabled Level #2)



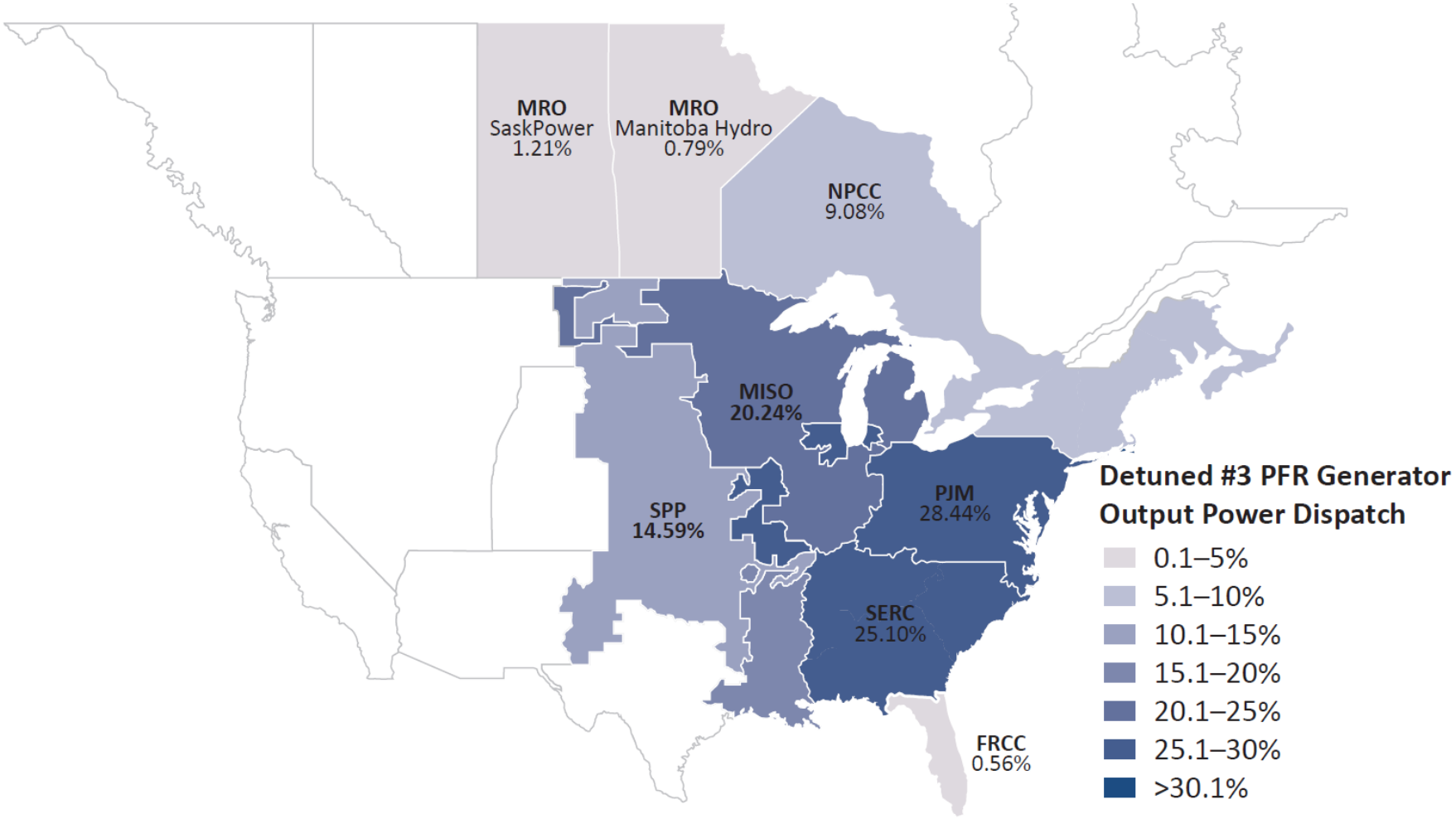
Disturbance #2 Synchronous Generation Governors (PFR Disabled Level #2)



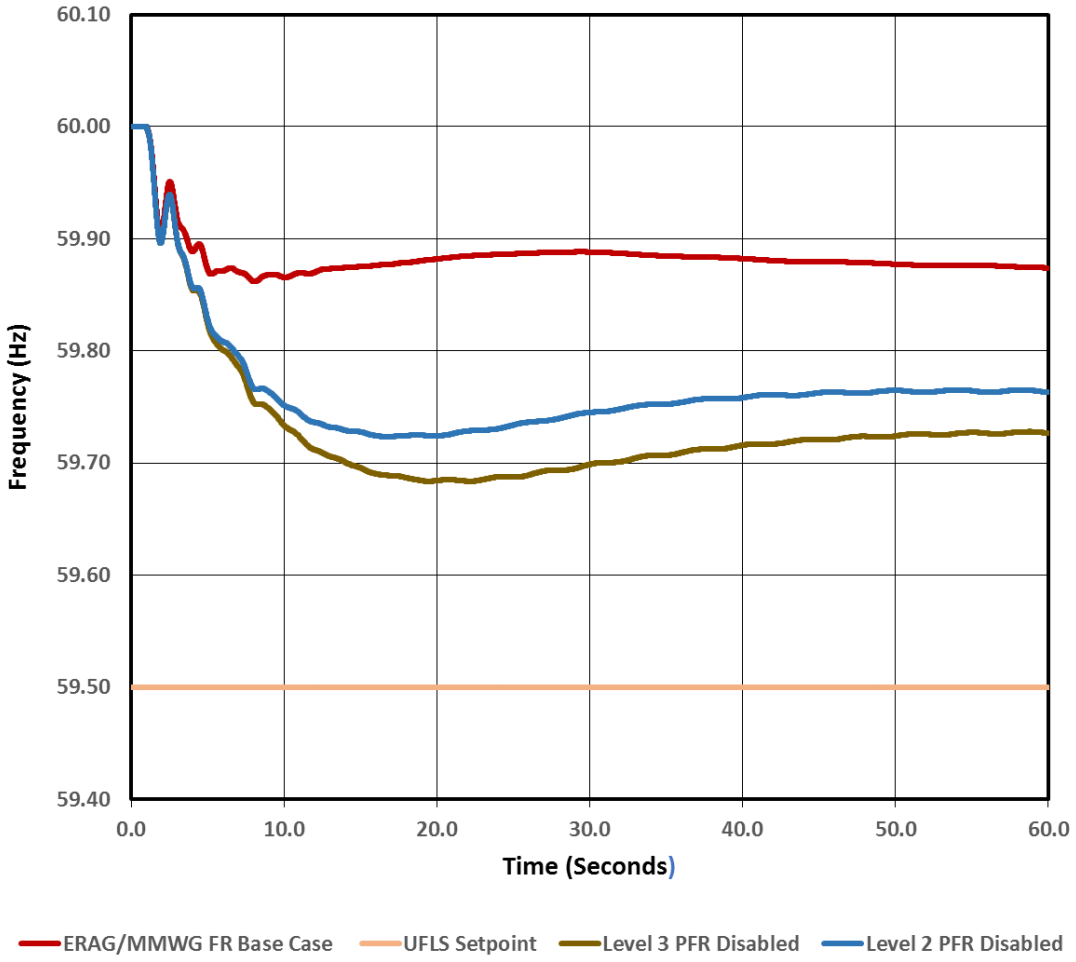
Synchronous Generation Governors (PFR Disabled Detuned Level #3)

Synchronous Generation Governors (PFR Disabled Detuned Level #3)			
EI Governors with PFR Disabled	**PFR Generator Dispatch (Pgen) MW**	**PFR Generator Dispatched %**	**Total Headroom of Generators with PFR MW**
GGOV1	5,444	6.81%	2,816
IEEEG1	20,532	25.70%	12,662
IEESGO	16,409	20.54%	7,600
TGOV	18,386	23.01%	14,031
Total FR Gen. with PFR Disabled	**60,771**	**76.06%**	**37,710**
Total Gen. with PFR	**79,905**		

IEEEG1/ IBRs Minimum FR Generation with PFR Disabled (Level #3)



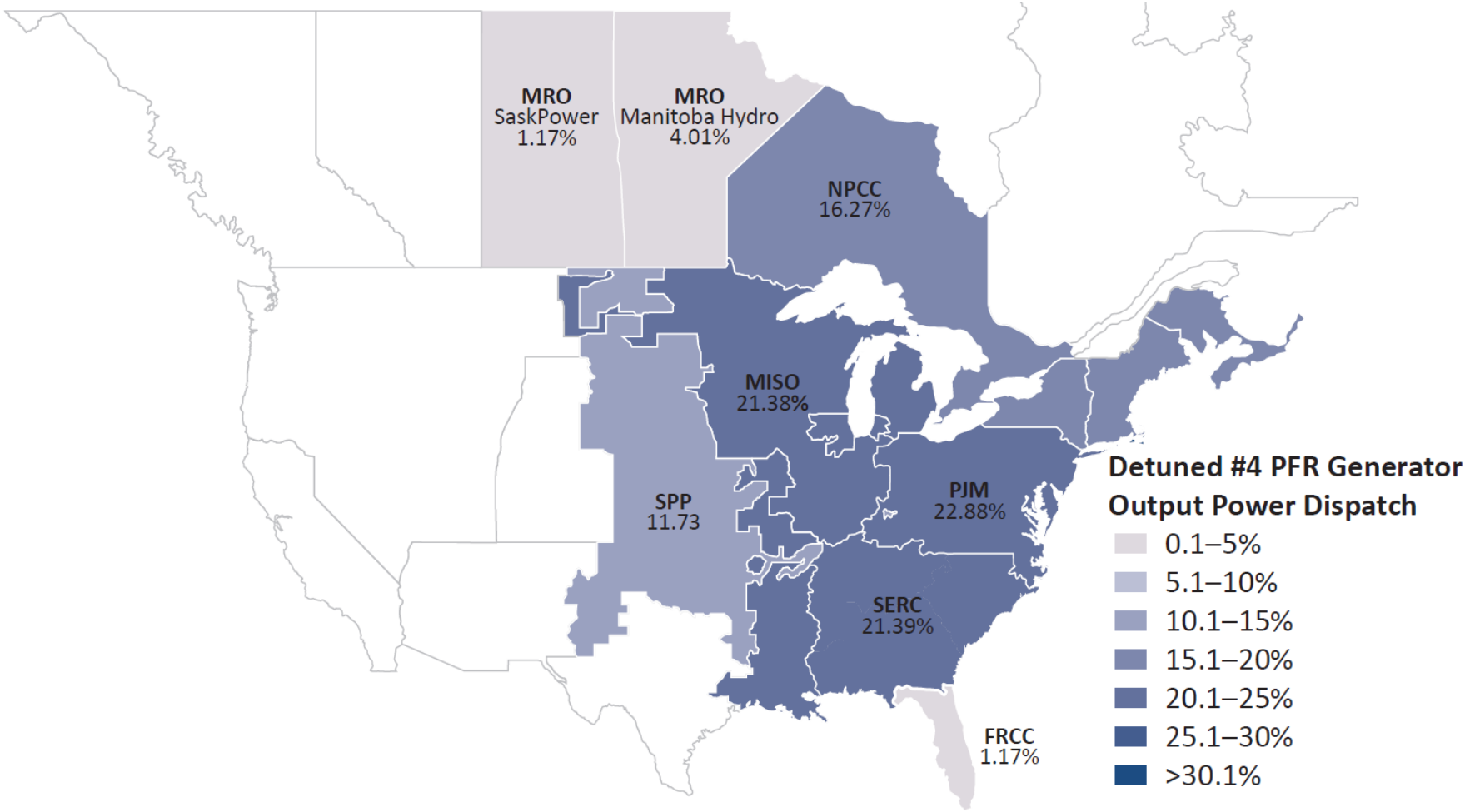
Disturbance #2 IEEEG1/ IBRs Minimum FR Generation with PFR Disabled (Level #3)



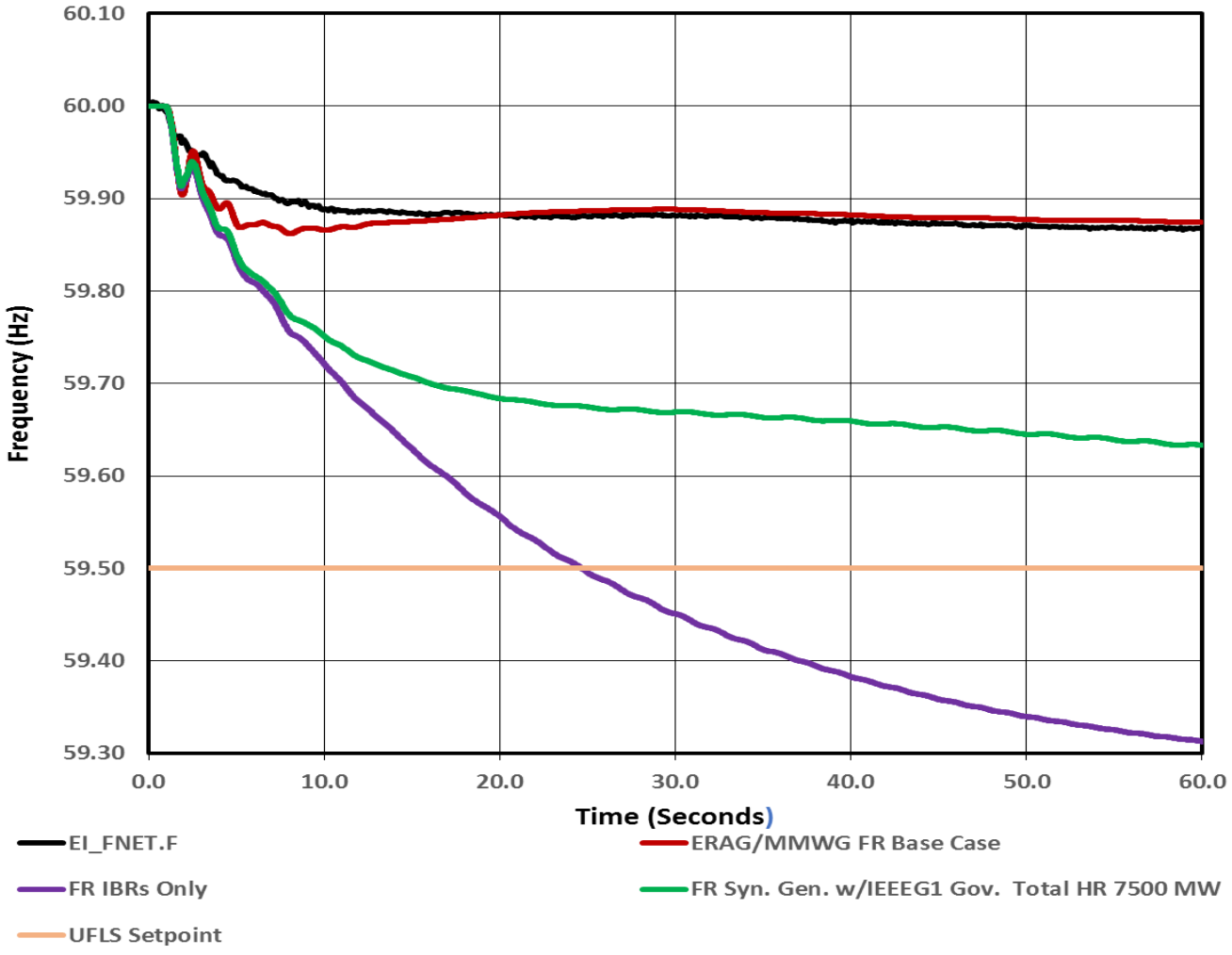
FR IBRs Replace FR IEEEG1 Synchronous Generation (Level #4)

- **Minimum FR IBRs (MIBR)**: This MIBR Case was based on MSG case with 20,532 MW synchronous generation (with IEEEG1 governors) all replaced by 103 FR IBRs (having a droop of five percent and headroom of five percent).

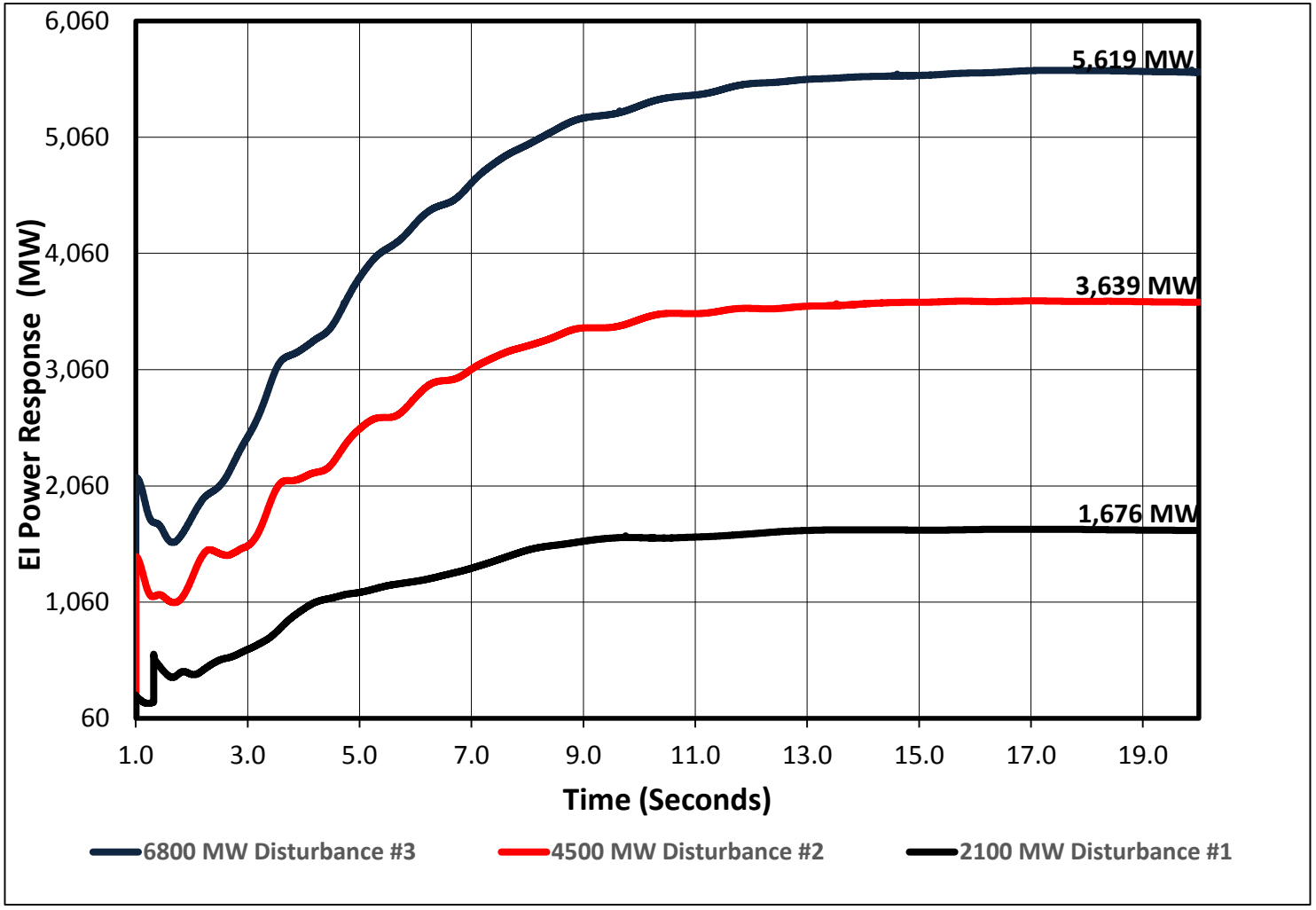
IEEEG1/ IBRs Minimum FR Generation with PFR Disabled (Level #4)



Disturbance #2 IEEEG1/ IBRs Minimum FR Generation with PFR Disabled (Level #4)



EI Dynamic Power Response for different Loss of Generation Events

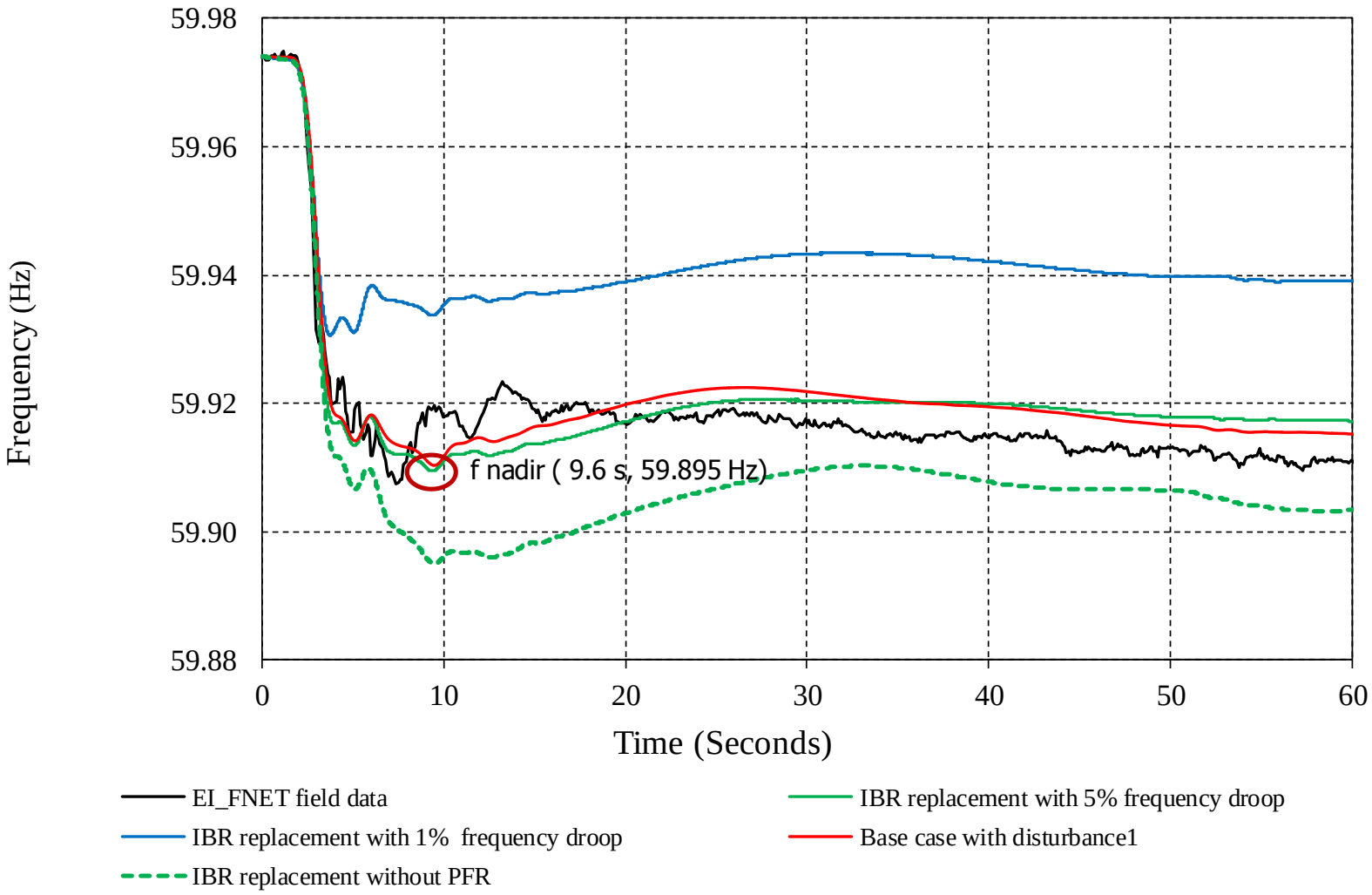


EI Dynamic Power Response

- Disturbance #1: 2100 MW Event, the EI uses 1,676 MW or 3.6% of the available FRR.
- Disturbance #2: 4500 MW Event, the EI uses 3,639 MW or 7.8% of the available FRR.
- Disturbance #3: 6800 MW, Event, the EI is far from exhausting all of its FRR. The EI uses 5,619 MW or MW is 12.6% of the available FRR.

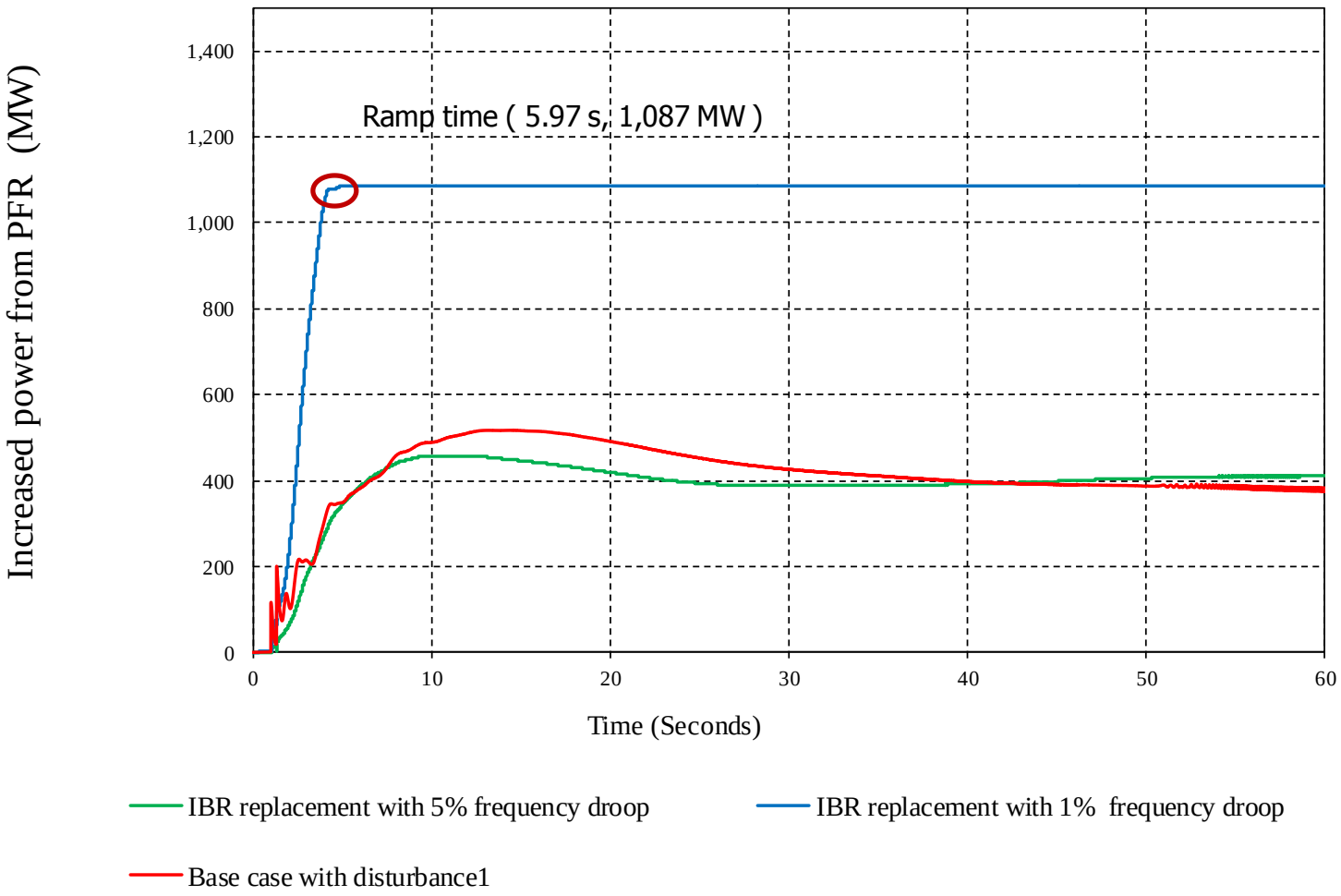
EI IBR Analysis of Disturbance 1

Frequency response for 2,100 MW resource loss



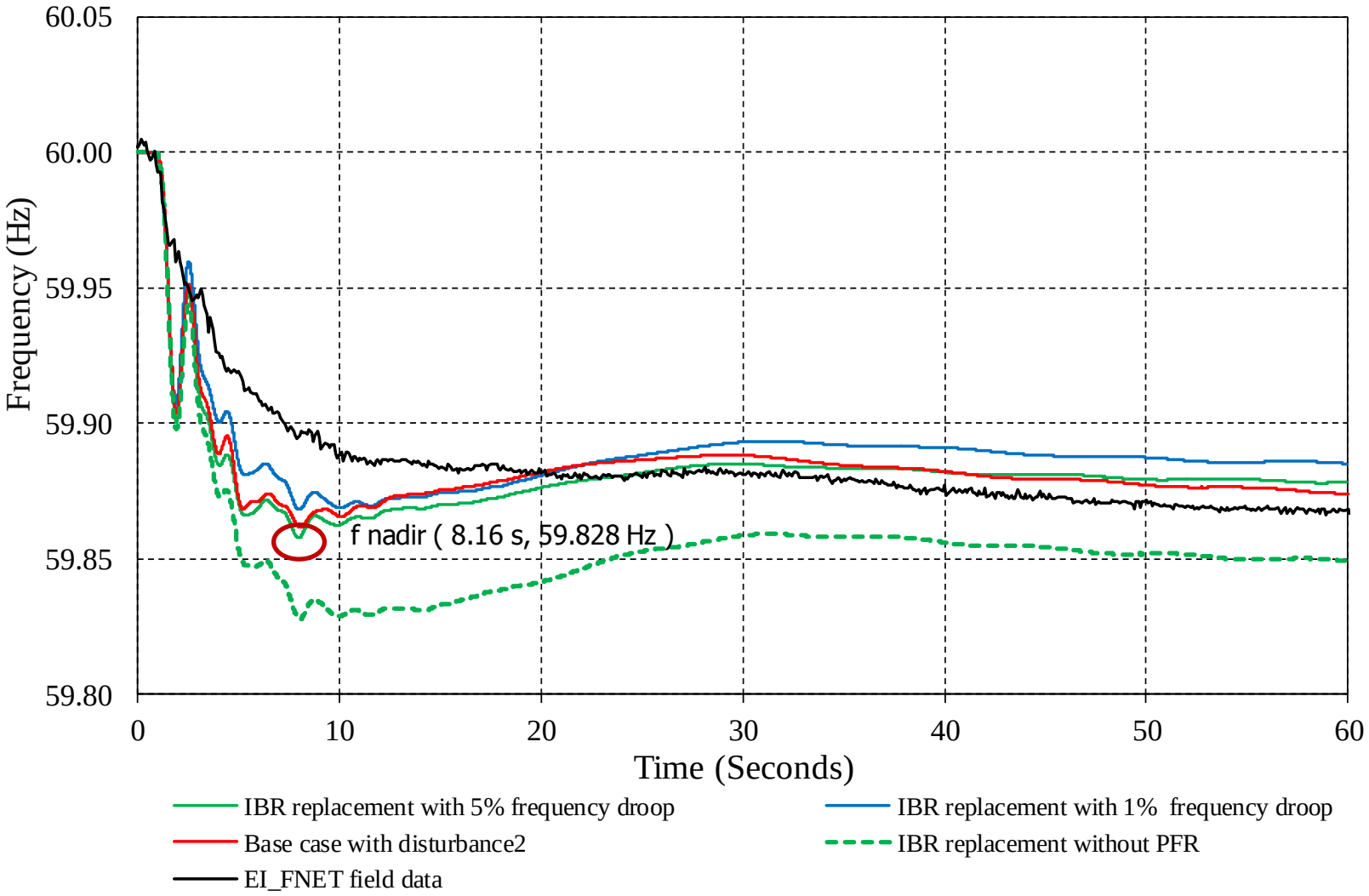
EI IBR Dynamic Power Response for Disturbance 1

Dynamic Power Response for 2,100 MW resource loss



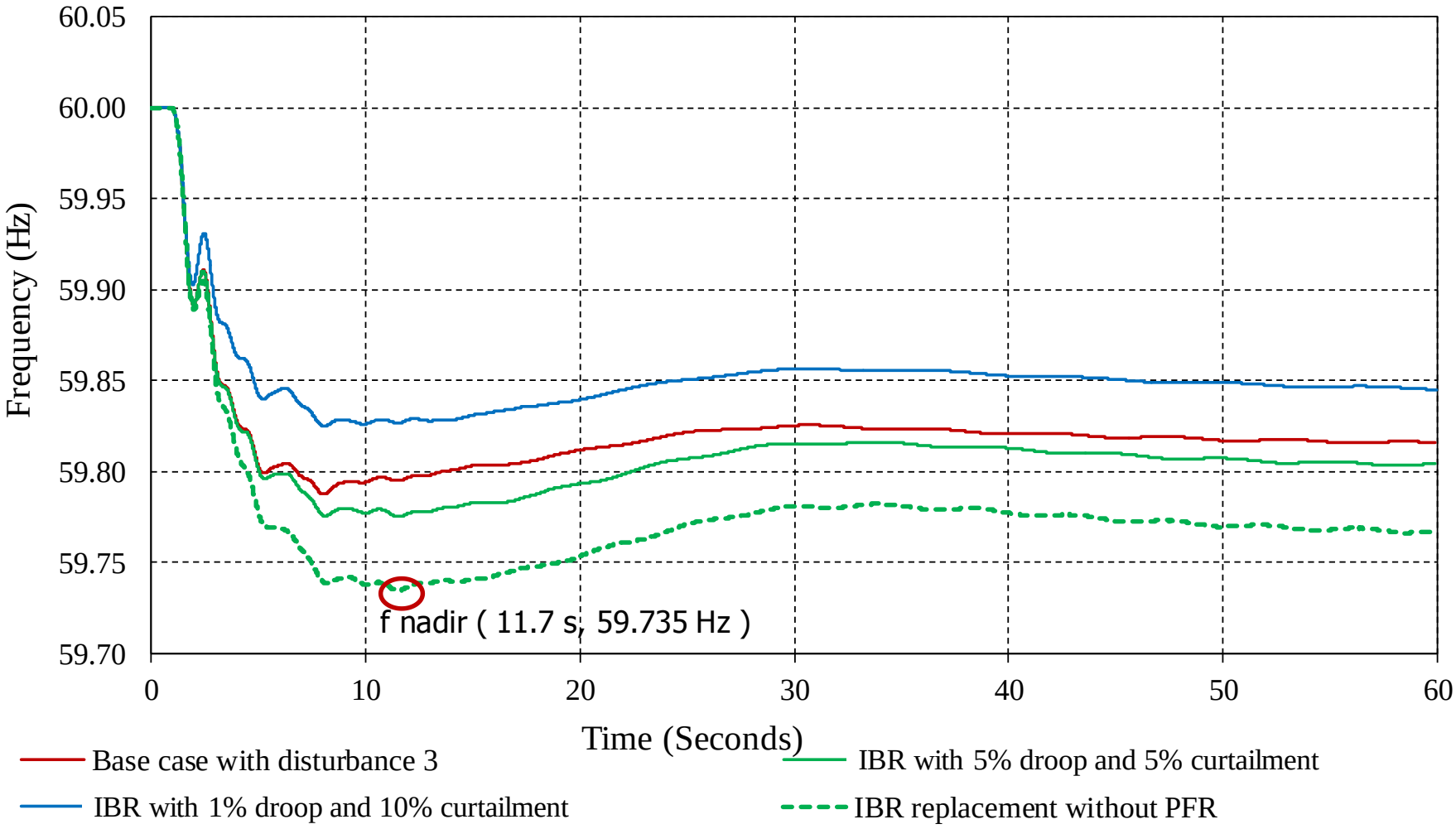
EI IBR Frequency Response for Disturbance 2

Frequency response for 4,500 MW resource loss



EI IBR Freqency Response for Disturbance 3

Frequency response for 6,800 MW resource loss



Conclusions for 20,000 MW of FR Sync. Generation Replaced by Non-FR IBRs

- **Finding 3**: The EI Grid will maintain stable operation above the UFLS set point of 59.5 Hz under generation loss events up to 6800 MW.
  - EI Grid frequency nadir will fall by 15 mHz and will not experience UFLS for a 2100 MW generation loss event
  - EI Grid frequency nadir will fall by 36 mHz and will not experience UFLS for a 4500 MW generation loss event
  - The EI Grid will maintain operation above the UFLS set point for loss of generation events up to 6800 MW

Conclusions for 20,000 MW of FR Sync. Generation Replaced by Non-FR IBRs

- EI Grid frequency nadir will fall by 15 mHz and will not experience UFLS for a 2100 MW generation loss event
- EI Grid frequency nadir will fall by 36 mHz and will not experience UFLS for a 4500 MW generation loss event
- The EI Grid will maintain operation above the UFLS set point for loss of generation events up to 6800 MW

Summary of Grid Frequency Response and Power Response

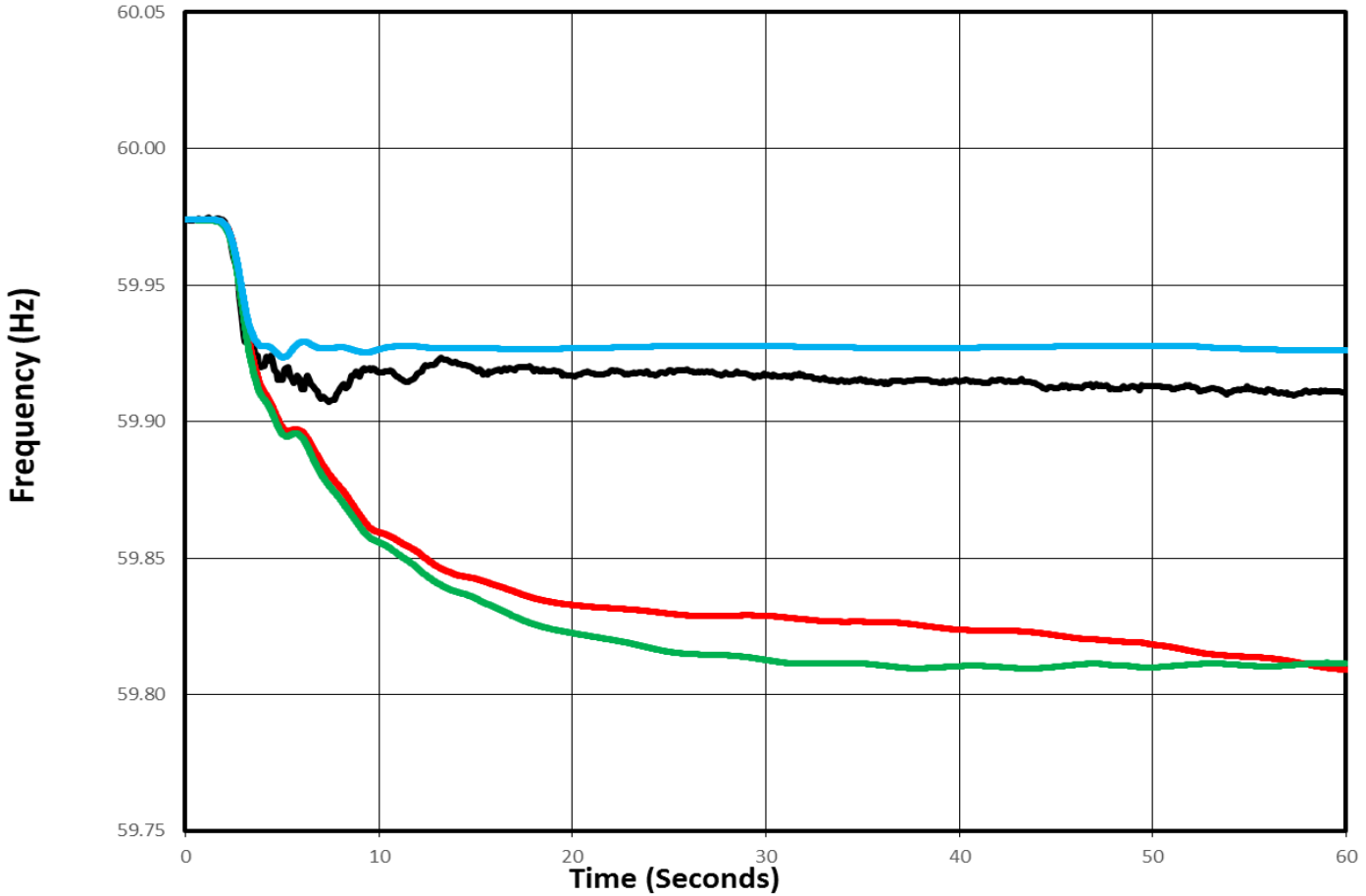
Summary of Grid Nadir and Increased Power for Different Disturbances			
Increased Output Power /Grid Nadir	**Disturbance #1 (2,100 MW Gen. Trip)**	**Disturbance #2 (4,500 MW Gen. Trip)**	**Disturbance #3 (6,800 MW Gen. Trip)**
Base Case with Synchronous Gen.	517 MW/ 59.91 Hz	1049 MW / 59.86 Hz	1604 MW / 59.79 Hz
Base Case with 6% IBR Replacement, 5% FRR, 5% PFR Droop	457 MW / 59.91 Hz	995 MW / 59.86 Hz	1087 MW / 59.77 Hz
Base Case with 6% IBR Replacement, 5% FRR, 1% PFR Droop	1087 MW / 59.93 Hz (5% FRR)	1087 MW / 59.87 Hz (5% FRR)	2294 MW / 59.782 Hz (10% FRR)

Frequency Response Minimum Resource Sensitivity

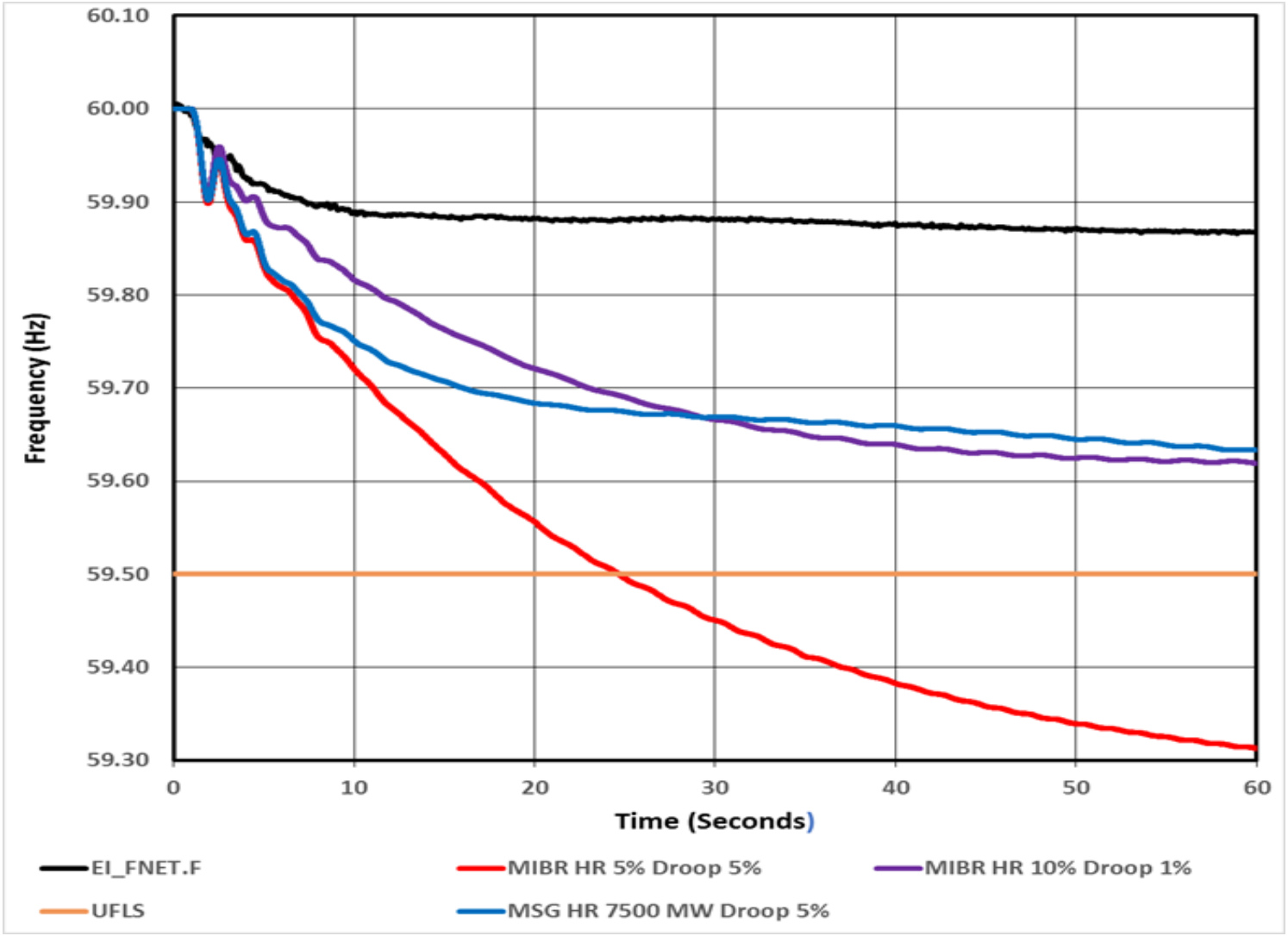
Minimum Frequency Responsive Resource Analysis

- **Minimum FR Synchronous Generation** (MSG): This MSG Modeling in the FR Base Case included 20,000MW of synchronous generation modeled with IEEEG1 governors.
- **Minimum FR IBRs (MIBR)**: This MIBR Modeling in the FR Study Case Replaced the MSG modeling with IBRs.

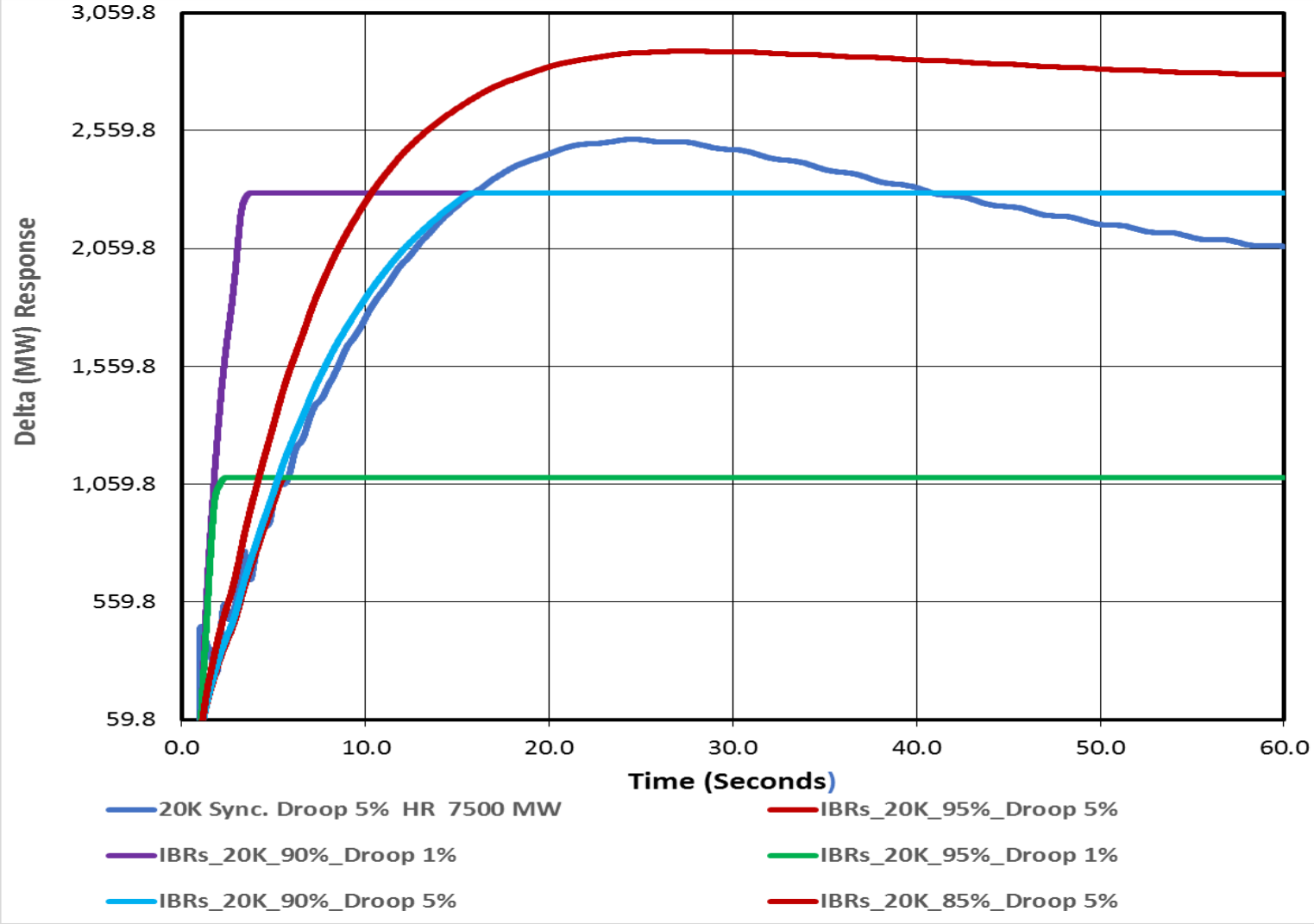
Disturbance #1 Minimum FR Resources Sensitivity



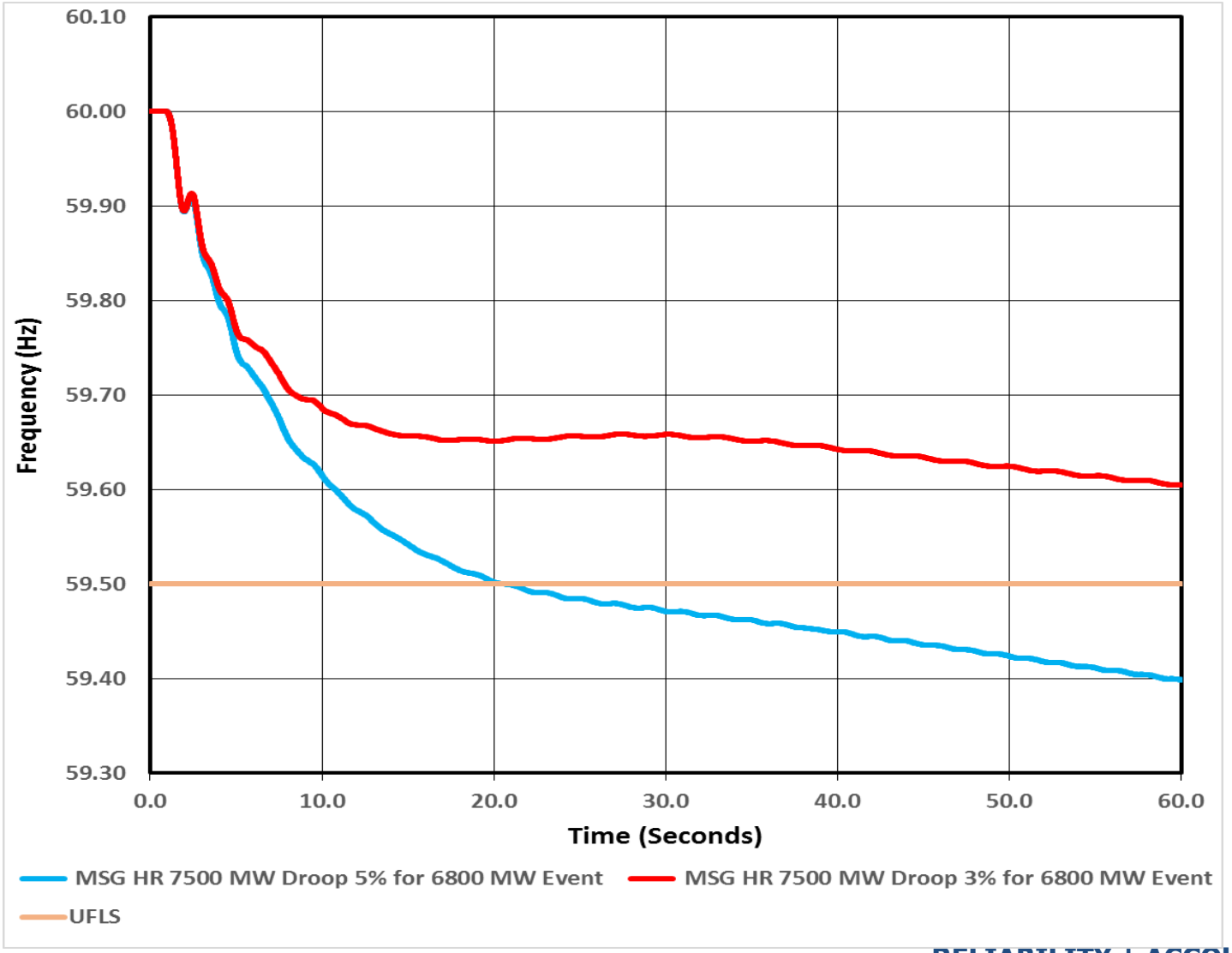
Disturbance #2 Minimum FR Resources Sensitivity



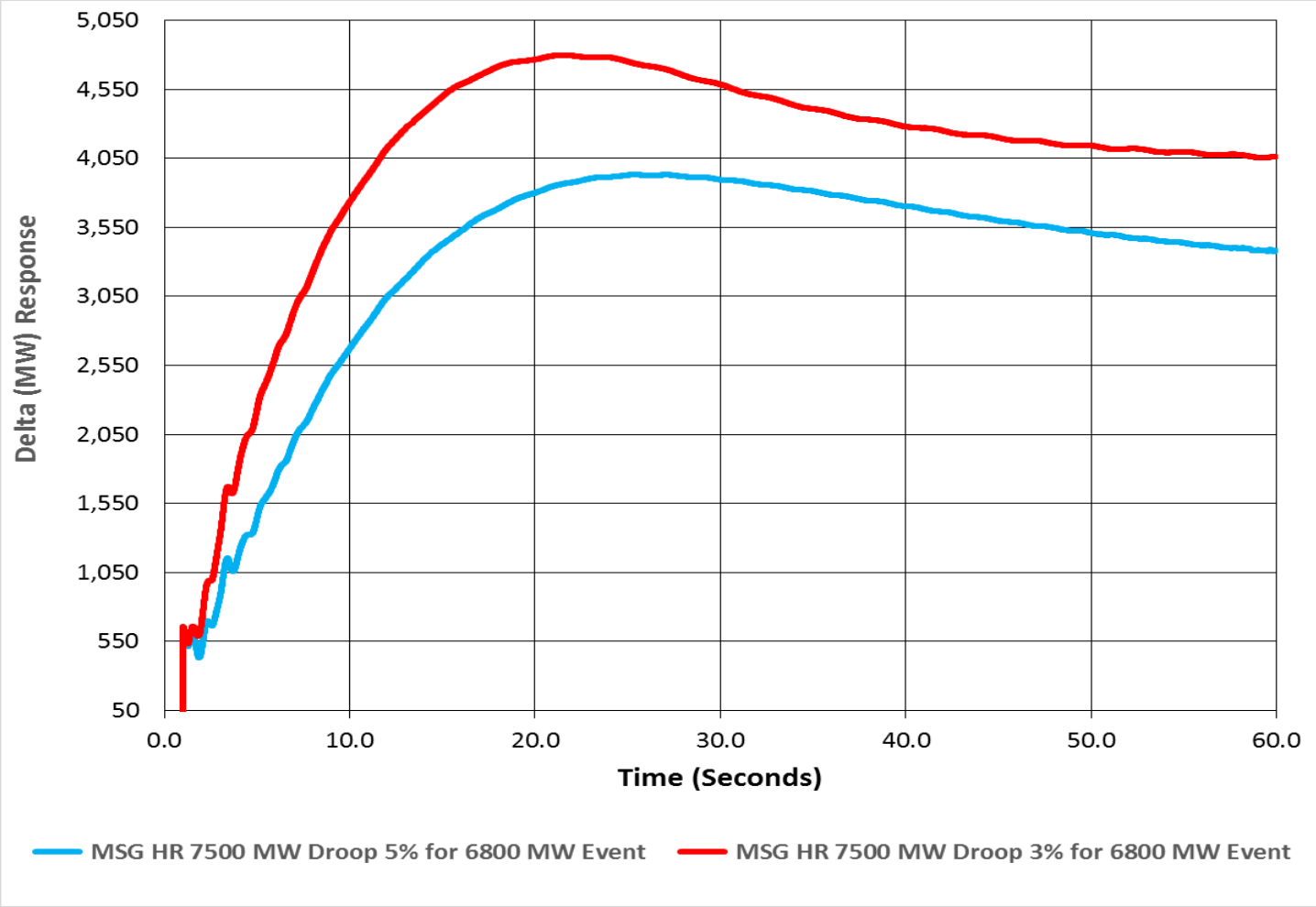
Dynamic Power Response for MIBRs for Disturbance #2



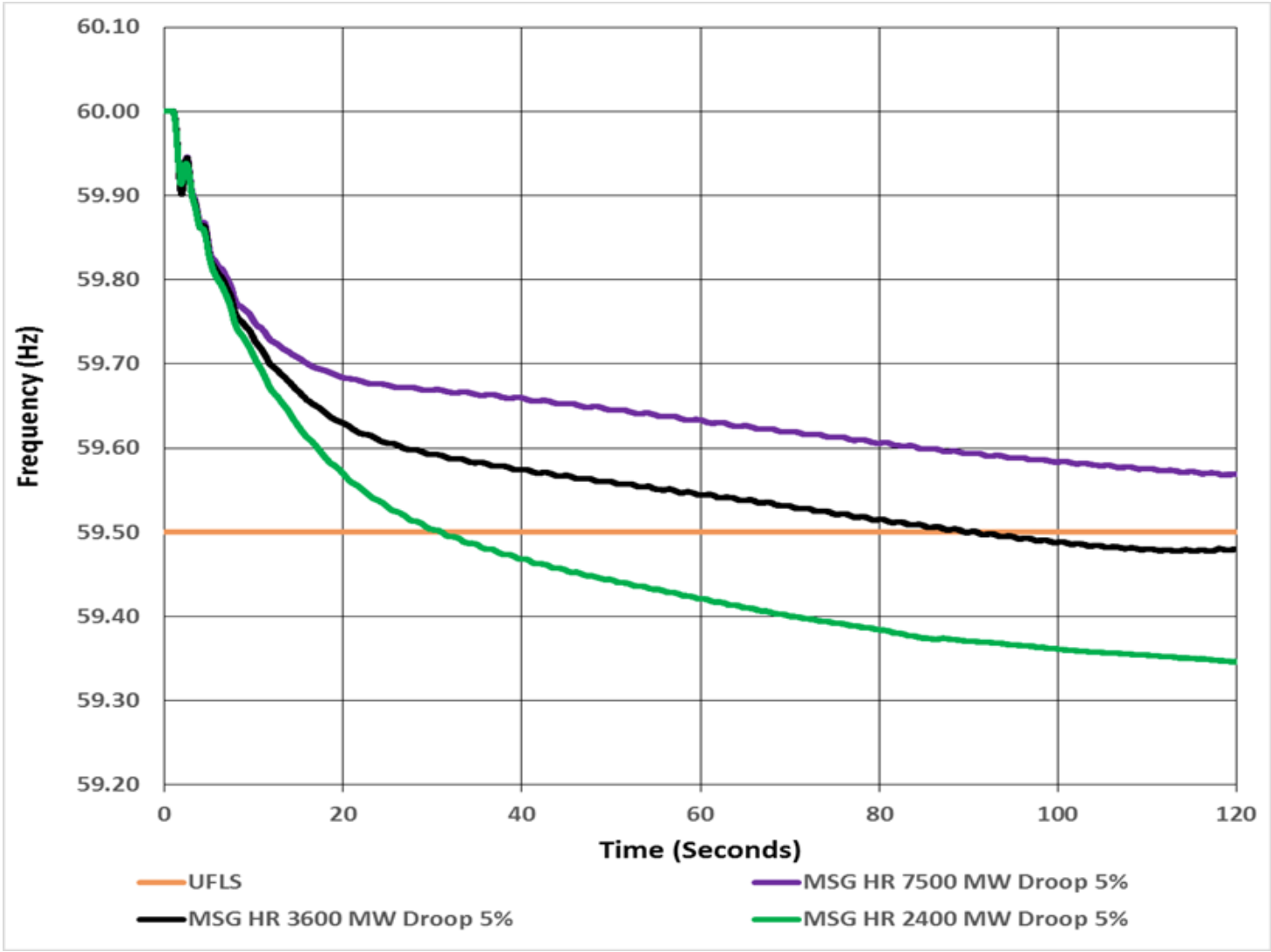
Frequency Response for MSG Disturbance #3



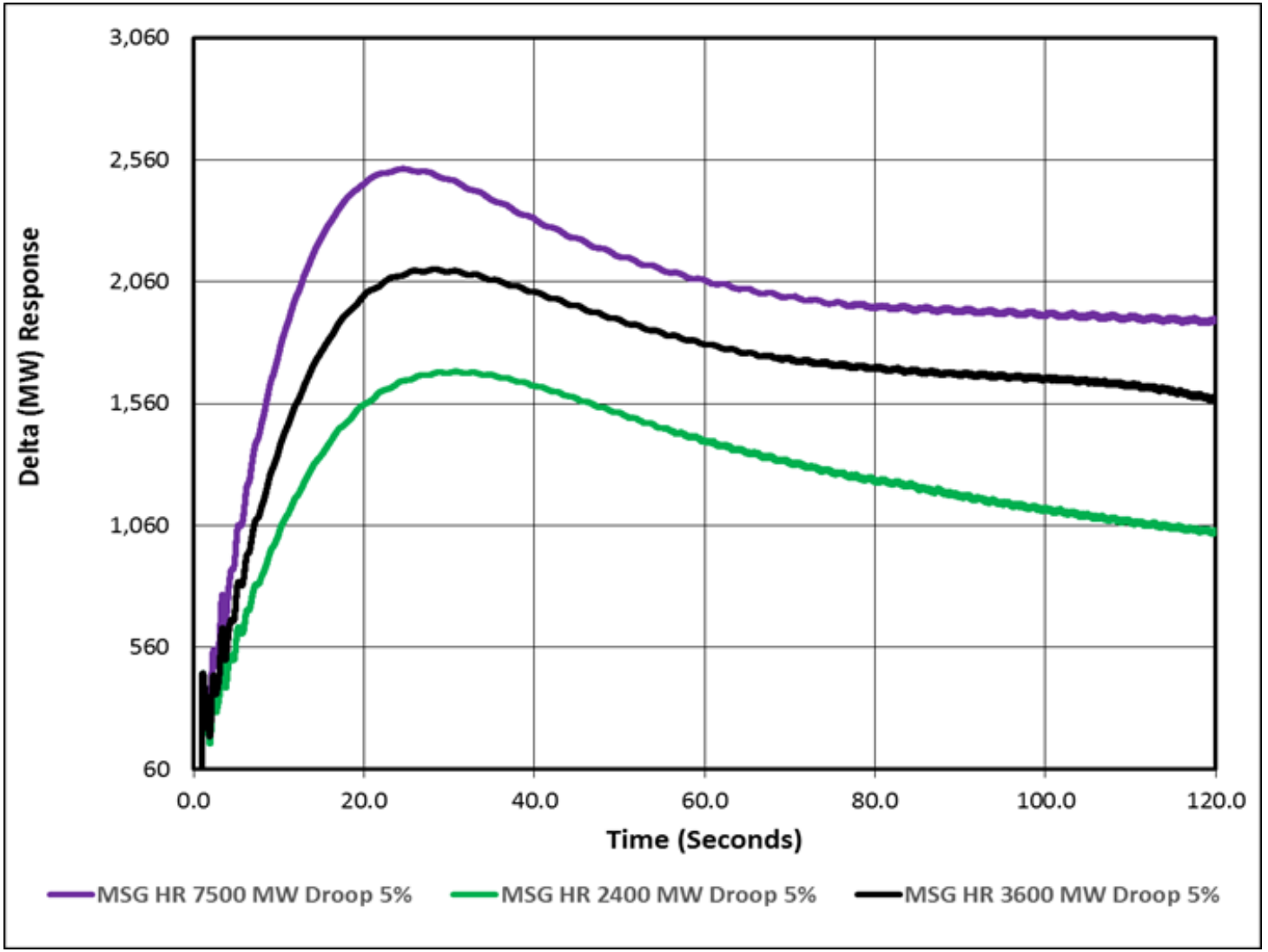
Dynamic Power Response for MSG Disturbance #3



Frequency Response Sensitivity to Different Levels of FRR

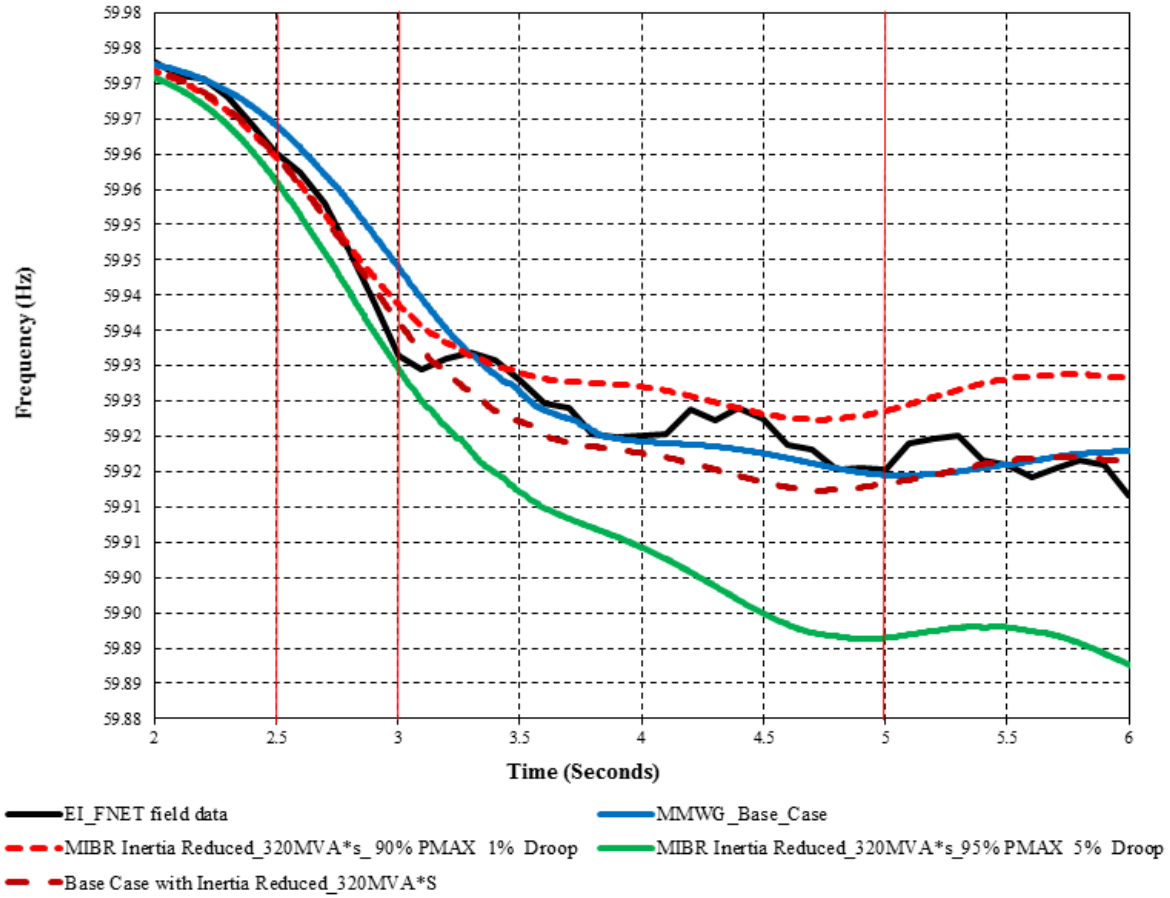


Dynamic Power Response Sensitivity to Different Levels of FRR



EI Grid Inertial Response Sensitivity

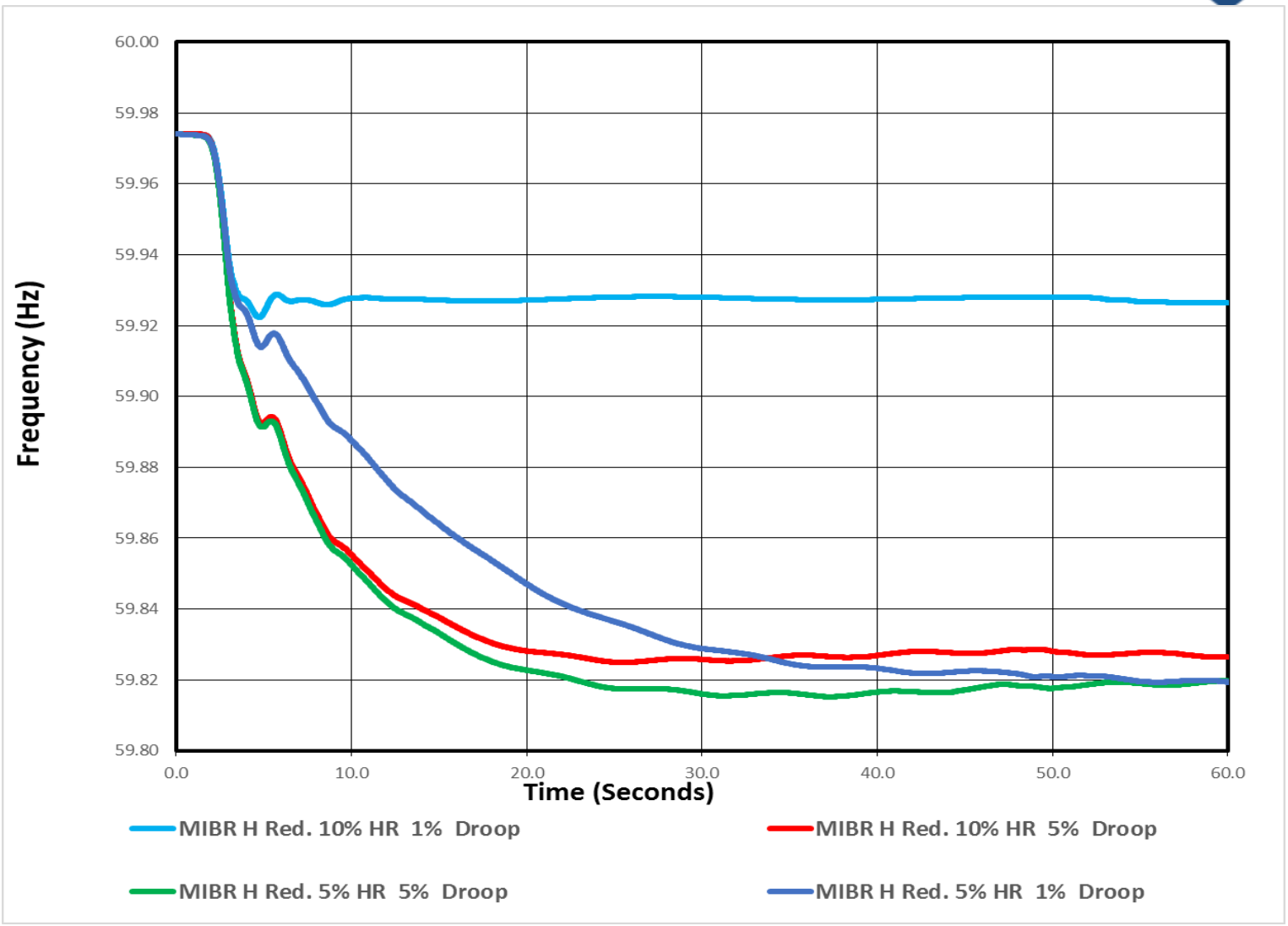
Frequency Performance with Inertia Change for Disturbance #1



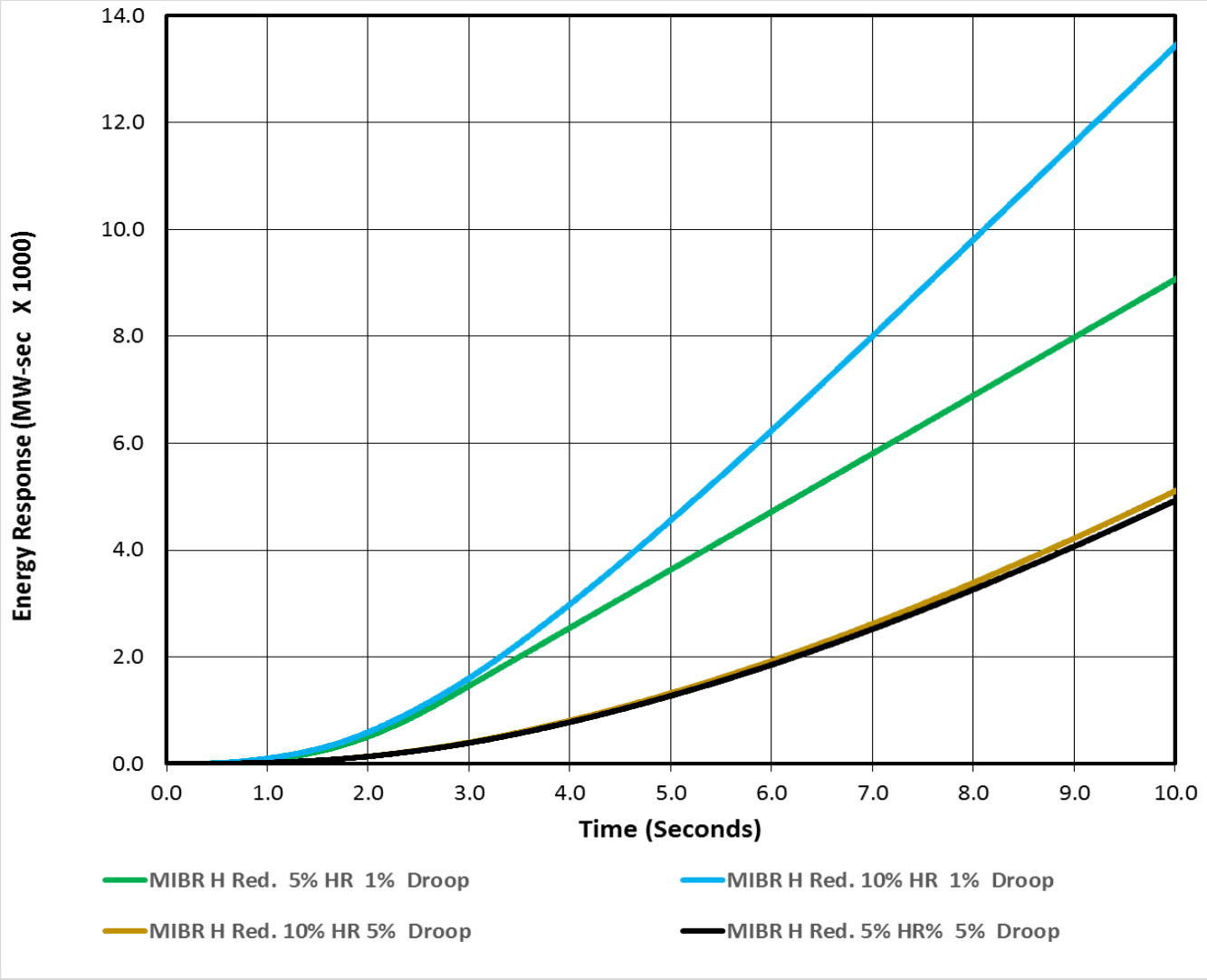
EI Grid RoCoF, Nadir, and Inertial Assessment of Disturbance #1

EI Grid RoCoF, Nadir and Inertial Assessment on 2100 MW Disturbance #1					
Event Time(s)	**EI_FNET.F**	**ERAG/MMWG FR Base Case**	**Base Case with 320k MVA*s Inertia Reduced**	**MIBR H Red. 10% HR 1% Droop**	**MIBR H Red. 5% HR 5% Droop**
2.0	59.972	59.972	59.972	59.970	59.970
2.5	59.960	59.964	59.960	59.959	59.956
RoCoF_0.5s(hz/s)	**0.0240**	**0.0160**	**0.0240**	**0.0220**	**0.0280**
Nadir (Frequency)	59.907	59.910	59.911	59.920	59.820
Nadir (Time _ s)	7.50	9.40	8.60	4.95	30.00
H from_0.5s (MVA*s)	2,625,000	3,937,500	2,625,000	2,863,636	2,250,000

2100 MW Disturbance #1 Frequency Response Sensitivity for Inertia Reduced w/MIBRs



Disturbance#1 Energy Response Sensitivity for Inertia Reduced



Energy Injection

- Tradeoff between lower system inertia and high-speed energy injection
- Objective – Return the system to balance by injecting larger amounts of energy sooner during the arresting period of the frequency excursion

Findings

Findings

- **Finding 1**: The ERAG/MMWG 2016 Series 2021-LL FR Base Case (2021-LL FR Base Case) provides a valid basis for studying the EI Grid Primary Frequency Response (PFR).
- **Finding 2**: The EI Grid Synchronous PFR Resources are adequate for the year 2021 and beyond based on expectations of synchronous resource retirements and the assumption that they will be replaced with IBRs.
- **Finding 3**:For likely retirements schedule that will retire up to 25% of synchronous generation while increasing the penetration of IBRs on the EI Grid by the year 2021 and beyond, the EI Grid will maintain stable operation above the UFLS set point of 59.5 Hz under generation loss events up to 6800 MW.

Findings

- **Finding 4:** The EI Grid will not maintain stable operation above the UFLS set point under dynamic conditions for loss of generation events greater than 4500 MW if the generation available for PFR consists of only non-responsive IBRs. If MIBRs replace the MSG, the amount of responsive IBRs must be increased with response capability based on droop, headroom, and dispatch availability.
- **Finding 5**: For a 6800 MW Stress Event that has never occurred on the EI Grid, the EI Grid will maintain stable operation above the UFLS set point of 59.5 Hz.
- **Finding 6**: The number of frequency responsive resources dispatched with headroom is a key determinant of the MSG and MIBRs power response required to avoid UFLS for a 4500 MW Event.
- **Finding 7:** The 2021-LL FR Base Case provides a good basis for the EI Grid inertial response simulation.

Findings

- **Finding 8:** The Rockport Event MSG Energy Response is not significantly impacted by changes in dispatched headroom for PFR resources during the arresting period less than 10 seconds.
- **Finding 9:** For a 2100 MW generator loss event, the necessary Interconnection FR performance increases from 420 MW/0.1 Hz to 700 MW/0.1 Hz as the deadband is increased from zero to 200 mHz.

Questions and Answers