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His dissertation topic and research interest are in Microgrid Stability Analysis, System Integration, Dynamic Modelling, and Battery Energy Storage controls, including Power Converter Control Design for Renewable Energy integration.

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Microgrid Resiliency: Control Design for Energy Storage Dispatch in Existing Critical Facility Microgrids Connected to Weak Utility Systems

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April 2024

Background

- Critical facilities
  - Traditionally equipped with oversized backup generators
    - Diesel, Natural Gas, etc.
- Many facilities are Opting to upgrade to a local **Critical Facility Microgrid (CFM)**
  - Introducing Solar, storage
  - Enhancing Sustainability by Reduction of Emissions
  - Increasing Reliability during a longer utility Outage

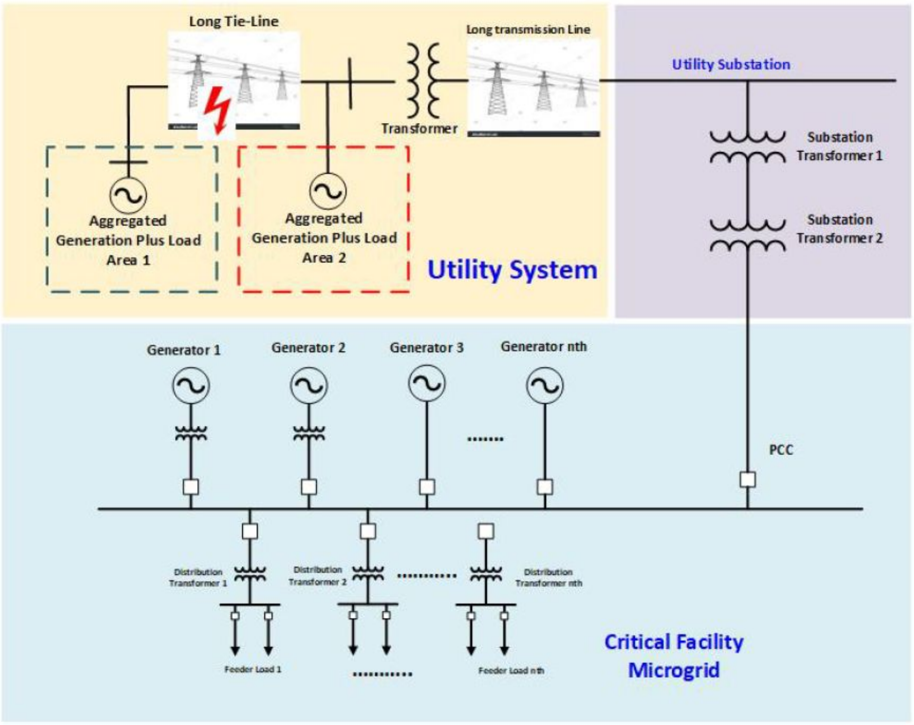


Figure 1. Typical CFM Diagram

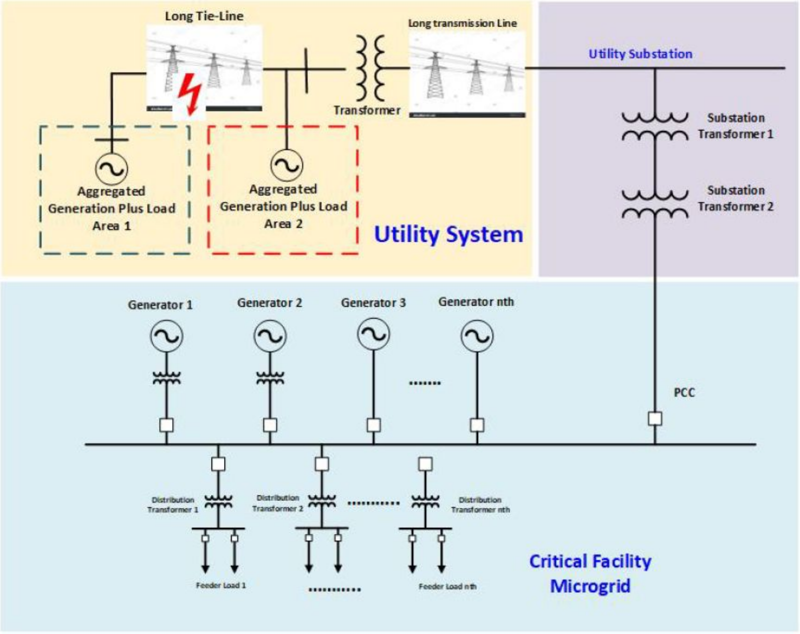
- IEEE 1547: CFM has to remain connected to the Utility during a period of time

Background

- IEEE 1547: The CFM has to remain connected to the utility for a period of time “Weak Grid Condition”

- Critical Transient Scenario:
  - Part of **Area 1** provide power to **Area 2** through the inter-tie under normal conditions and then a **fault occurs**
  - The frequency at the Point of Common Coupling drops due to the fault.
  - The ride through requirement allows the frequency of the CFM to drop to a very low level resulting in instability and high **ROCOF**

- Ride Through delay can further worsen the stability at the POC in a post-islanding scenario



Proposed Approach

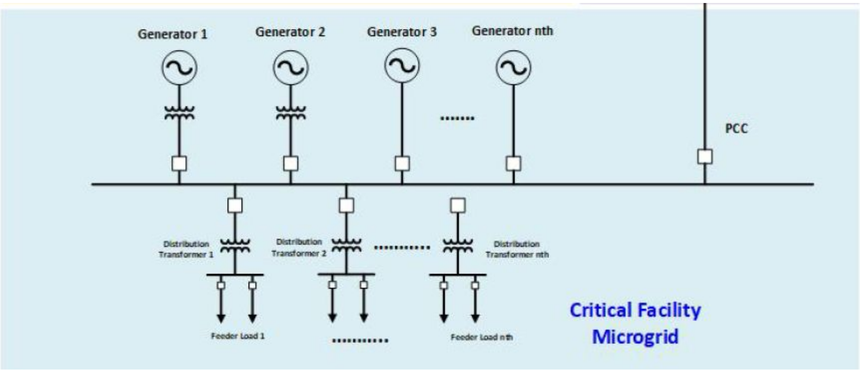
- The proposed solution: Design a Battery Energy Storage System (BESS) control to guarantee:
  - Stable post islanding conditions
    - Similar Approach is taken to provide **Fast Frequency Response (FFR)** providing by properly injecting active power. Based on the **Rate of Change of Frequency (RoCoF)** in the system, adding ”inertial-control”

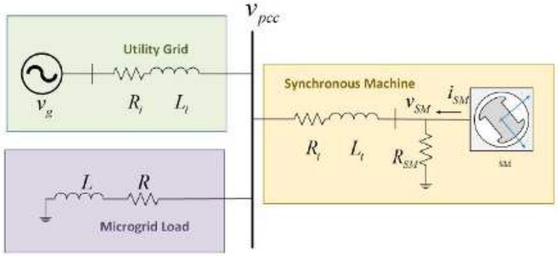
- Method:

1. Creation of an aggregated model of the CFM
2. Validation of the Model with Field Transient Data
3. Next, a linearized state space model is created whose eigenvalues are studied for different operating scenarios to understand the instability issue
4. An adaptive droop control is then developed to dispatch active power from the BESS
5. based on the post islanding scenario to reduce settling time while maintain stability margin.

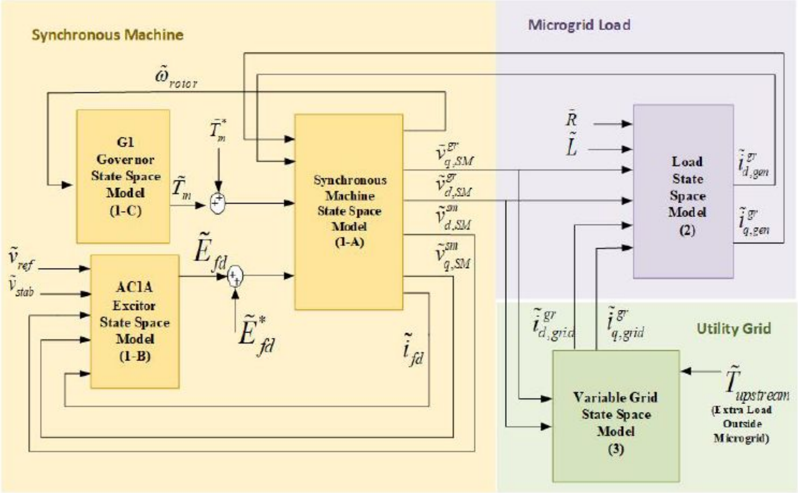
Development of the Proposed Approach

- First approach is to develop an **Aggregated Model of System**
  - Utility Model (PCC), Load Model, Aggregated Generator model
- The Upstream Grid is modeled with a dynamic model with Adjustable Parameters:
  - Utility System Equivalent Governor, Utility Inertia, Utility Damping Torque
  - Generator Model: exciter (AC1A type), governor plus turbine, and a detailed synchronous generator in the DQ reference frame





(a) Equivalent circuit representation



(b) Equivalent State Space representation

Weak Utility Model Calibration

- Real transient Data from the field oscillation
  - 59.6 Hz Underfreq and 700msec delay for disconnection
  - matching within about 80 seconds for the utility
  - frequency to settle down after the event, as well as a maximum
  - oscillation peak of about 60.3 Hz p.u.

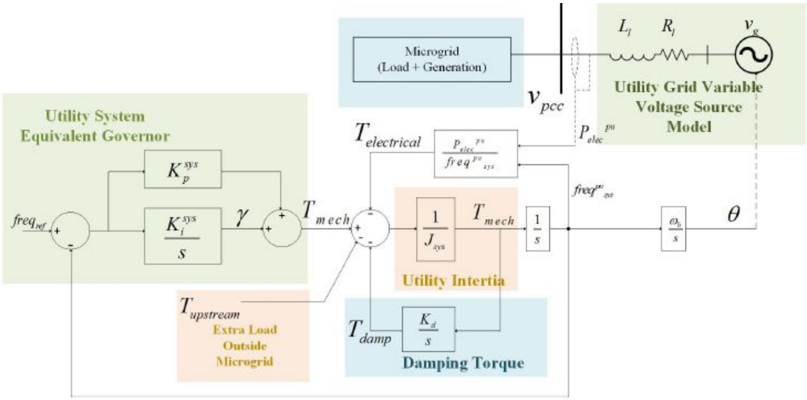
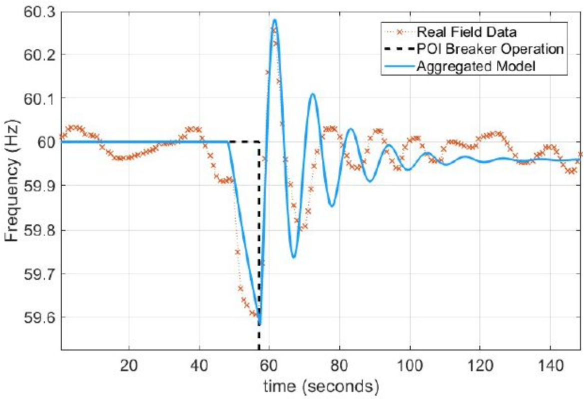
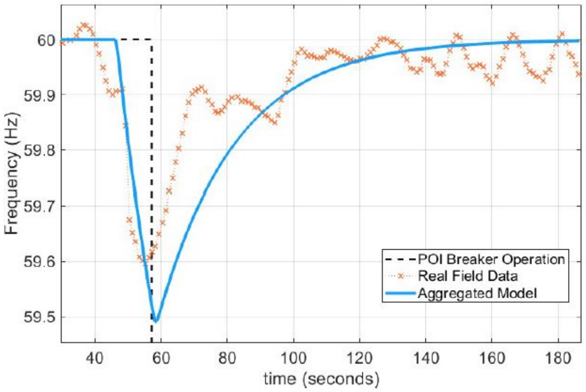


Fig. 3: Equivalent Weak Utility Model PCC representation



(a) Frequency of the Generator's rotor in the CFM



(b) Frequency of the Utility

CFM Stability Analysis (No BESS)

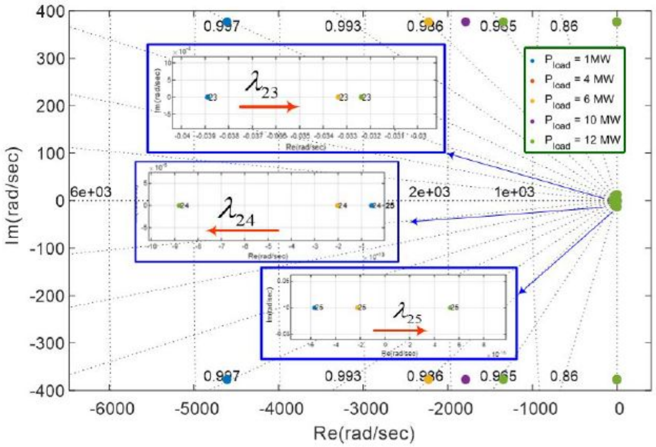


Fig. 5: Critical Eigenvalue for different CFM total aggregated load

TABLE IV: Critical Major Participation Factor States for Eigenvalues closer to instability for 12MW load in the CFM.

Eigenvalues	State	P_{ni} Magnitude
λ_{23}	21	0.839
	22	1.200
	24	0.854
λ_{24}	22	1.187
	23	1.183
	24	1.003
λ_{25}	22	1.004

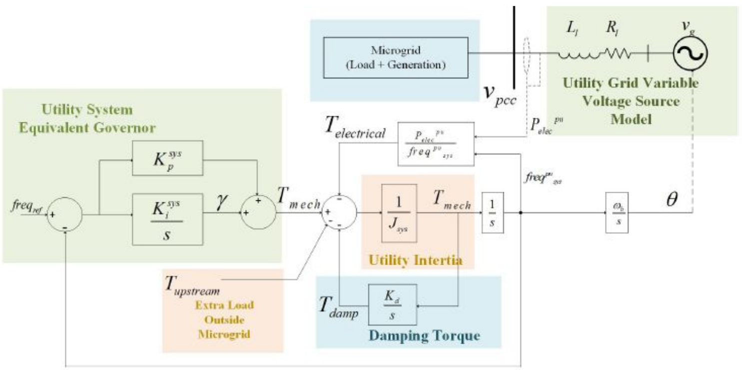
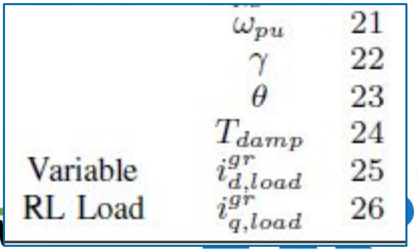


Fig. 3: Equivalent Weak Utility Model PCC representation

- SSDM of the system is obtained for the CFM and effect is analyzed for different loading conditions
- Identification of Critical Eigen Values for different variations of the Microgrid Load

Participation factor P_{ni} correspond to the equivalent utility model state variables:



	ω_{pu}	21
	γ	22
	θ	23
	T_{damp}	24
Variable RL Load	$i^{gr}_{d,load}$	25
	$i^{gr}_{q,load}$	26

ω_{pu}, γ, θ, and T_{damp}.

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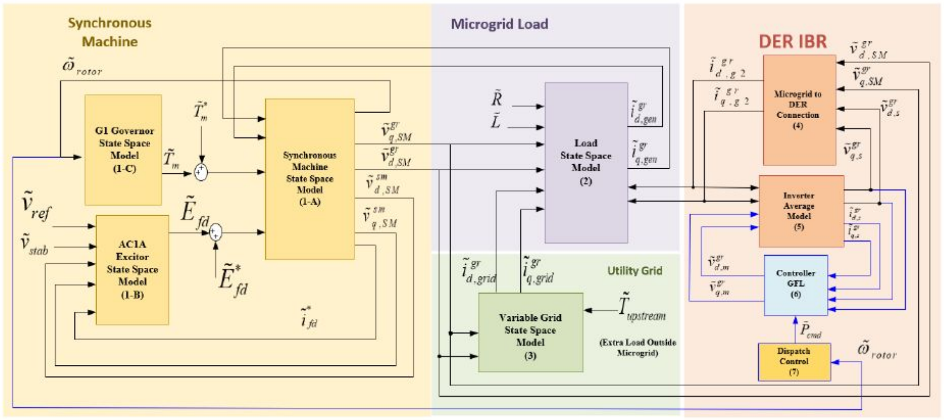
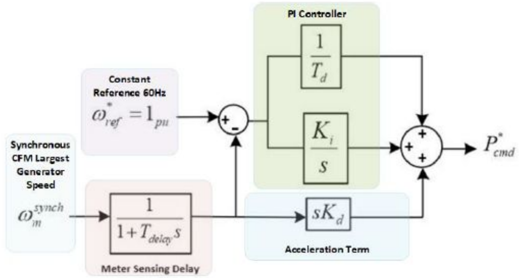
Energy Storage Inclusion in GFL Mode



(a) Equivalent State Space representation



(b) BESS Dispatch Algorithm: PI plus Acceleration Term and Frequency Measurement

- Inclusion of the BESS in the GFL Mode
  - The GFL control technology for IBRs, widely used in the industry, is adopted in this work for the BESS unit. The energy storage solution is required for:
    - 1) fast transient detection
    - 2) fast response for islanding
    - 3) coordinated controls for power management in the CFM after islanding.

- Design of the BESS Dispatch Algorithm
  - Acceleration Term (Rate of Change of Frequency)
  - Meter Sensing Delay
  - Measurement of rotational speed of the largest Generator

Large Signal Model in Islanded Condition

- Reduced Large Signal Model is completed.
- Simplified model dynamics of the inverter with a delay constant
- **Pmech and Pload** are assumed as constant values to simplify the model as the load is assumed to remain almost unchanged during the islanding process
- The governor response for the aggregated generator is slow compared to the BESS discharging

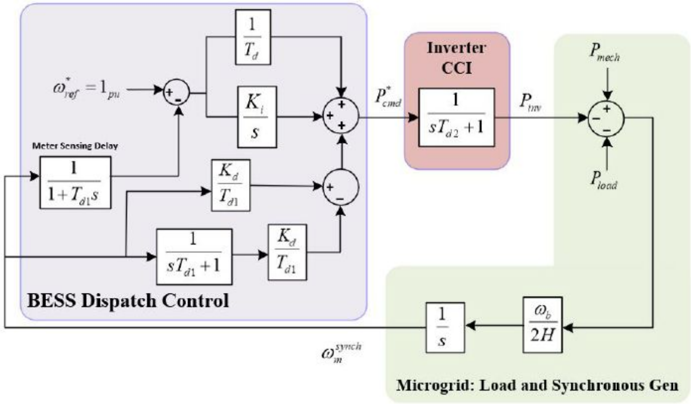
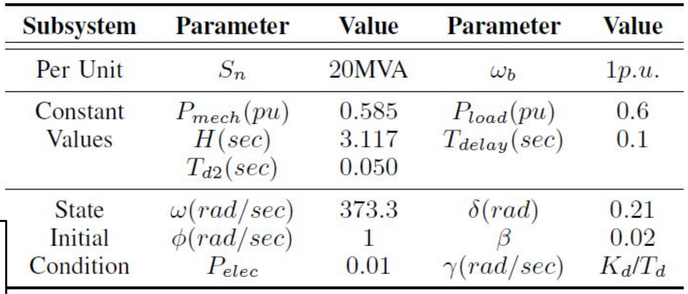


Fig. 8: CFM Large-Signal reduced model in Islanded Mode



Subsystem	Parameter	Value	Parameter	Value
Per Unit	S_n	20MVA	ω_b	$1p.u.$
Constant Values	$P_{mech}(pu)$ $H(sec)$ $T_{d2}(sec)$	0.585 3.117 0.050	$P_{load}(pu)$ $T_{delay}(sec)$	0.6 0.1
State Initial Condition	$\omega(rad/sec)$ $\phi(rad/sec)$ P_{elec}	373.3 1 0.01	$\delta(rad)$ β $\gamma(rad/sec)$	0.21 0.02 K_d/T_d

$$\frac{\omega_m^{synch}(s)}{\omega^*_{ref}(s)} = \frac{\omega_b(1 + sT_{delay})(s + T_{delay}K_i)}{(2H(sT_{d2}+1)(sT_{delay}+1)T_d - K_d\omega_b T_d)s^2 + \omega_b s + K_i\omega_b T_d}$$

Phase Portraits states behavior

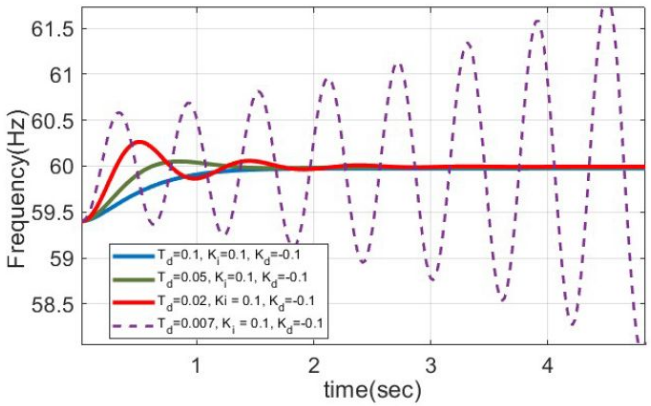


Fig. 12: CFM Frequency response after isolation from the grid. Initial Frequency 59.5 Hz

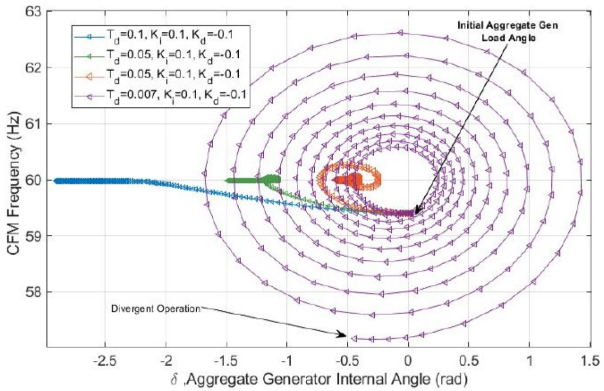


Fig. 13: Phase Portrait of CFM Frequency and internal Aggregated Generator load angle after disconnection for different controller gains

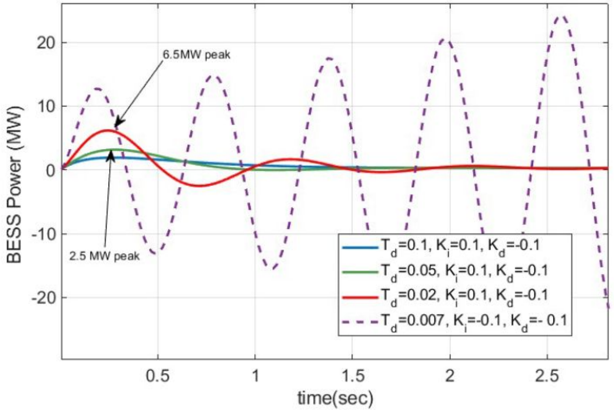


Fig. 14: Power injected to the CFM after the isolation from the grid for different control gains

PSCAD Modeling Results

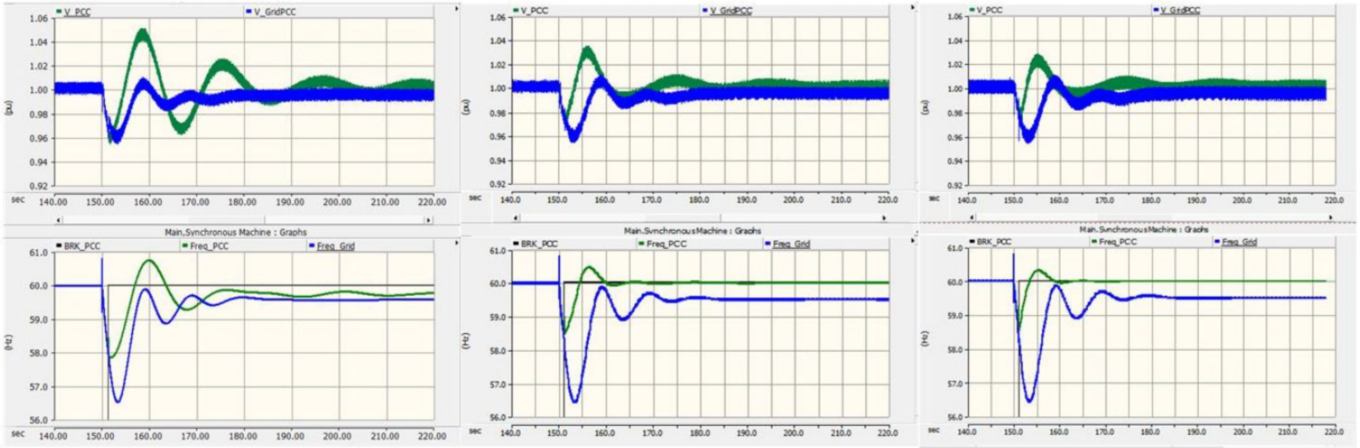


Fig. 11: Oscillation result obtained in full PSCAD detailed Model for under-frequency oscillation at 150 seconds. (Left) Results for Voltage and Frequency without BESS. (Center) Improved voltage and frequency response with BESS using $T_d = 0.05$, $K_i = 0.1$, $Kd = 0$. (Right) Improved voltage and frequency response with BESS using $T_d = 0.05$, $K_i = 0.1$, $Kd = -0.1$

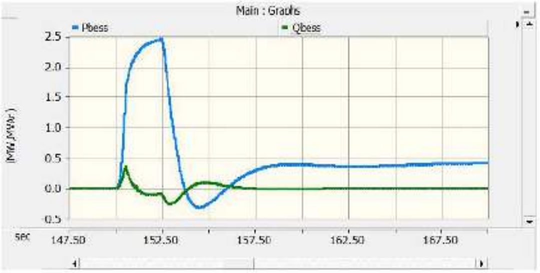


Fig. 15: Power Discharge from the BESS during the transient in PSCAD verification.

Conclusion and Discussion

- A detailed methodology to model CFM and design storage control is documented in this paper.

- It includes characterization of existing CFMs using equivalent aggregated models tuned by field collected data of frequency oscillation, addressing the inclusion

- Proper control dispatch scheme of Energy Storage to enhance the power quality response while maintaining proper stability

- The analysis and control tuning in grid connected and islanded modes includes an initial eigenvalue analysis for a linearized model and extension onto a large signal analysis to verify stability after the PCC disconnection.

Next Steps in Process

- Explore control schemes and optimization using non-linear control techniques.
- Validate the algorithm on a real-time platform using available microgrid controllers.
- Automated, online estimation of the system inertia value of utility and CFM for better performance in different operational scenarios
- Consideration of GFR Modes in the application

This material is based upon work supported by ERDC-CERL through Contract No W9132T-20-C-0002. The opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of ERDC-CERL.

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