Evaluation of Island Frequency Control via Chronological Production Simulations

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Alternate Presentation Title:

"How I justified my December trip to the Tropics"

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Background

- Island/isolated power systems can pose interesting engineering challenges
- Attributes of variable renewable generation can be "frightening" with respect to isolated power system operation
- Control of power system frequency is primary operational objective for reliability
- Frequency control performance can vary substantially depending on size, types of units, control sophistication, etc.
- Significant variable renewables will always increase this specific challenge

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Power System Frequency Control

- Frequency is key metric of system stability
- Isolated systems vs. Interconnected systems
  - Laws of physics are identical for both
  - Scale is the key differentiator – amount of load, number of generating units, geographical diversity, etc.
  - With isolated systems, focus is always on the “whole”
  - Single portion of an interconnection (e.g. operating company, RTO, wholesale energy market) must “support” frequency, but cannot necessarily “control” it

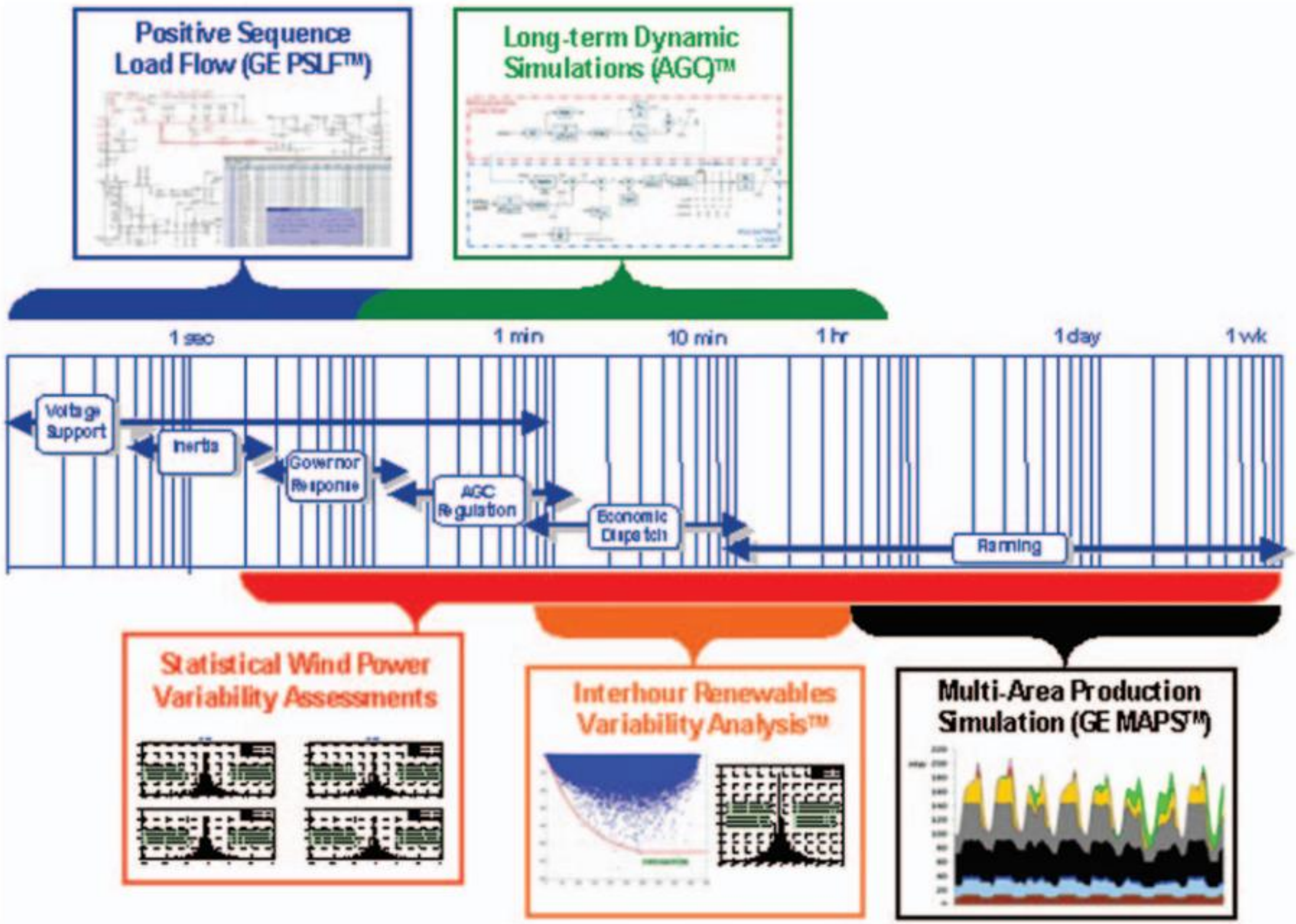
Small System Frequency Control

- Generation/load mismatch translates (much more) directly to frequency deviations
- Normal frequency bounds will likely increase as system size decreases
  - Smaller load, less diversity, larger per-unit deviations
  - Fewer units for control
- Large amounts of variable renewable energy can substantially increase the frequency control challenge
- Question: How can impacts of variable renewable energy on small power system frequency control be assessed?

Integration Study Tools and Techniques

- Chronological production simulation is primary tool
  - Mimics power system operator actions – unit commitment and economic dispatch
  - With hourly time steps, all within-hour activities represented as constraints
  - Higher temporal resolutions (e.g. 5 minutes) allow direct simulation of flexible capacity dispatch
  - Long-term (e.g. annual) simulations are needed to capture economics
- Time frames in production simulations do not get directly at frequency control issues
- Other tools needed for detailed assessment

Comprehensive Methodology used by GE for Hawaiian Island Studies



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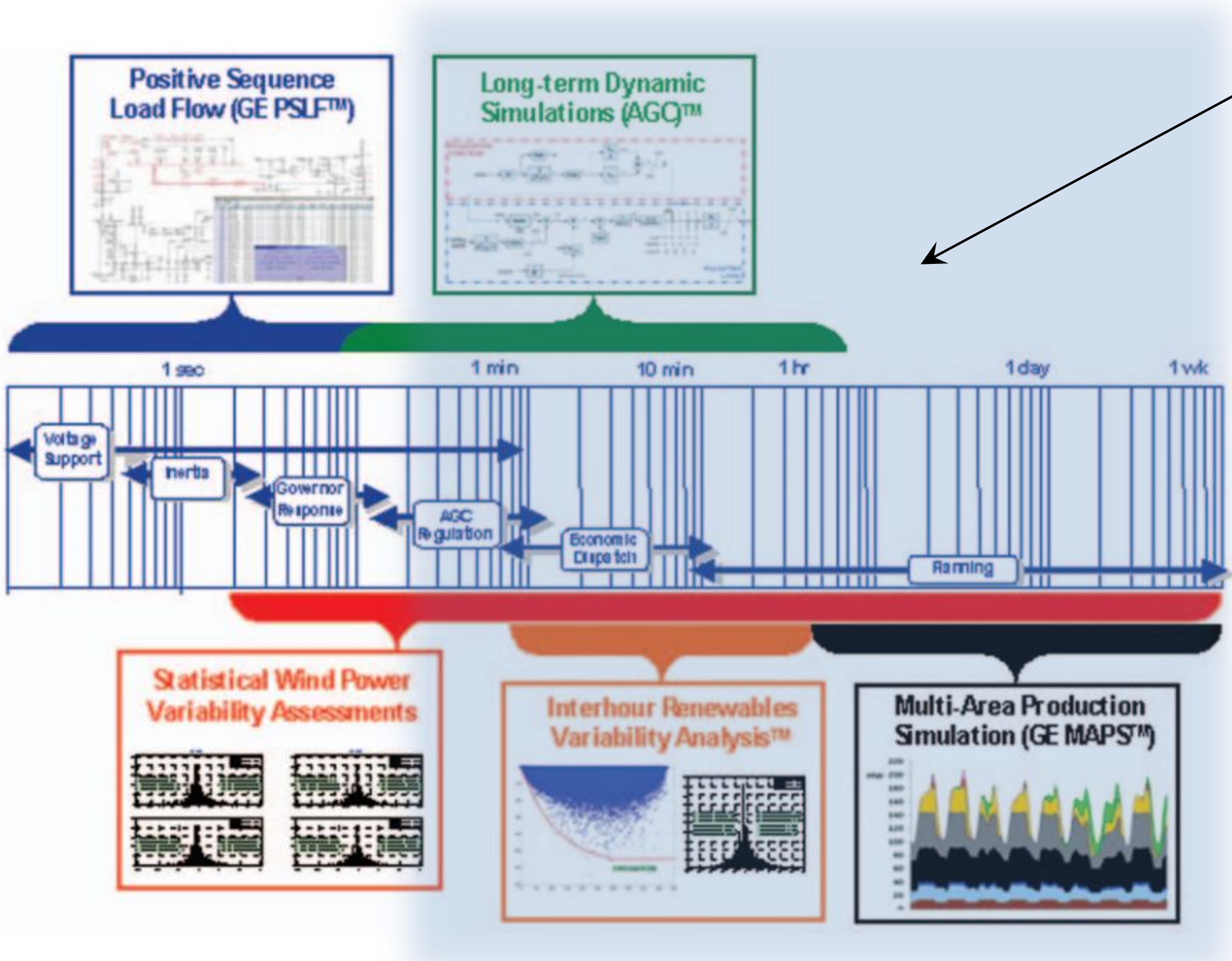
Concept:
Augment production simulation tool to allow more direct examination of isolated system frequency control strategies and performance



Integrated Evaluation:

- Stable frequency control
- Reserve adequacy
- Economics associated with different strategies
- Cost of frequency control

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PSO Prototype Enhancements

- Addition of a UR ("Unit Response") library that allows simulation of
  - Stable frequencies achieved after disturbances
  - AGC signals and deployment of regulation reserves
  - ACE and impact of lagging AGC response
  - Generator primary and secondary responses
  - Reliability metrics (CPS1, BAAL violations)
- Can be used to evaluate impacts from future system conditions and policies including
  - Resource mix needed to ensure availability of sufficient response capacity
  - Maintenance scheduling and unit commitment impacts on dynamic availability of response
  - Procurement of regulating reserve and influence on frequency
  - AGC tuning needed to ensure appropriate restoration of nominal frequency
  - System conditions that need transient, stability or protection analysis

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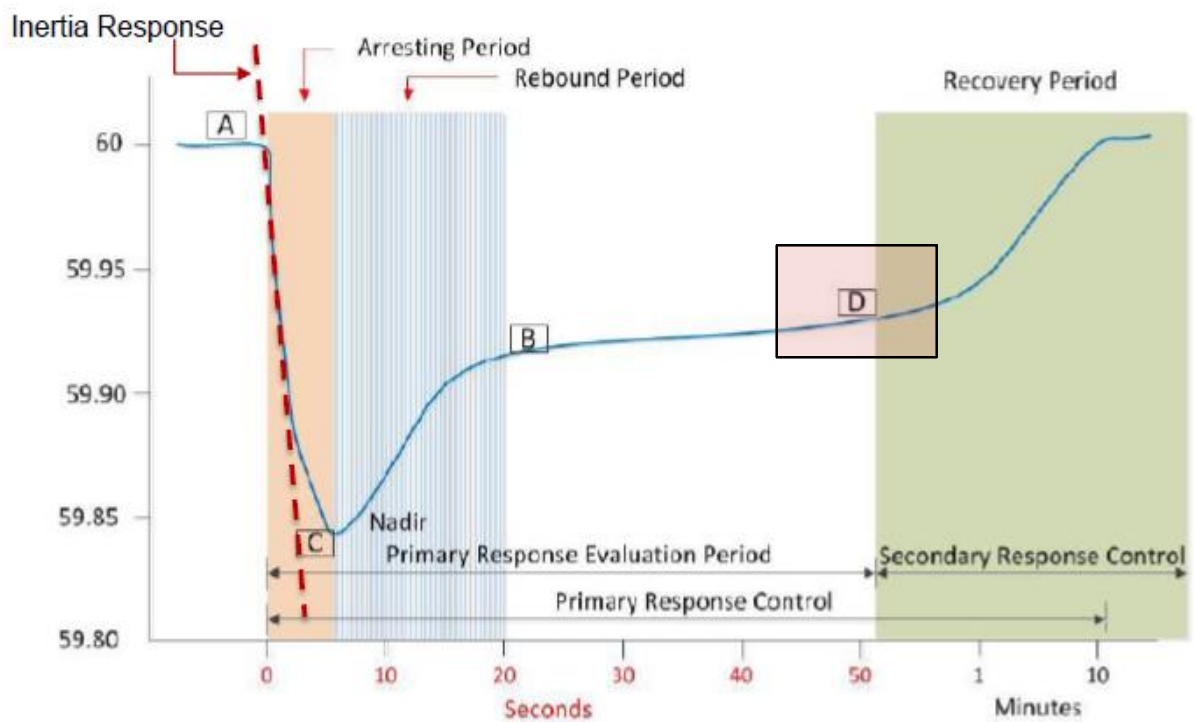
Primary vs. Secondary Frequency Response

- Inertial response and PFR not directly considered
- Objective is to estimate Point “D” on chart from governor droop characteristics
- Secondary response is simulated directly
- Some details
  - Governor deadbands
  - Autonomous response may be invoked without major “disruption”
  - Secondary response controlled by AGC



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Calculating System Frequency

<u>Definitions</u>

The following equations relate data values used to calculate AGC:

	ACE	$= NI_A - NI_S - 10 * B * X$
	FT	$= 3 * FB$
	BAAL	$= -10 * B * (FT^2 / X)$

Where	ACE	Area Control Error: (+) excess export, (-) excess import (MW)
	NI_A	Actual Net Interchange, (+) export, (-) import (MW)
	NI_S	Scheduled Net Interchange (MW)
	B	Frequency Bias of balancing authority (MW / 0.1 Hz), negative value
	X	Frequency deviation (Actual Frequency – Target Frequency) (Hz)
	FB	Targeted Frequency Bound of interconnection (deviation from target) (Hz)
	FT	Frequency Trigger of interconnection (deviation from target) (Hz)
	BAAL	Balancing Authority AGC Limits (MW)

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PSO Implementation

- Libraries that allow definition of generator and area autonomous response to frequency deviations
- AGC libraries specify closed loop control of units dispatched in the last model cycle

6.1.1.1 INJECTOR AUTONOMOUS PRIMARY RESPONSE (INJ_APR)

Record	*Type*	*Description*
Injector	char	{ injectors }
R	float	Per-unit change in frequency divided by per-unit change in power output
Deadband	float	(Hz) Identifies sufficiently-large deviation from nominal frequency

6.1.1.3 AREA AUTONOMOUS PRIMARY RESPONSE (ARA_APR)

Record	*Type*	*Description*
Area	char	{ areas }
D	float	Per-unit change in area load divided by per-unit change in frequency

6.1.2.1 AREA AGC (ARA_AGC)

Record	*Type*	*Description*
Area	char	{ areas } Balancing area
B	float	(MW/0.1Hz) Balancing area frequency bias
NCB	float	(MW) Normal control band
KI	float	(MW/MWh) Integral impact of accumulated ACE on AGC
KP	float	(MW/MW) Proportional impact of current ACE on AGC
KE	float	(MW/MWh) Emergency impact of current BAAL violation on AGC

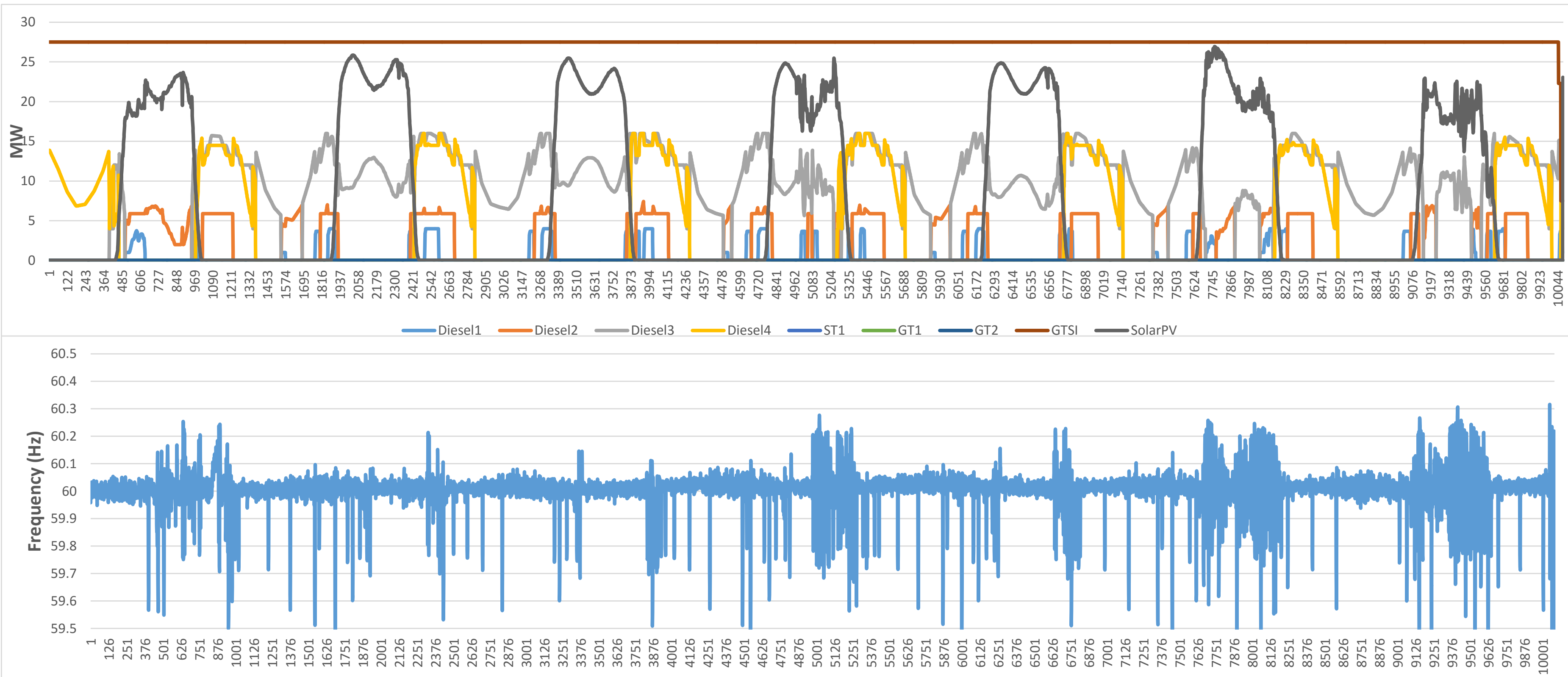
6.1.2.2 INJECTOR AGC (INJ_AGC)

Record	*Type*	*Description*
Injector	char	{ injectors }
Factor	char	Participation Factor

Illustration

- Generic island power system – “Bob’s Island”
  - ~80 MW peak load
  - Conventional generators
    - Baseload steam-injected base load unit
    - Several diesels of various sizes
    - More expensive gas turbines
  - Approximately 27 MW of solar; 3 separate projects
- Three overlapping, rolling decision cycles
  - 15 minutes ahead
  - Economic dispatch at 5 minute intervals
  - AGC cycle at 1 minute time step (deploy frequency control reserves based on output of AGC)
- Assess how PV affects frequency control

Commitment & Dispatch for 7 Days



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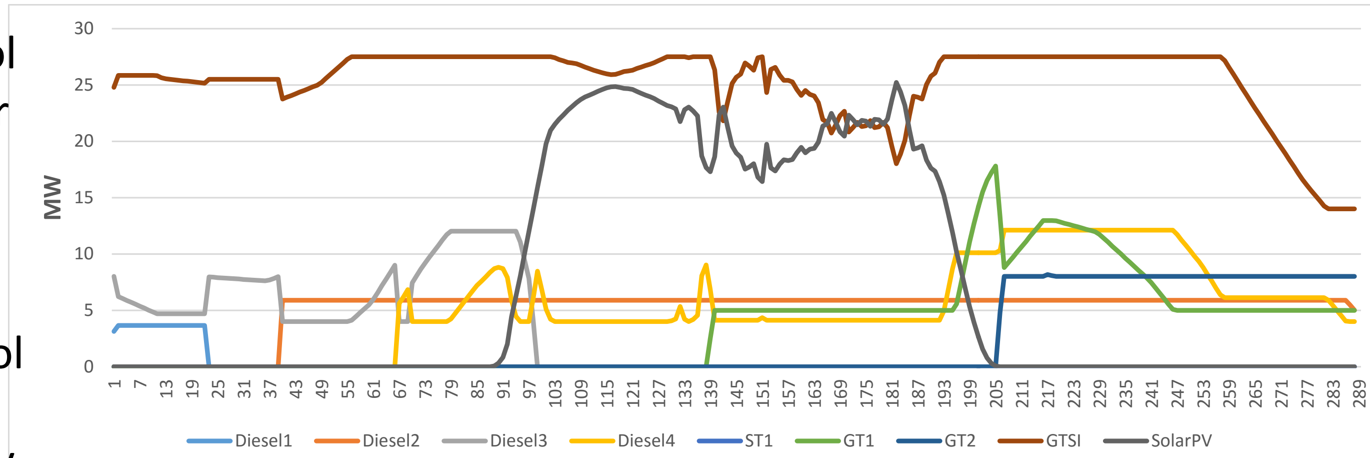
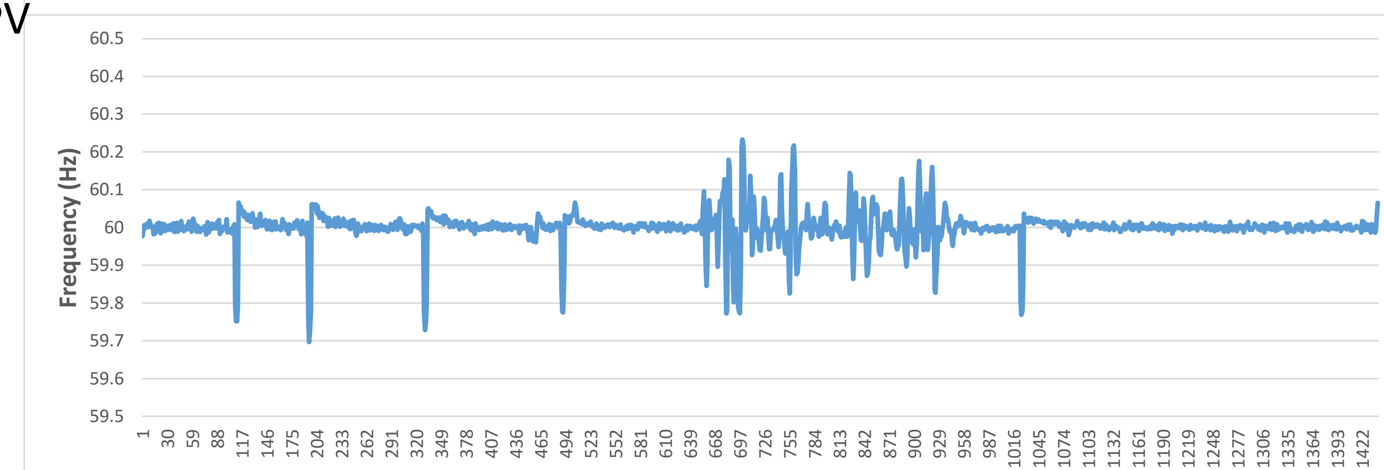
Better view of Day 4

- Without PV, frequency control is tight except for instants when generators are shut down
- Frequency control is much poorer under variable PV generation conditions





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Applications

- Small Isolated Systems – assessing frequency control strategies, performance, *and* costs
  - Islands
  - Hybrid power systems
  - Micro-grids
- Large Interconnections – evaluating secondary frequency control for avoiding BAAL violations
  - When interconnection frequency is near scheduled value, allowable ACE (Balancing Authority ACE Limit) is very large
  - As frequency error increases, BAAL decreases
  - When outside of these limits, operators must get back in bounds within 30 minutes
  - Because a single BAAL violation can carry significant financial penalties, current operation practice appears to be maintaining very tight control limits at all times

Issues & Questions

- Validation
- Parameter derivation
- High temporal dataset construction
- Necessary model time step?

Thanks!

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