Hawai'i Island Planning and Operations MEASURES TO IMPROVE RELIABILITY WITH HIGH DER

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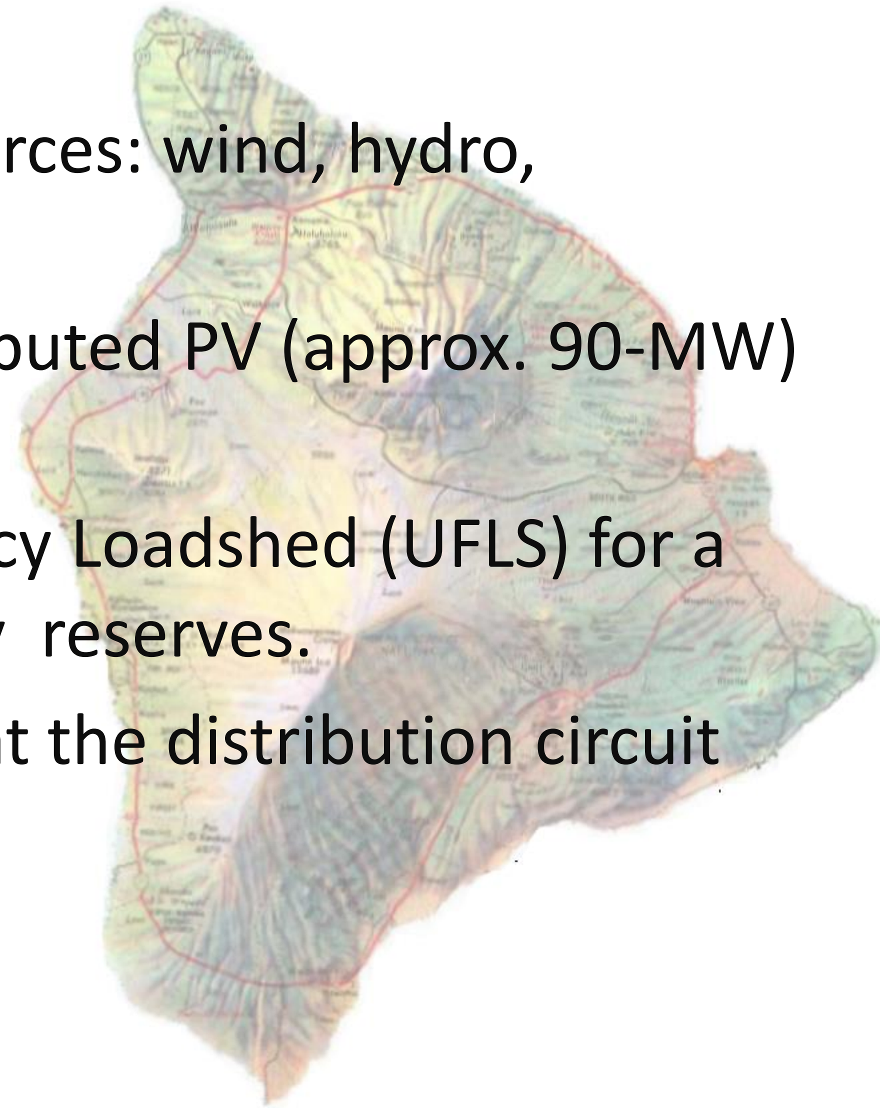
Hawai'i Electric Light System Overview



– No interconnections
– Renewable energy sources: wind, hydro, geothermal, and solar
– Large amount of distributed PV (approx. 90-MW) and increasing
– Rely on Underfrequency Loadshed (UFLS) for a portion of contingency reserves.
– UFLS is implemented at the distribution circuit level

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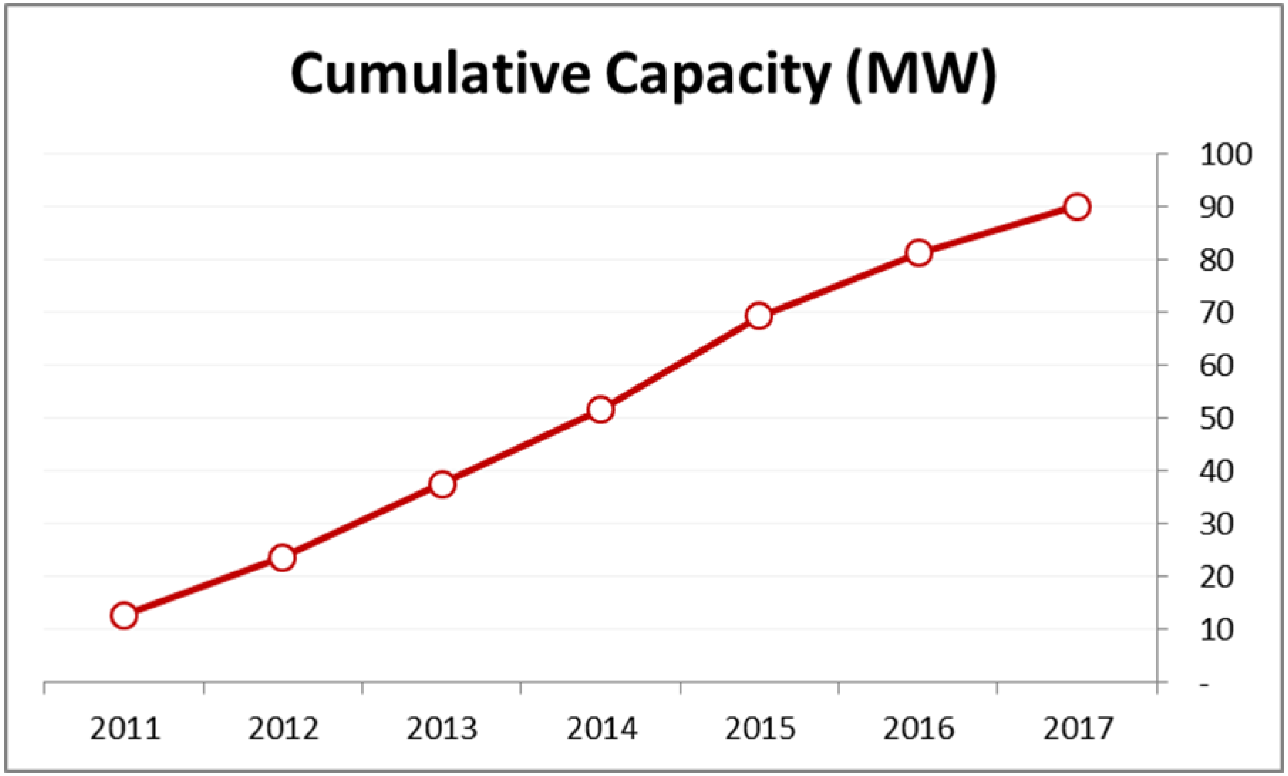
Hawaii Island Distributed Solar

- Distributed solar (DG-PV) (over 90-MW) twice as large as any single generating plant.
- Other generation provides all the balancing
- No direct monitoring, no control



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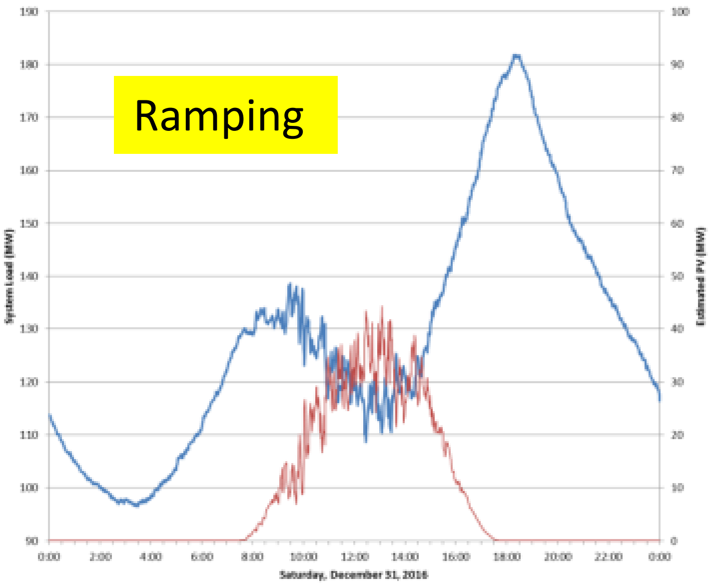
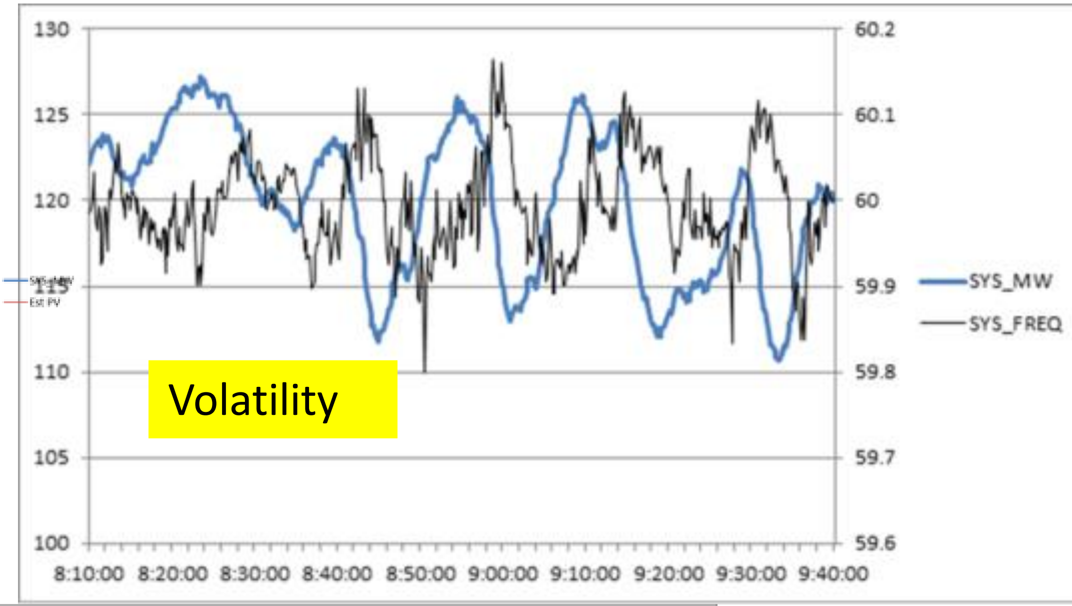
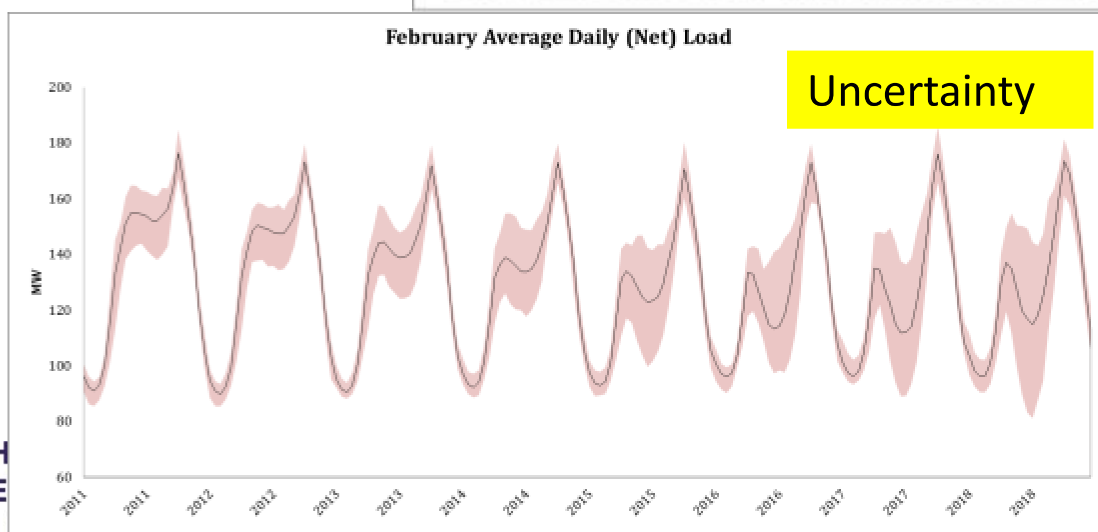
Increased DER Variability







Activities to Improve System Reliability

- DER interconnection requirements for bulk system reliability
  - Monitoring, Control, Disturbance ride-through
  - Older (legacy) systems installed earlier do not have these capabilities
- Adaptive under-frequency load-shed
- Fast responding contingency reserve to mitigate legacy DER (mostly PV) trip

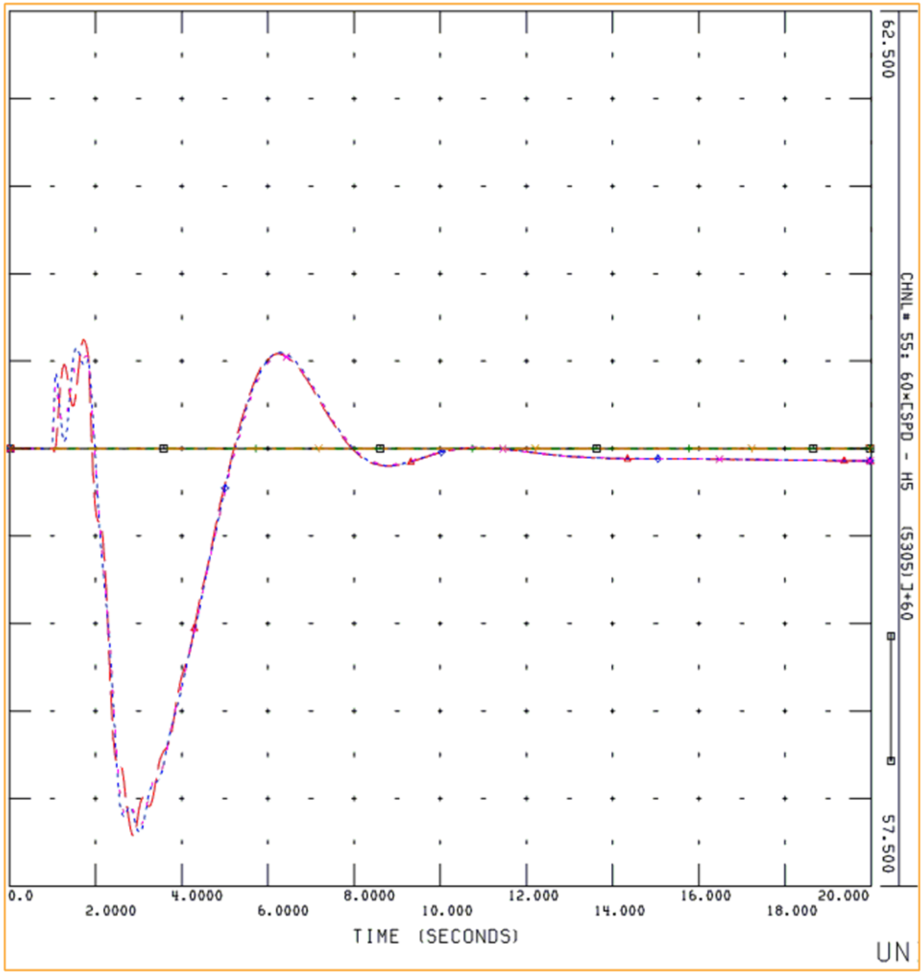
Under frequency Load-shed Planning Studies

- 2014: initial study to determine impacts of DER (mostly solar PV) on the under frequency scheme
  - Risks:
    - Aggregate loss of DER at legacy settings: 59.3 Hz, 60.5 Hz, and high/low voltage
    - Biggest risk is 60.5 he
  - Interim static scheme implemented to reduce potential over-shed, possibly reaching 60.5 Hz.
  - Identified the need for adaptive or dynamic assignment of circuits to UFLS for higher DG-PV levels due to variation in circuit
- 2015: Adaptive Study for DUFLS design.

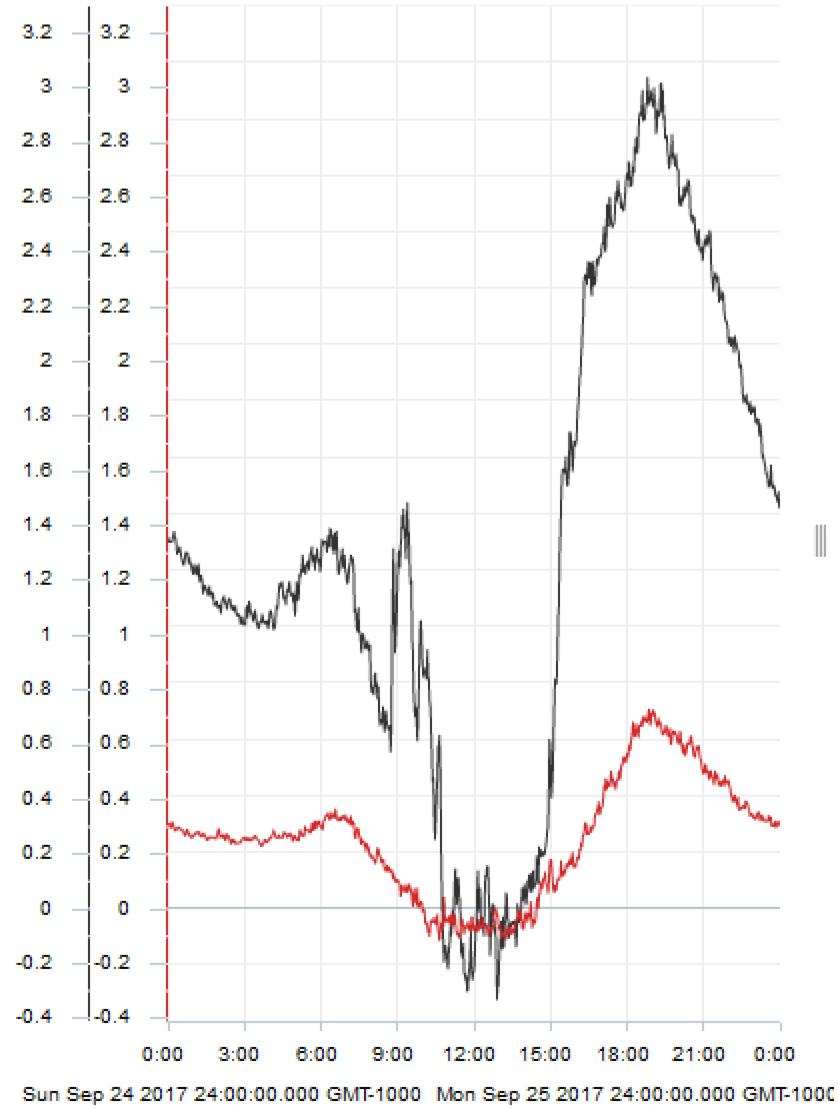
2015 Adaptive Under frequency Study Results

- Problem 1: Target load shed and circuit contribution varies throughout day
  - Calculate right amount of under frequency load shed for present net load and circuit load telemetry measurement to avoid both Over- and Under-Shedding.
  - Energy Management System (EMS) custom application to automatically assign UFLS Stages (trip settings) to the distribution circuit relays, based on System load and circuit load telemetry every 15-minutes.
- Problem 2: Need faster detection that load shed is required.
  - Recommended triggering load-shed on fast rate of change of frequency
- Periodic review recommended (annual or biannual)

DER Impacts: Require Adaptive Scheme



60.5 Hz DG PV trip (Simulation)



Daytime Exporting Circuits

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Adaptive UFLS Design

- Stage 1 and stage 2 should sum to 15% of the system net load
  - maximum allowed load shedding for N-1 unit trips.
- Stage 1 through stage 4 should sum to 40% of the system net load which is the maximum allowed load shedding for N-1-1 unit contingencies
- Adjust the stages of UFLS to reflect a percentage of net system load on each stage.
  - Df/dt – 15%, 0.5 Hz/sec, 9 cycle relay plus breaker time (not currently active)
  - Stage 1 – 5%, 59.1 Hz, 8 cycle relay plus breaker time
  - Stage 2 – 10%, 58.8 Hz, 8 cycle relay plus breaker time
  - Stage 3 – 10%, 58.5 Hz, 8 cycle relay plus breaker time
  - Stage 4 – 15%, 58.2 Hz, 8 cycle relay plus breaker time
  - Stage 5 – 10%, 57.9 Hz, 8 cycle relay plus breaker time
  - Stage 6 – 20%, 57.6 Hz, 8 cycle relay plus breaker time
- Retain most recent UFLS settings in the event of SCADA/EMS communication failure until communications are restored.

Adaptive Scheme Implementation Scope

- 41 substations, required relay upgrades, RTAC installation
  - 109/138 = 78% circuits on UFLS
  - 70% peak load
- EMS custom application to assign circuits to UFLS Blocks, issue settings
- Monitor events to determine effectiveness of new UFLS scheme.
- Implemented late 2017.

Considerations Added to Initial Scope

- Circuit rotation
- "Hot line tag" status considered
- 2017 study update identified requirement to turn ROCOF (Rate of Change of Frequency) on/off
  - (due to reduced legacy DER)

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EMS Application Function

- Monitors System load, and circuit loads, limited hold-offs, and number of UFLS operations.
- Calculates target MW for each stage
- Assigns circuits to UFLS stages to achieve MW targets
- Displays circuits by UFLS stage groups.
- Some alarms include:
  - assigned loading ≠ target load
  - Feedback stage ≠ Assigned stage

Inputs to the application

- Each circuit is assigned a Priority (PRI):
  - 1 – Normal circuit, no restrictions.
  - 2 – Restricted circuit, avoid tripping if possible
  - 3 – Highly restricted circuit, last resort
  - 4 – Not participating, do not trip.
- Limited Hold-offs applied using a Hot Line Tag will add a small restriction.
- Circuits that operate frequently (FreqOp) due to UFLS will add a small restriction.

Participation Factor

- UFLS circuits are assigned to blocks based on a participation factor (PART) of 1 through 9.
- Kicker Stage assignments utilizes a similar algorithm, but the “Eligible” circuits are taken from the normal stages (typically Stage 3 or 4).

Cust Priority		Participation
1	Always participates	1
		2
		3
2	Restricted	4
		5
		6
3	Last Resort	7
		8
		9
4	Does not participate	10

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Summary Display

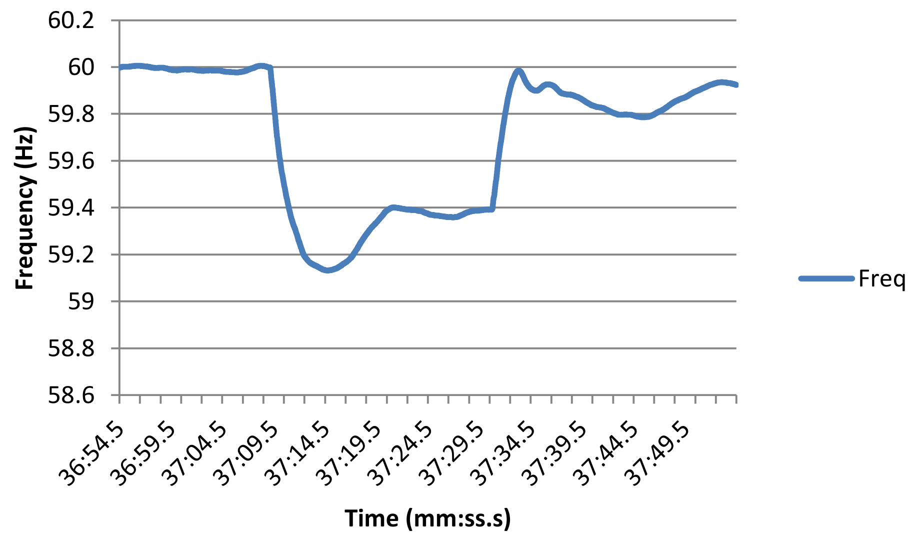
UFLS STAGE DATA

System Load:	141.853
Total Target:	112.185
Total Available:	114.292

Stage	Frequency	Percent	Target MW	Avail MW	Tol %	Tolerance	Delta MW
STAGE1	59.100	5.00	7.01154	6.82032	5.000	0.351	0.191
STAGE2	58.800	10.00	14.02308	13.83560	5.000	0.701	0.187
STAGE3	58.500	10.00	14.02308	13.34422	5.000	0.701	0.679
STAGE4	58.200	15.00	21.03462	22.24468	8.000	1.683	-1.210
STAGE5	57.900	10.00	14.02308	14.21575	8.000	1.122	-0.193
STAGE6	57.600	20.00	28.04617	25.46988	25.000	7.012	2.576
KICKER1	59.500	5.00	7.01154	6.79824	8.000	0.561	0.213
KICKER2	59.300	5.00	7.01154	6.54598	8.000	0.561	0.466

Dynamic Underfrequency Loadshed (DUFLS) - Events

- 5 events occurred following the loss of a geothermal plant to the grid due to lava impacts
- 1st event occurred on June 14, 2018 after months of anticipation. A steam plant tripped offline, and the 2nd kicker stage operated. It had a 59.5 Hz trip setting with 20-second time delay.



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Dynamic Underfrequency Loadshed (DUFLS) - Events

- 2nd event was due to the loss of a combustion turbine that resulted in the 1st stage of UFLS to operate.
- 3rd, 4th and 5th events were cascading generation losses, resulted in multiple stages of UFLS to operate
- The scheme has performed well for single and multiple loss of gen, in each case System stabilized.

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Contingency Reserve Battery Energy Storage System (BESS)

- For the small island system of Hawaii Island, over-frequency 60.5 Hz can occur for various scenarios
- Aggregate loss of legacy DER at 60.5 Hz is largest contingency, large losses for voltage excursions also possible
- Driver for need tor large, fast responding contingency storage

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Overview

- Storage (BESS) or Diesel Rotary Uninterruptable Power Supply (DRUPS) for Fast Contingency Reserves
  - Loss of legacy DER will result in widespread customer outages and high risk of system failure
  - Legacy DER not able to convert to full ride-through
- The following are the specific triggers:
  - Voltage excursions for transmission faults
  - Frequency excursions during faults, load trips, and unit trips
- Series of studies examined risks and solutions

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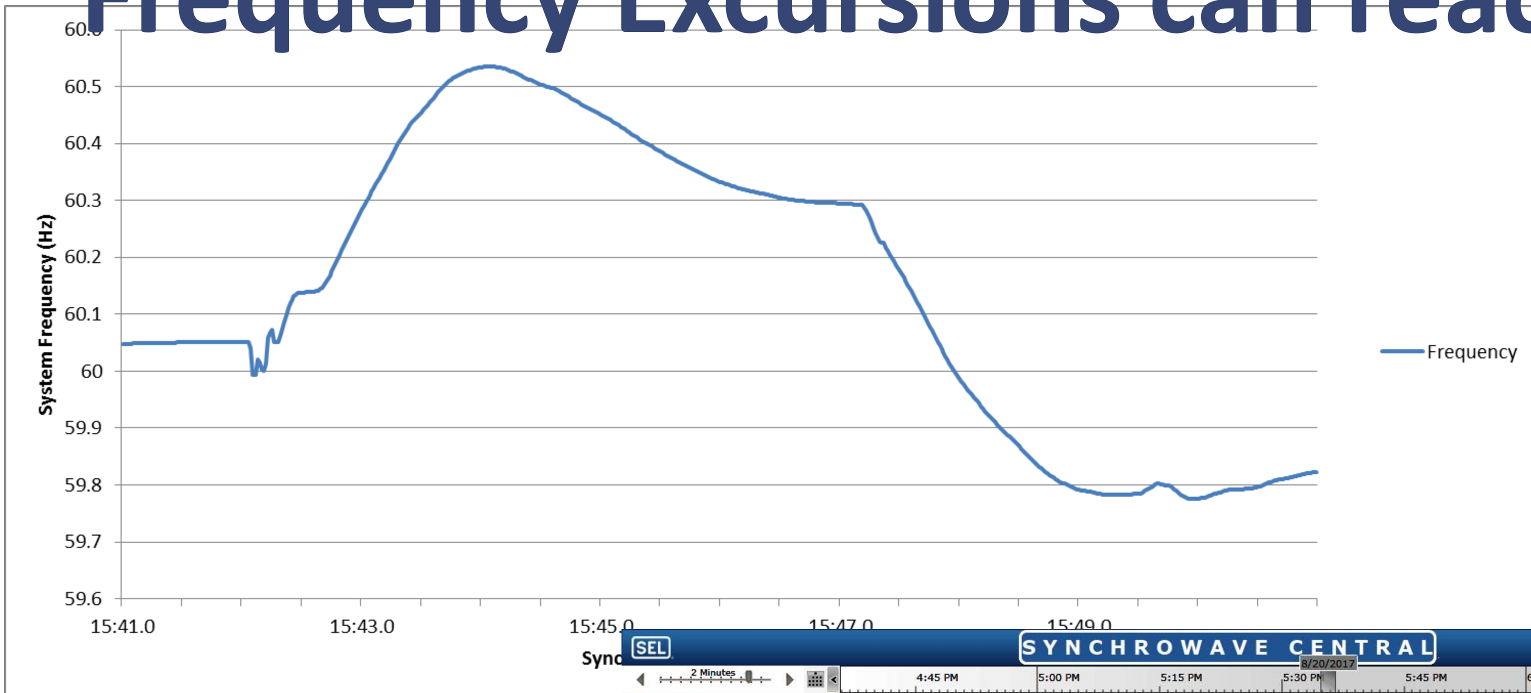
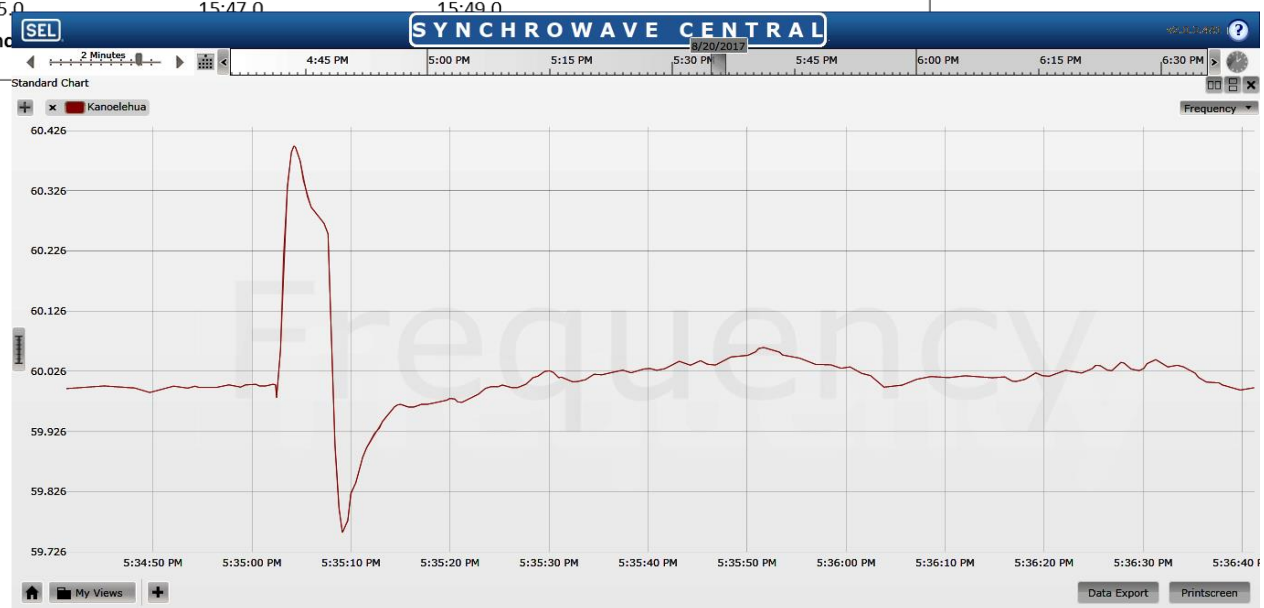
Frequency Excursions can reach 60.5





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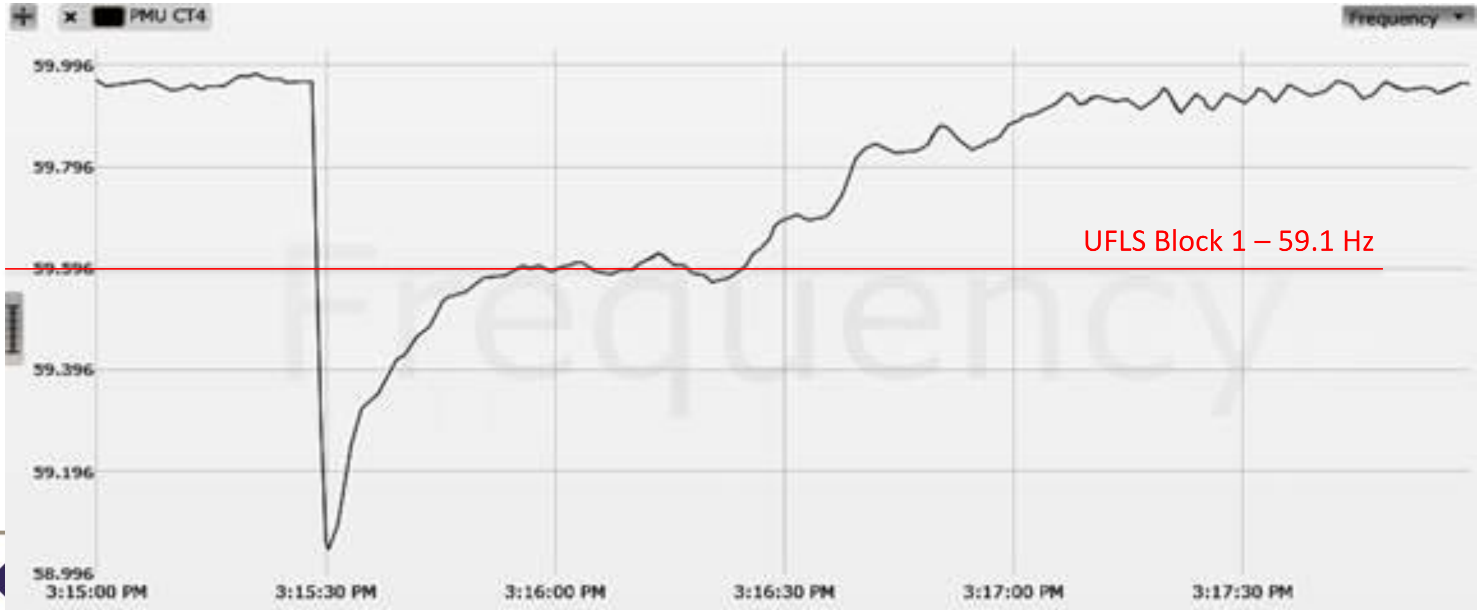
DER Adding to Contingencies Today

- One example: Nov 6, 2018 a unit tripped at 11.9 MW. Under-frequency load shedding (UFLS) Stage 1 operated despite 12 MW of spinning reserve at the time.
- Legacy DER loss due to voltage and frequency excursion exacerbates impact



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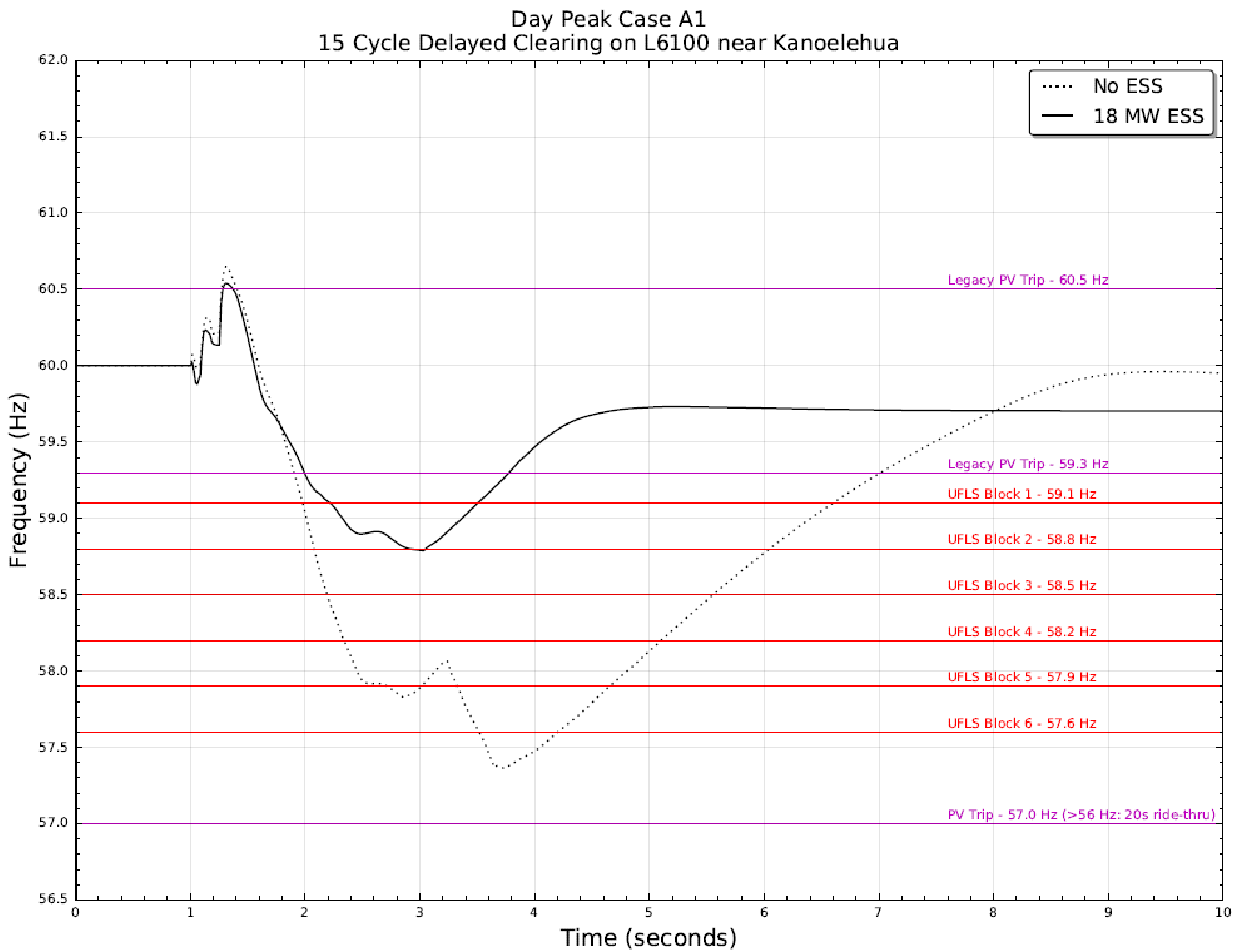
BESS Sizing Study Scenarios

- Study analysis considered various future scenarios
  - Geothermal plant online/offline
  - Line reconfiguration for lava impacts
  - Planned new resource additions (less responsive than displaced resources)
  - Updated Legacy DG-PV Capacities based on supplier data and reports, engineering records
  - New Under-frequency adaptive scheme
  - Updated modeling of DER dynamics

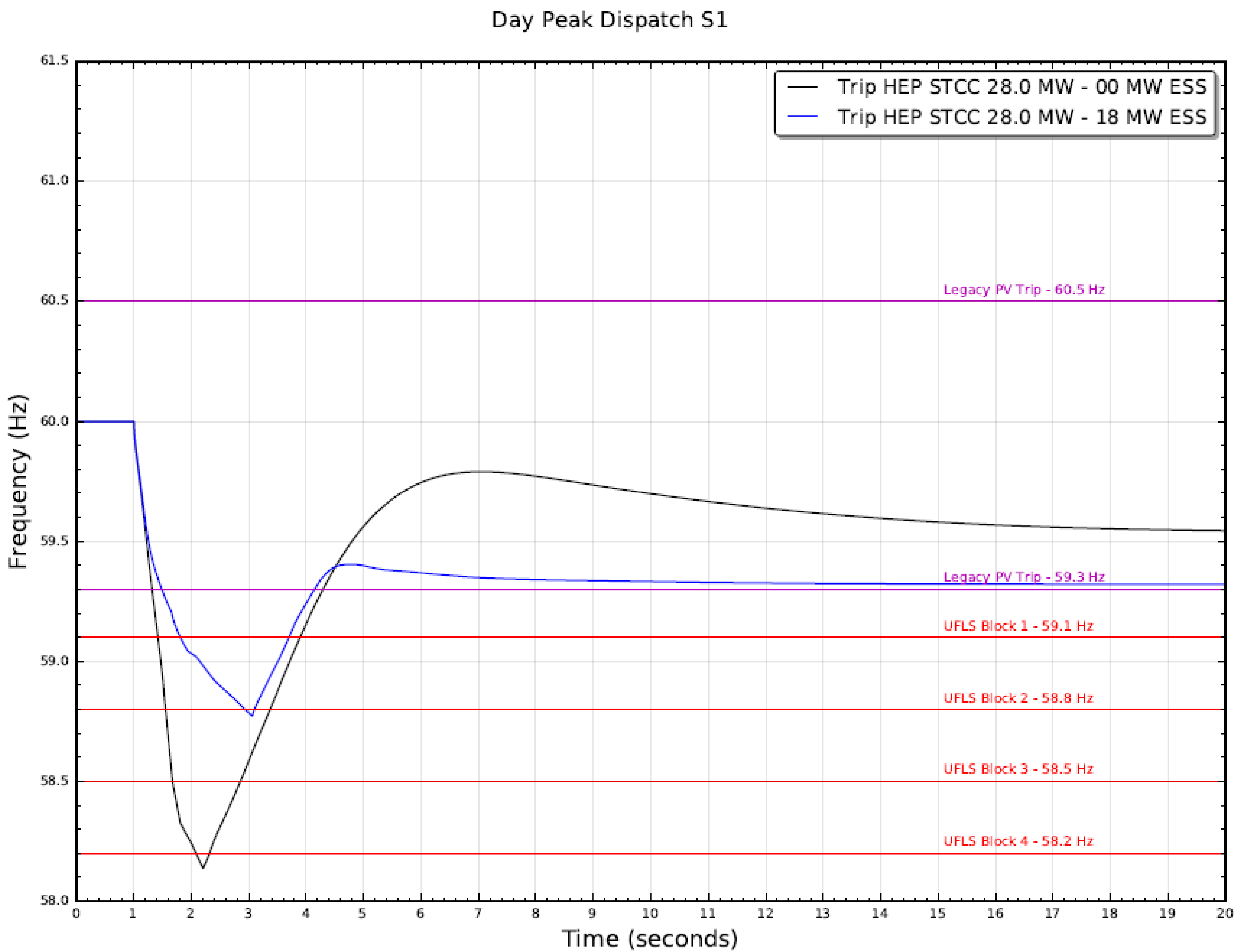
Storage Assumptions and Study Recommendation

- 0.1 Hz deadband with 1% droop
- Sized for planning criteria:
  - No more than 2 stages of load shedding (15% net load) for unit trip contingencies
  - System survives secondary fault-clearing
    - Without storage, numerous cases were unstable
- Size was driven by unit trips and secondary fault clearing scenarios

Study Example : Avoid failure from delayed clearing of a fault on 6100 Line near Kanoelehua



Example : Avoid large outage for Unit Trip



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Contingency Storage (BESS) Project

- 18 MW/18 MWh BESS Fast Contingency Response
  - Reduce excessive customer outages and possible system failure; caused by high penetration DER
  - Size reflects current configuration, resource plans, and legacy DER amounts
    - 18 MW capacity
    - 30 minute duration to bring standby generation online
    - Propose increased duration to allow more flexibility to respond to over-frequency (1 hour)
- Integrate with SCADA/EMS system
- Proposing two locations geographically separated

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Alternatives Analysis for Energy Storage

- Retrofit all PV with full-ride through settings
  - Estimated cost to retrofit inverters to full ride-through exceeded cost of storage
- Increase number of online generators, limiting output on certain generators, and increasing online spinning reserves
  - Was somewhat helpful for n-1
  - Would not reduce size of battery required for secondary fault clearing
  - Conventional plants would displace variable RE
  - Would hasten need to control DG-PV for excess energy
- Pumped Storage Hydro (PSH)
  - PSH would take much longer to implement, limited potential sites, significant environmental impact

Alternatives in order of effectiveness

1. Most effective: all DG retrofitted to full ride-through
2. Fast responding storage second most effective.
3. T&D and Protection improvements do not eliminate storage for unit trips. However, reduction in clearing time is needed to address possible system failure (in addition to storage).
4. Increasing gen reserves would reduce the size of battery required for unit trips, but does not eliminate need for storage. Cost increases for gen.
1. Do nothing: allow system risk and reliability impacts, no cost increase.

PV Concerns				Mitigation Steps				
	Type	MW	Setting	Retrofit PV	Additional Regulation	Improve Protection	Transmission Upgd	Energy Storage
Efficacy	U/F	12	59.3 Hz	High	Medium	Low	Low	High
		>50	57.0 Hz	Medium	Medium	Low	Low	High
	O/F	>50	60.5 Hz	High	Medium	High	Low	Medium
	U/V	>50	0.5, 10cyc	High	Low	High	Low	Low
		0	0.5, 30cyc	N/A	Low	Low	Low	Low

Demand Response Potential

- Does DR offer alternatives with Storage?
  - Initial evaluation does identify a small amount of fast-responding DR
  - Conclusion: impact would be very limited impact on sizing (if any)

Other work in progress/completed

- Breaker Failure
- Replacing 5 cycle oil breakers
- Reducing secondary clearing time
- Dual communication for POTT schemes
- Dynamic UFLS – in service 12/2017

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