

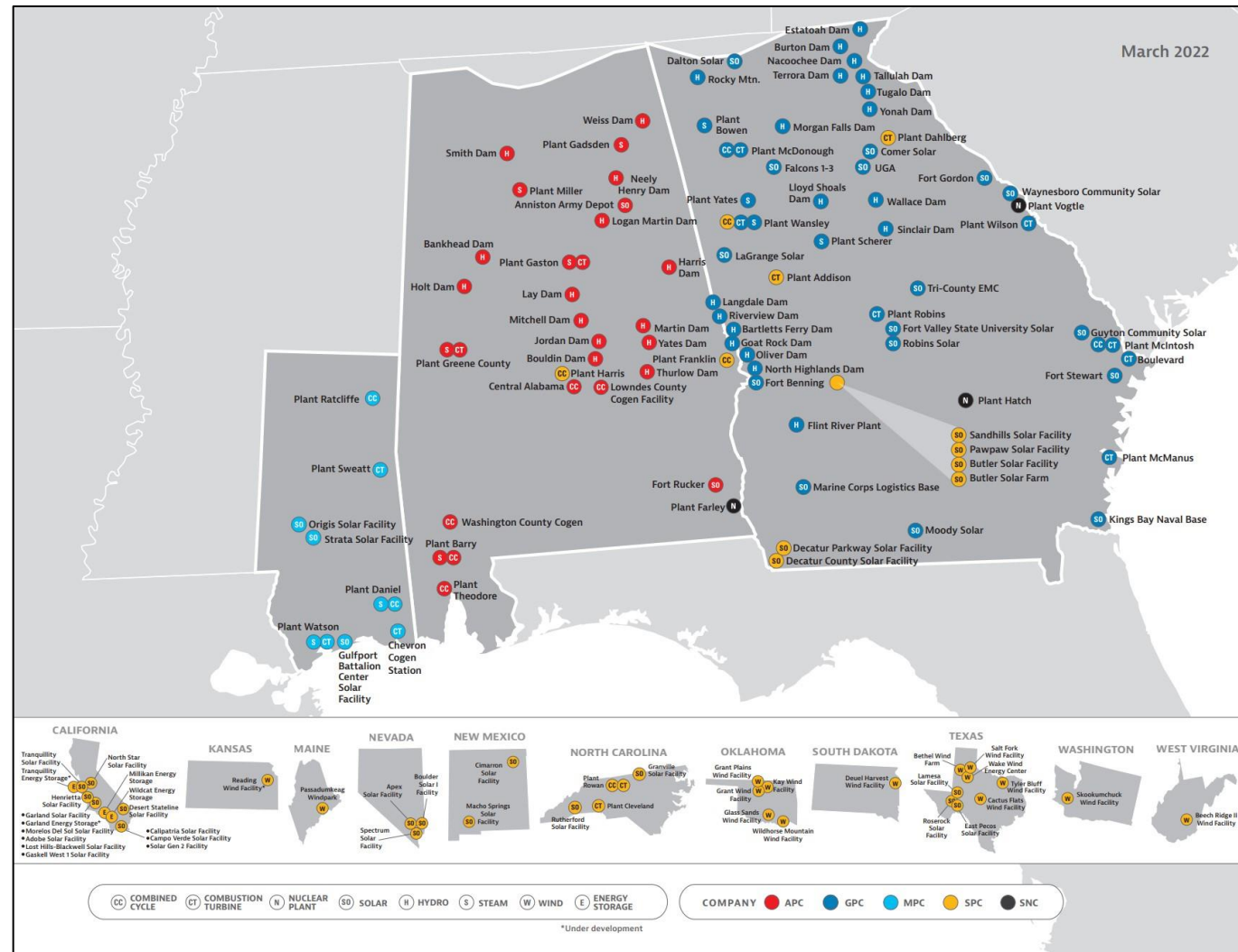
Probabilistic Methods in Operations

Will Hobbs, PE
Southern Company R&D
March 23, 2022



Southern Company

This work focuses on our balancing area in the Southeast



Outline

- **OPTSUN**: Using probabilistic information
- **Solar Forecast Arbiter**: Evaluating forecasts (probabilistic or otherwise)
- **Flexible Solar**: Another tool in the toolbelt



OPTSUN Acknowledgments

- Aidan Tuohy
- Dan Kirk-Davidoff
- David Larson
- Miguel Ortega-Vasquez
- Mobs Bello
- Qin Wang
- Russ Philbrick
- (Others I'm forgetting)



EPRI OPTSUN Project

- Operational Probabilistic Tools for Solar Uncertainty
- **Forecast**: improved probabilistic forecasts
- **Design** methods for managing uncertainty (using production cost modeling)
- **Demonstrate** a scheduling management platform (SMP) to support decision making



POLARIS



Southern
Company



Hawaiian
Electric



U.S. DEPARTMENT OF
ENERGY

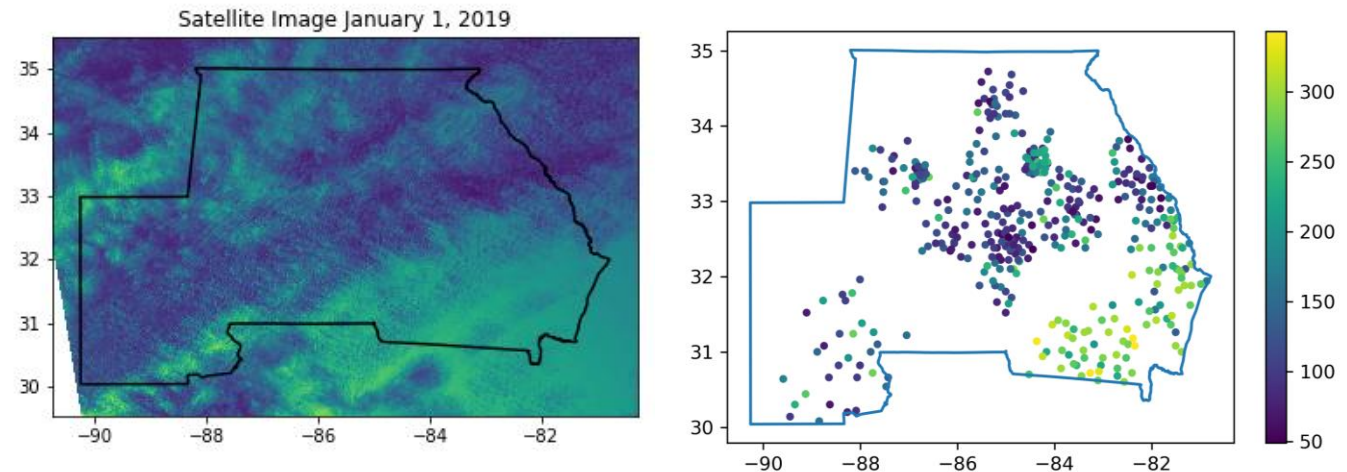
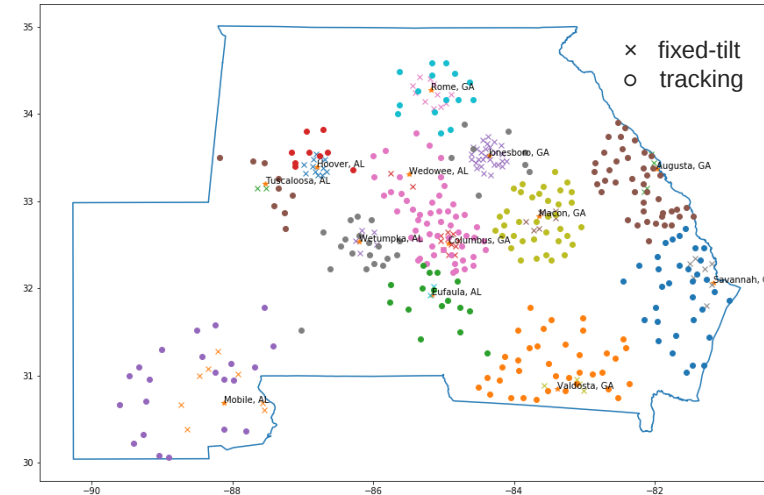
Energy Efficiency &
Renewable Energy

Solar Plants, Power Output

- Solar capacity scenarios:

- Existing (~2 GW)
- 7 GW
- 10 GW
- 20 GW

1. Select sites
2. Collect satellite data* and tune
3. Model individual plant power
4. Sum



*160,000 visible and IR satellite images from the GOES 16 satellite



Forecasts

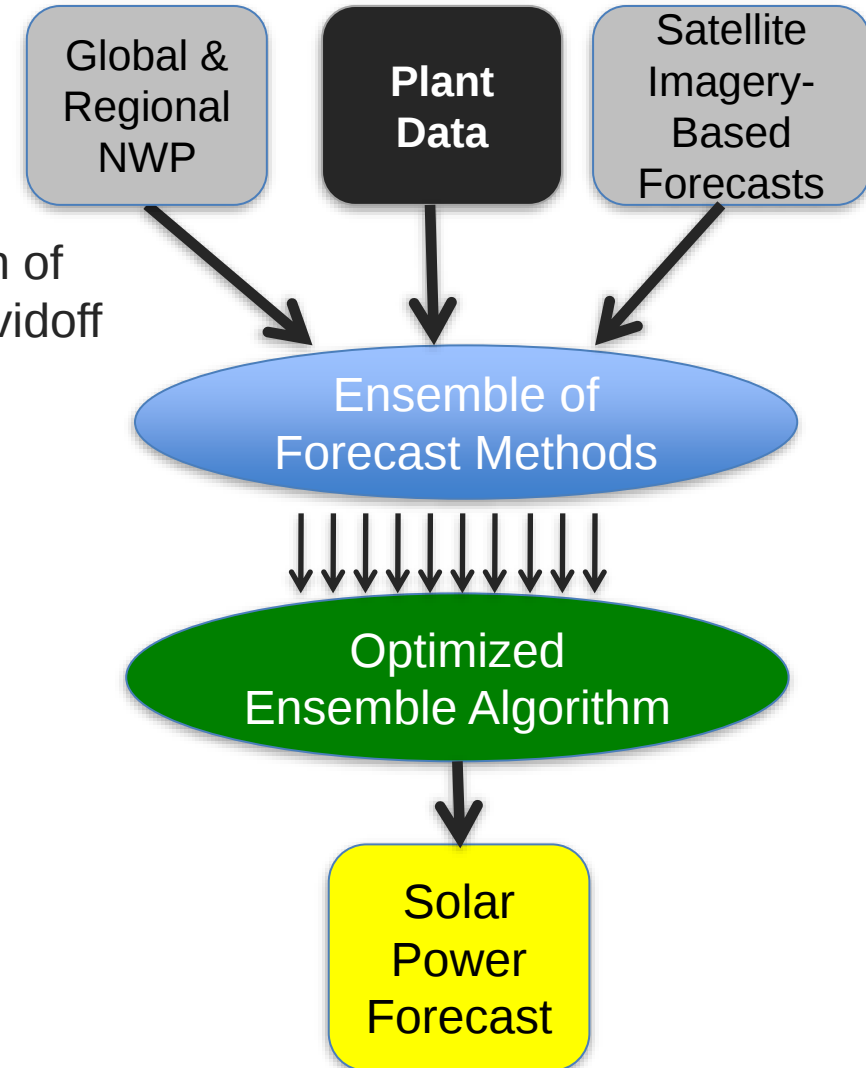
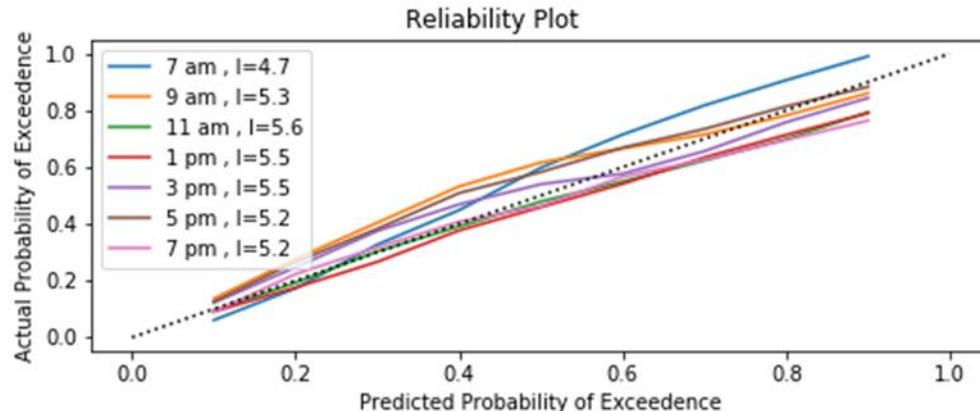
- Re-run forecasts from archived NWP and satellite data

- Horizons:

- Multi-day ahead
- Day Ahead (DA)
- 2-Hours Ahead (2HA)

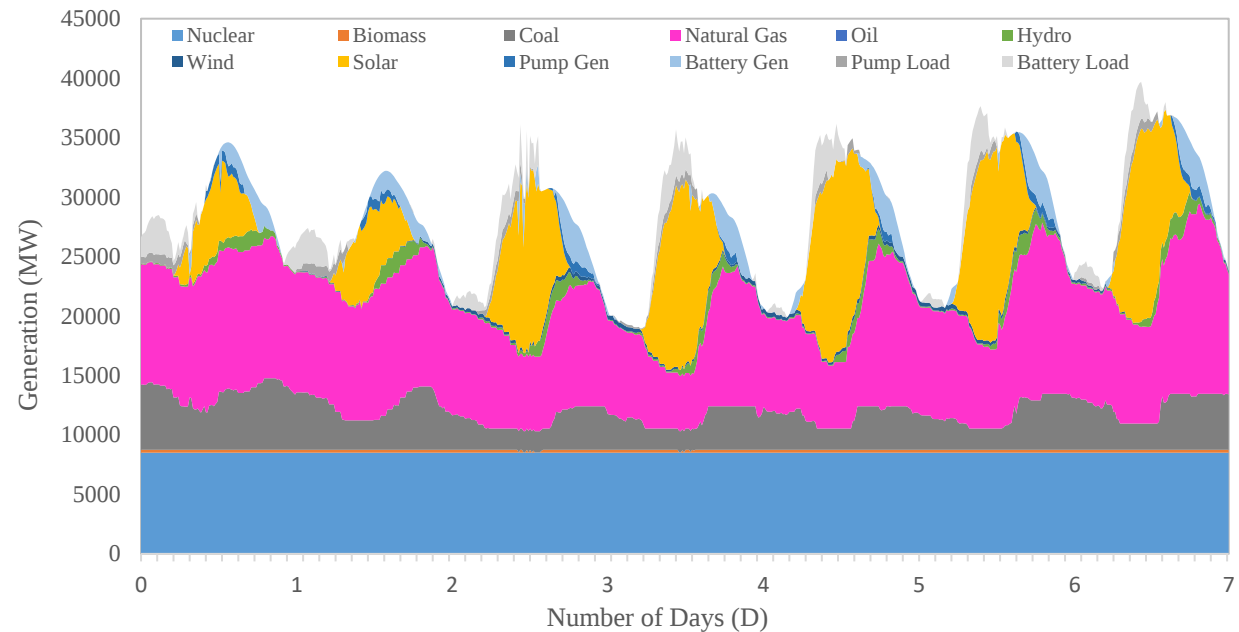
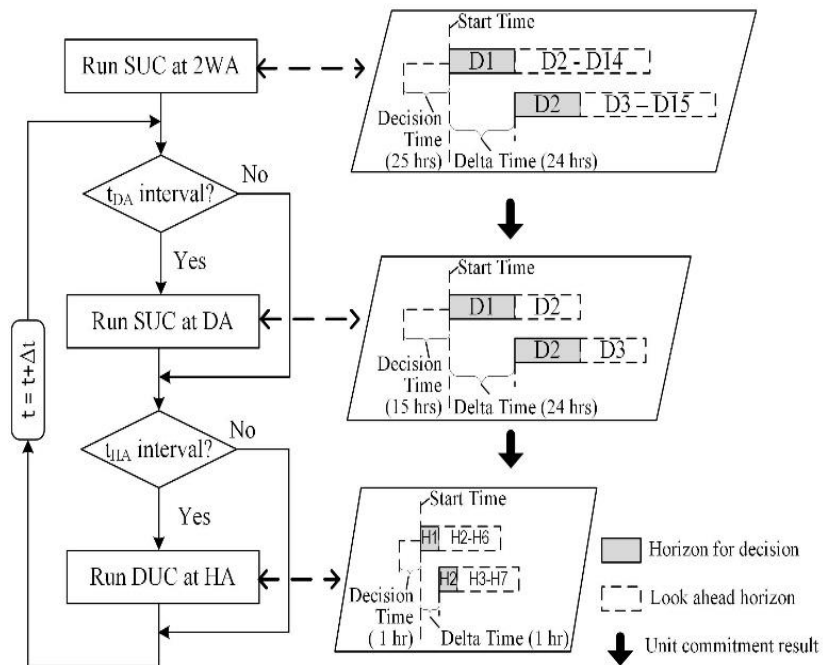
(big oversimplification of work by Dan Kirk-Davidoff and UL team)

- Tune an ML-based analog ensemble



Production Cost Model

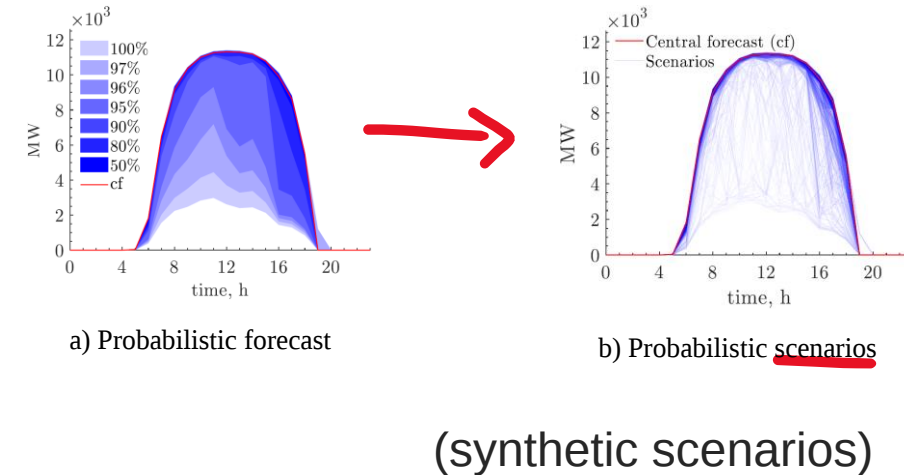
- Representative inputs (not a match for future system)
- Multiple commitment cycles
- deterministic unit commitment (DUC)
- stochastic unit commitment (SUC)



Reserve Determination Methods

- **D** – Deterministic Forecast (Baseline)
- Based on **Historical Observations**:
 - **P1** – All scenarios: Consider all possible conditions from observations
 - **P2** – Extreme scenarios: Consider only worst possible conditions
- Based on **Forecasted Conditions**:
 - **P3** – Bounds of Extreme Scenarios
 - **P4** – Prediction Interval

EPRI's DynaDOR tool



All P Methods: “Robustness” is selectable.
E.g., 0.99 covers 99% of scenarios or 99% f.cast confidence. 0.90 is lower, ...



Results

Results (draft)

7 GW Solar

Methods	D	Static	Risk (100MW)	P3 (90%)	P3 (99%)	P4 (90%)	P4 (99%)	Hybrid
Annual fuel cost w/o penalties (\$)	2,997 M	2,997 M (↑0.0%)	2,997 M (↑0.0%)	2,998M (↑.002%)	3,006 M (↑0.3%)	2,997 M (↓.03%)	3,013M (↑0.5%)	3.013 M (↑0.5%)
Annual total cost w/ penalties (\$)	3,004 M	3,004 M (↑0.0%)	3,003 M (↓.02%)	2,999 M (↓0.17%)	3,008 M (↑0.13%)	3,001 M (↓.09%)	3,013 M (↑0.3%)	3,013 M (↑0.3%)
Reg. Down vio. (MWh)	3,490	3,522 (↑1%)	2,575 (↓26%)	2,831 (↓19%)	797 (↓77%)	1,934 (↓45%)	896 (↓74%)	163 (↓95%)
Operating reserve vio. (MWh)	1,995	2,404 (↑20%)	2,884 (↑45%)	2,323 (↑16%)	641 (↓68%)	2,048 (↑3%)	229 (↓89%)	139 (↓93%)
Total reserve vio. (MWh)	5,485	5,927 (↑8%)	5,459 (↓0.5%)	5,154 (↓6%)	1,438 (↓74%)	3,983 (↓27%)	1,125 (↓79%)	302 (↓94%)
Balance vio.	None							

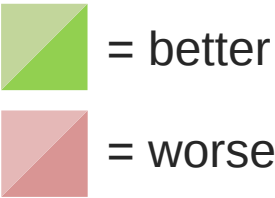
20 GW Solar

Methods	D	Static	Risk (160MW)	P3 (90%)	P3 (99%)	P4 (90%)	P4 (99%)	Hybrid
Annual fuel cost w/o penalties (\$)	2,493 M	2,496 M (↑0.1%)	2,491 M (↓0.1%)	2,522 M (↑1.1%)	2,631 M (↑5.5%)	2,594 M (↑4.1%)	2,635 M (↑5.7%)	2,632 M (↑5.6%)
Annual total cost w/ penalties (\$)	2,610 M	2,614 M (↑0.16%)	2,608 M (↓0.1%)	2,635 M (↑0.93%)	2,635 M (↑0.96%)	2,628 M (↑0.67%)	2,639 M (↑1.1%)	2,637 M (↑1.01%)
Reserve vio. (MWh)	15,406	14,535 (↓5.7%)	14,562 (↓5.5%)	14,415 (↓6.4%)	3,959 (↓74.3%)	8,411 (↓45.4%)	3,844 (↓75%)	3,854 (↓75%)
Balance vio. (MWh)	19,893	20,383 (↑2.5%)	19,924 (↑0.2%)	19,269 (↓3.1%)	0 (↓100%)	4,745 (↓76.1%)	0 (↓100%)	0 (↓100%)



Results (draft)

7 GW Solar



20 GW Solar

Costs

Methods	D	Static	Risk (100MW)	P3 (90%)	P3 (99%)	P4 (90%)	P4 (99%)	Hybrid
Annual fuel cost w/o penalties (\$)								
Annual total cost w/ penalties (\$)								
Reg. Down vio. (MWh)								
Operating reserve vio. (MWh)								
Total reserve vio. (MWh)								
Balance vio.	None							

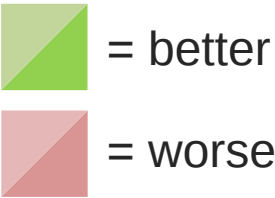
Violations

Methods	D	Static	Risk (160MW)	P3 (90%)	P3 (99%)	P4 (90%)	P4 (99%)	Hybrid
Annual fuel cost w/o penalties (\$)								
Annual total cost w/ penalties (\$)								
Reserve vio. (MWh)								
Balance vio. (MWh)								



Results (draft)

7 GW Solar



20 GW Solar

Costs

Methods	D	Static	Risk (100MW)	P3 (90%)	P3 (99%)	P4 (90%)	P4 (99%)	Hybrid
Annual fuel cost w/o penalties (\$)								
Annual total cost w/ penalties (\$)								
Reg. Down vio. (MWh)								
Operating reserve vio. (MWh)								
Total reserve vio. (MWh)								
Balance vio.	None							

Violations

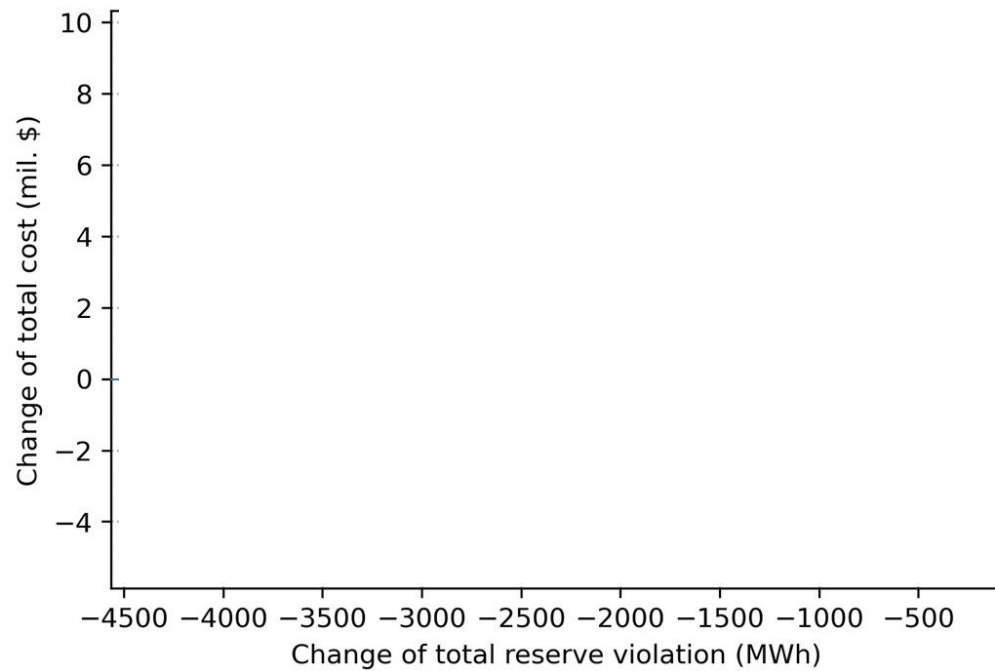
Methods	D	Static	Risk (160MW)	P3 (90%)	P3 (99%)	P4 (90%)	P4 (99%)	Hybrid
Annual fuel cost w/o penalties (\$)								
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Reserve vio. (MWh)								
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Model is only representative.
Includes no capacity expansion, etc.



Results (draft)

7 GW Solar



20 GW Solar

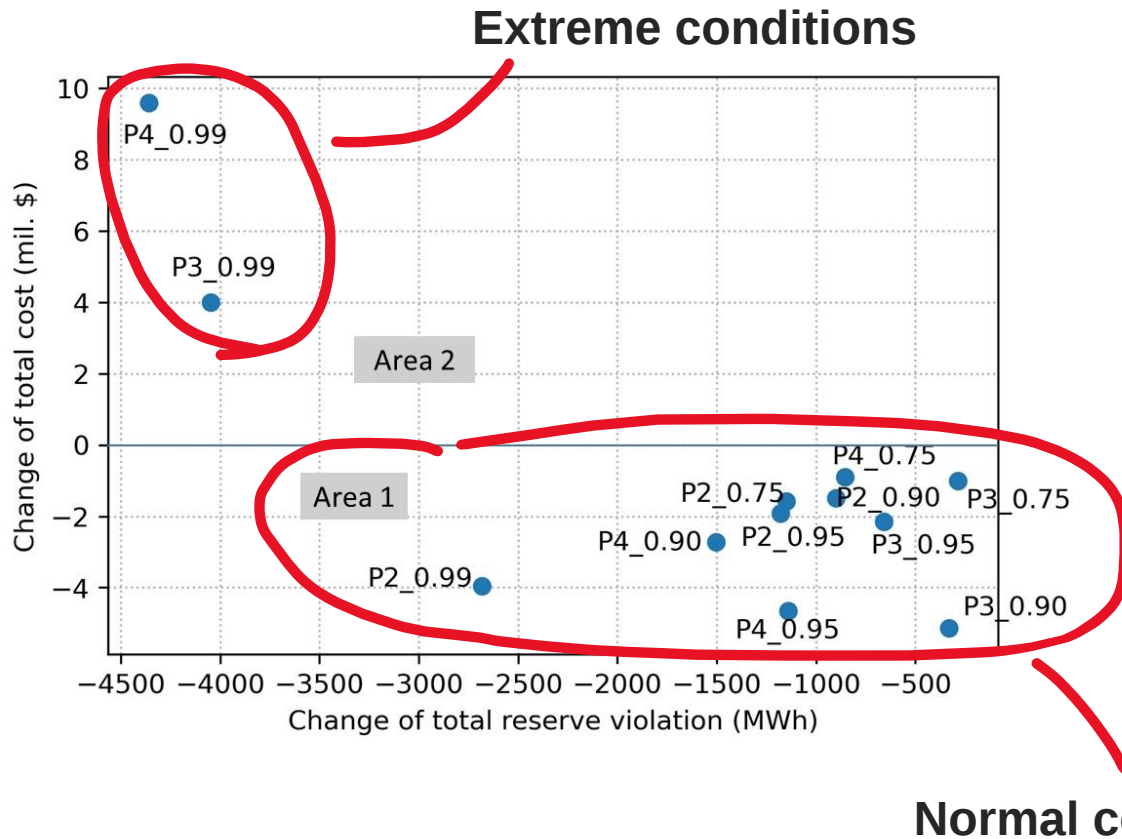


Results (draft)

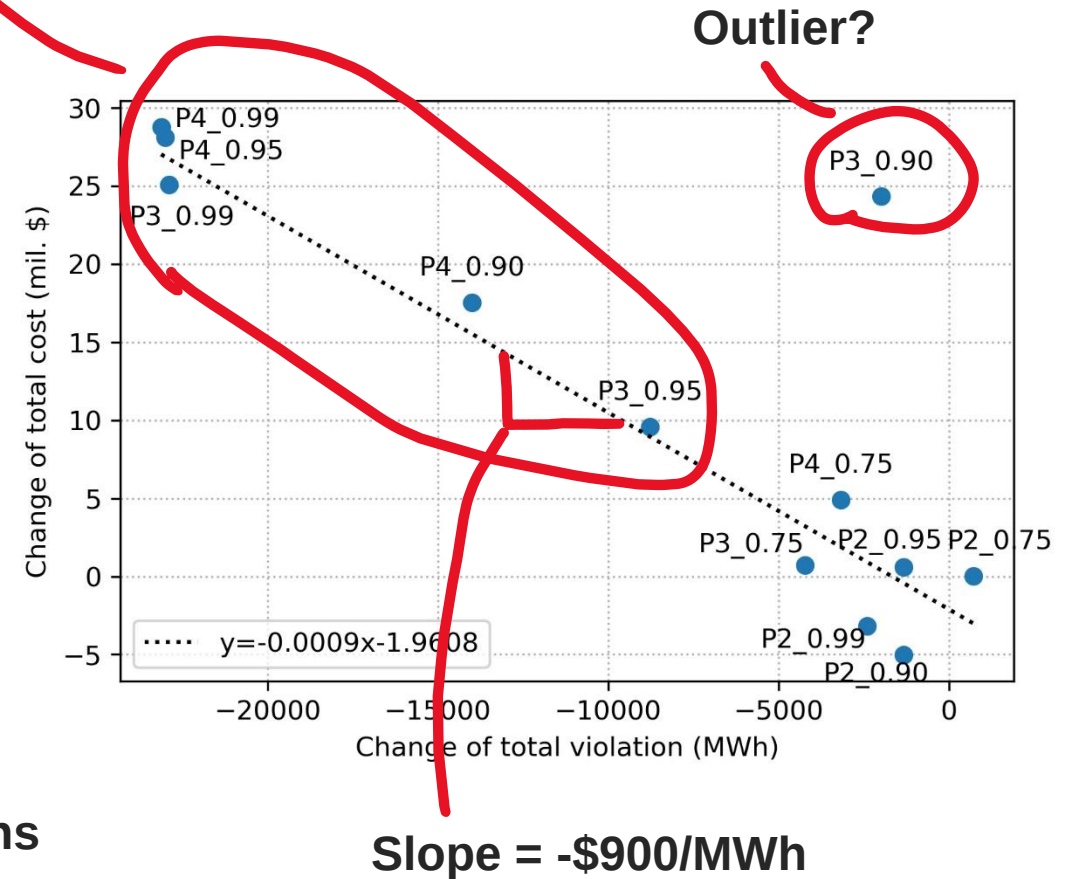
7 GW Solar

P3 & P4:

- Help violations most
- About equal



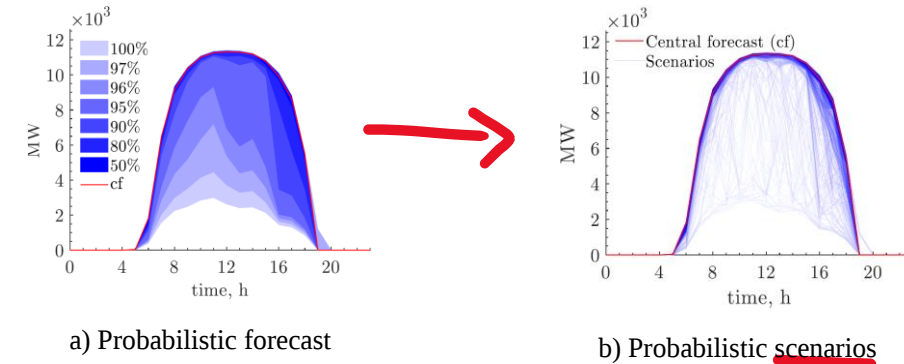
20 GW Solar



Reserve Determination Methods

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EPRI's DynaDOR tool

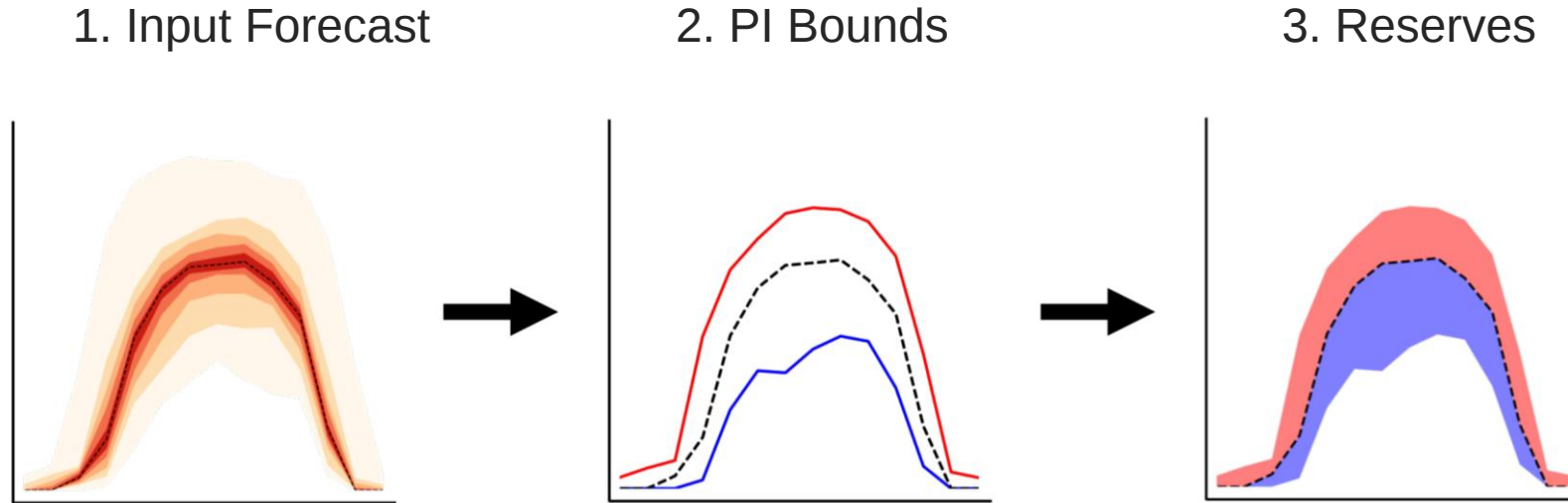


(synthetic scenarios)

No synth scenarios

All P Methods: “Robustness” is selectable.
E.g., 0.99 covers 99% of scenarios or 99% f.cast confidence. 0.90 is lower, ...

P4 – Prediction Interval method



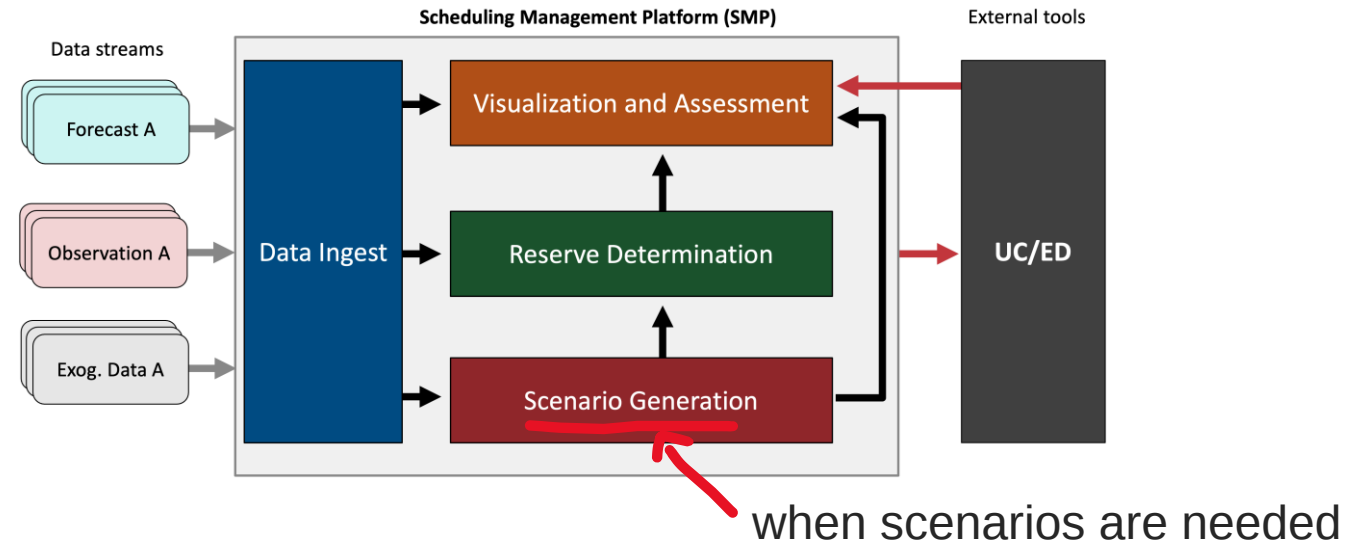
1. Input probabilistic forecast, e.g., day ahead
2. Select prediction interval (PI), e.g., 90% (p5-p95)
3. Determine reserves from PI bounds and p50 forecast
 1. Upward reserves
 2. Downward reserves

Scheduling Management Platform

(a.k.a., how we might apply this)

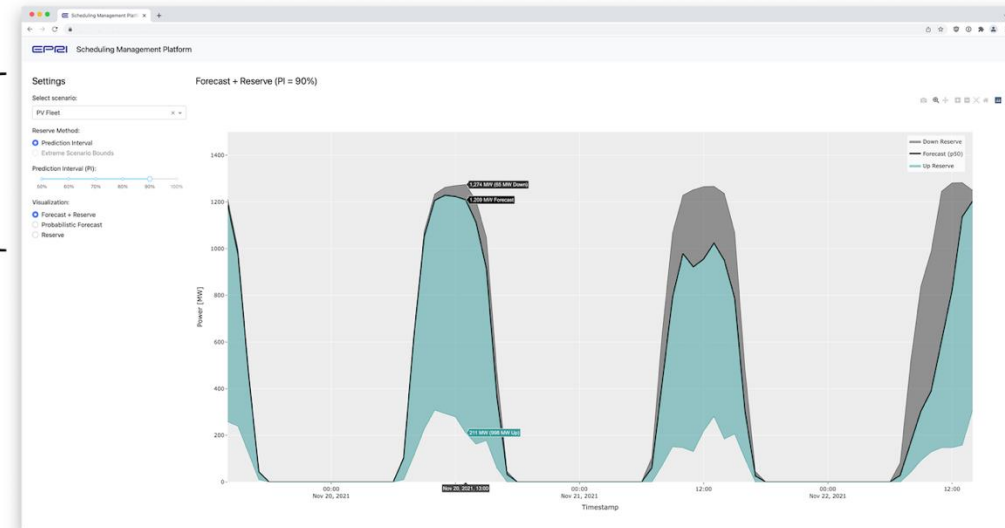
Scheduling Management Platform

- Integrate probabilistic forecasts and scheduling decisions
- Modular and customizable
- Will be open-source
- Browser-based interface



```
34 def extreme_bound_reserves(fx, fx_prob, lower_bound, upper_bound,
35                             reserve_type='intra-interval'):
36     """Reserves based on probabilistic forecasts and extreme scenario bounds.
37
38     Parameters
39     -----
40     fx : (m, n)
41         Probabilistic forecasts for m timestamps and n CDF intervals.
42     lower_bound : (n,) array_like
43         Lower bound on the extreme scenarios.
44     upper_bound : (n,) array_like
45         Upper bound on the extreme scenarios.
46     reserve_type : ('intra-interval', 'uncertainty', 'inter-interval'), optional
47         The type of reserve:
48         - 'intra-interval':
49             - 'uncertainty'
50             - 'inter-interval'
51
52     Returns
53     -----
54     up, down : (m,) array_like
55         The upward and downward reserves.
56
57     Notes
58     -----
59     If 'reserve_type' is set as 'inter-interval', the outputs of this function
60     are length 'm-1' (instead of length 'm') as inter-interval reserves
61     correspond to ramping between sequential intervals. Also, the output of
62     function is the same when the reserve type is set as intra-interval or
63     uncertainty.
64
65     See Also
66     -----
67     .py:func: 'smp.scenarios.generate_extreme_bounds'
68
69     """
70
71     # find the HW for the central forecast (CF)
72     fx_interp = interpfd(fx_prob, fx, kind='linear', axis=1)
73     cf = fx_interp[0.50]
74
75     # force small values (from numerical precision limitations) to zero
76     cf[cf < 1e-1 * 100] = 0.0
77
78     if reserve_type == 'inter-interval':
79         # compute ramps for each reserve requirement
80         up = np.maximum(cf[1:] - lower_bound[1:], 0)
81         down = np.maximum(upper_bound[1:] - cf[1:], 0)
82     elif reserve_type in ('intra-interval', 'uncertainty'):
83         # compute reserve requirement
84         up = cf - lower_bound
85         down = upper_bound - cf
86     else:
87         raise KeyError(
88             f"('reserve_type') does not match any of the supported reserve "
89             f"types ('intra-interval', 'uncertainty', 'inter-interval')."
90         )
91
92     return up, down
```

User settings



Interactive (dynamic) display



Solar Forecast Arbiter

Evaluating forecasts (probabilistic or otherwise)

Forecast Arbiter Working Group

- Contact David Larson (dlarson@epri.com) or Aidan Tuohy (atuohy@epri.com) for more info
- Aims to start mid-2022 and will include:
 - annual meetings,
 - updates on performance, and
 - support in benchmarks and use



Flexible Solar

Another tool in the toolbelt



Flexible Solar Study

- Published in JPV
- Used PSO model from OPTSUN
 - deterministic forecasts
 - **5-min** intervals
- Solar: 2, 7, and 20 GW
- **Solar Control Scenarios:**
 - Must-Take
 - Curtailable (limited control)
 - Flexible (economic dispatch, reserves)
- **Results for flexible vs. curtailable:**
 - Similar reduction in violations
 - Reduced cost (~\$13M/yr, or 0.5% of total production cost)
 - Cut solar curtailments by about 1/2 (10% → 6% for 20GW)

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IEEE JOURNAL OF PHOTOVOLTAICS, VOL. 12, NO. 1, JANUARY 2022

Evaluating Potential Benefits of Flexible Solar Power Generation in the Southern Company System

Qin Wang¹, Senior Member, IEEE, William B. Hobbs², Member, IEEE, Aidan Tuohy³, Senior Member, IEEE, Mobolaji Bello⁴, Senior Member, IEEE, and David J. Ault

(<https://doi.org/10.1109/JPHOTOV.2021.3126118>)

Future work:

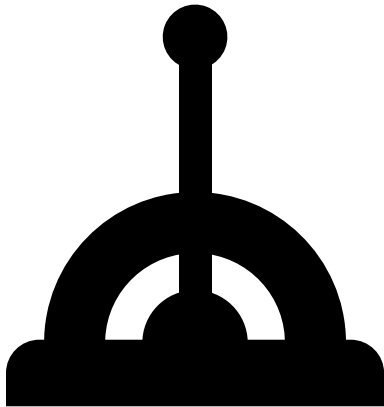
Storage sensitivity study?

- Adding 4hr ES at 20% of PV (1.4, 4 GW) closed gap between curtailable and flexible
- How much ES is flexible solar “worth”?

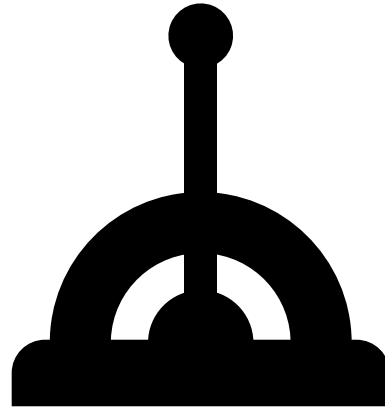
Probabilistic Forecasts?



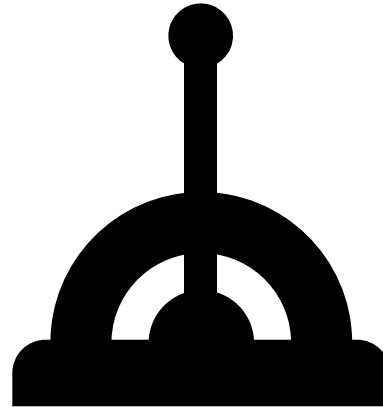
4 (+) levers:



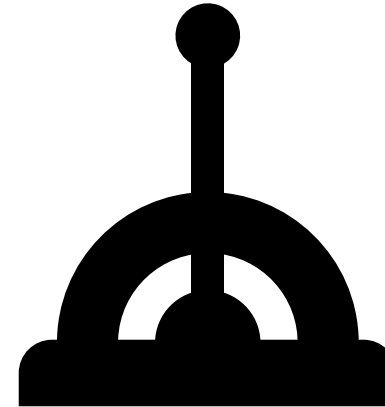
**Probabilistic
Information**



**Forecast
Accuracy**



**Renewable
Flexibility**

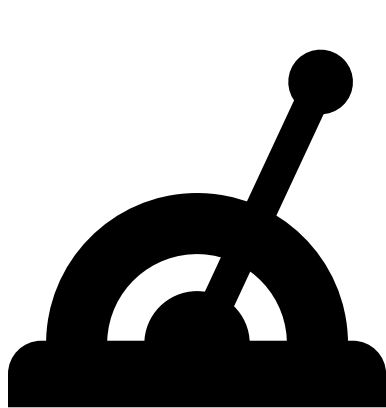


**Storage
(Fleet flexibility)**

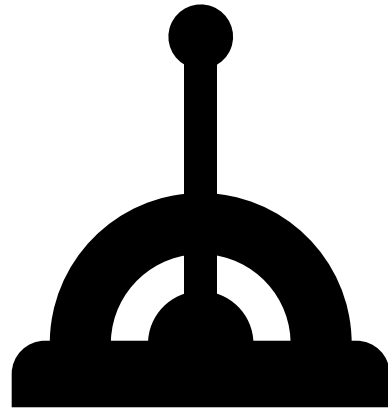


4 (+) levers:

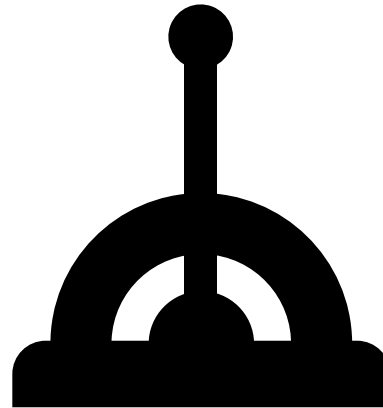
- Improvements in any one...



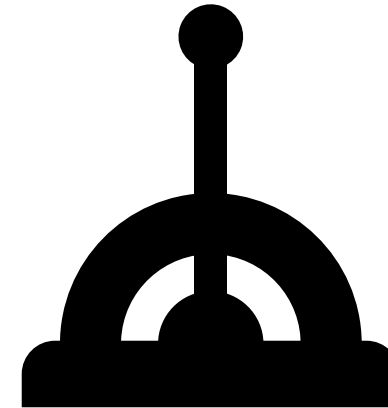
**Probabilistic
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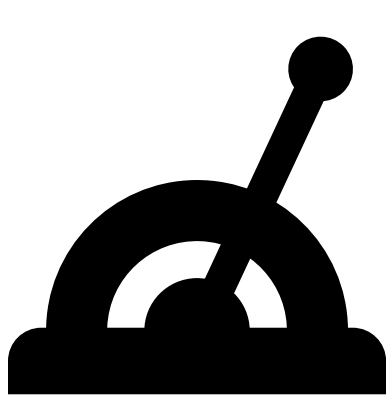


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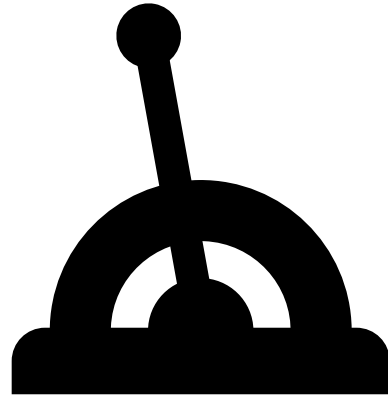


4 (+) levers:

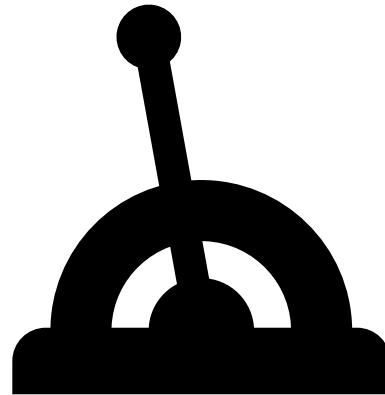
- Improvements in any one... could mean less need for others



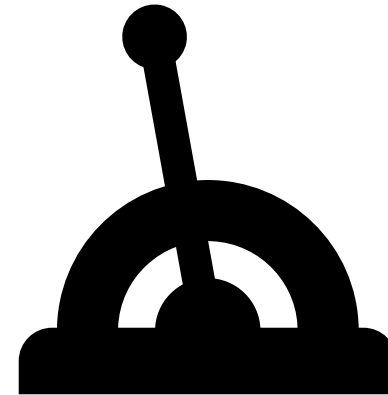
**Probabilistic
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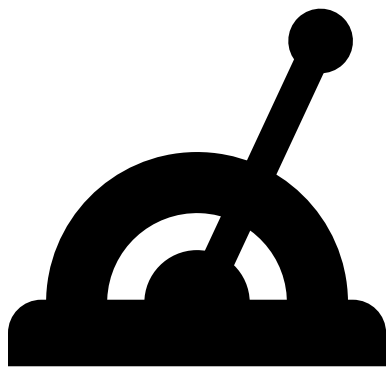


**Storage
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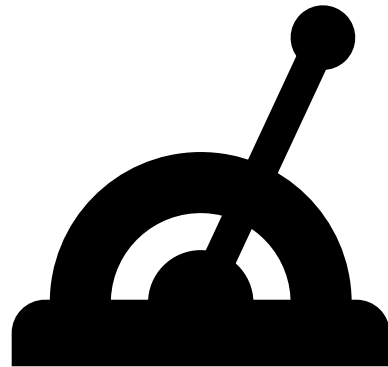


4 (+) levers:

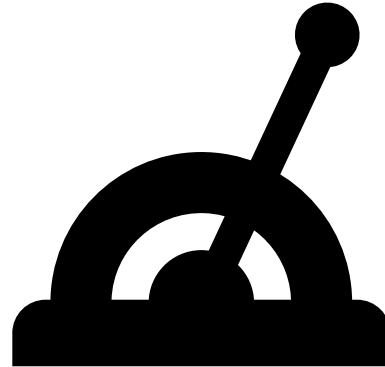
- Improvements in any one... could mean less need for others
- Improvements in all could reduce cost and increase reliability
- (flexible load, others?)



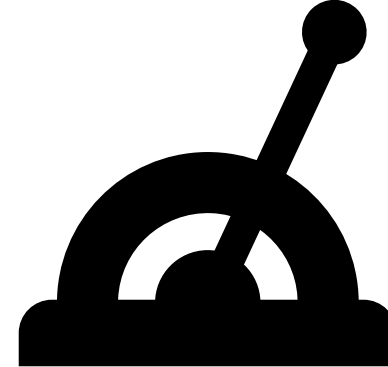
**Probabilistic
Information**



**Forecast
Accuracy**



**Renewable
Flexibility**



**Storage
(Fleet flexibility)**

Understanding how to “actuate” these levers and what their impact will be is key to the future of the grid



Thanks for your time!

Questions: whobbs@southernco.com

