Solar Uncertainty Management and Mitigation for Exceptional Reliability in Grid Operations (SUMMER-GO)

Bri-Mathias Hodge, Ph.D.

July 12, 2018
Technology Summary: The SUMMER-GO Team will design novel algorithms to create probabilistic solar power forecasts and automate their integration into power system operations. Adaptive reserves will dynamically adjust reserve levels conditional on meteorological and power system states. Risk-parity dispatch produces optimal dispatch strategies under uncertainty by cost-weighting solar generation scenarios.

Technology Outcomes: Adaptive reserves and risk-parity dispatch will reduce system operating costs while increasing system reliability. A situational awareness tool will help system operators understand the uncertainty in the solar power forecasts, and the impacts on operations.

Project Objectives and Approach: This project will bring probabilistic solar forecasts into ERCOT's real-time operation environment through automated reserve and dispatch tools that increase economic efficiency and improve system reliability. The adaptive reserves aim to reduce overall reserve levels by 25% while maintaining or improving system reliability. The risk-parity dispatch will automate the use of probabilistic forecast information in a 5-minute dispatch window. The situational awareness tool will present forecast uncertainty information that is relevant, timely, and allows for better decision making.

SUMMER-GO is a suite of tools that enable the incorporation of probabilistic solar forecasts into operations to improve system reliability and will be validated in ERCOT's real-time operational test system.
Project Background and Motivation

Examples: Large deterministic over and under-forecasting events in ISO-NE 18% solar power scenario

Consequences:
- Excess generation a mid-day; shortage of ramping capability in the evening
- High solar curtailment
- Higher system costs
- Reliability concerns from thermal ramping availability

Consequences:
- Shortage of generation in RT
- Need quick-start units
- Reliability concerns if enough ramping capacity not available
- High marginal costs of these units translate to high system costs
Project Background and Motivation

ERCOT:
- Largest single-state energy market in US
- Recent increase in renewable (wind) and flexible gas capacity
- Rapid increase in solar installations
Texas has:
- Largest solar resource in US
- Peak energy needs in summer
- Sustained drought periods
- Land availability
- Transmission availability (CREZ)

Distributed PV in ERCOT (2015)
Registered: 57.12 MW
(Incl. registered NOIE: 55.12 MW)
Unregistered: 50.10 MW
Total: 107.22 MW
Project Background and Motivation

- Radiant Solutions and ERCOT have an existing collaboration, with Radiant Solutions having provided ERCOT’s operational solar power forecast for over a year already.
- Radiant Solutions’ deterministic forecasting system is top-of-the-industry (see recent trial results for multiple locations in the bottom left figure).
- Already produce well-calibrated probabilistic solar power forecasts (see bottom right), and currently deliver the 80% exceedance value to ERCOT operationally.
Project Objectives

• Produce and deliver operationally accurate, sharp, and well-calibrated probabilistic solar power forecasts.
• Reduce system operating reserves through dynamically adaptive reserve setting algorithms.
• Reduce system operating costs and increase reliability scores through risk-parity economic dispatch.
• Provide an open-source solar power forecasting visualization tool for industry adoption.
Probabilistic Solar Forecasts

Planned Improvements:

- Increase the Radiant Solutions ensemble to greater than 75 members from 6 distinct NWP systems, from 13 members from 4 distinct NWP systems.
  - Adding in the European Centre for Medium-Range Weather Forecasts (ECMWF) 50 ensemble members and High Resolution Rapid Refresh (HRRR) model.
- Utilize an ensemble of hybrid machine learning-statistical techniques to improve probabilistic forecast accuracy, sharpness, and calibration through situational dependent blending.
Adaptive Reserves

- Update Non-Spinning Reserve Service (NSRS) on a daily basis based on historical data, solar forecast, and power system state forecast.
- Values assessed using online tool for determining loss-of-load-probability (LOLP) and ramping capabilities.

**Grid condition**
- Solar forecasts
- Ramping capabilities
- Meteorological Condition Clustering
- Power System State

**Daily NSRS requirement**
- Historical data
- 70th-95th percentile of 4h block
- Solar ramping

**Real-time NSRS adjustment**
- Loss-of-load probability (LOLP)
- Insufficient ramping capabilities

**Assessment**
- Economics and reliability
- IEEE 118-bus system
- ERCOT’s iTest system
Radiant Solutions predicts sub-hourly variability

White curve=measured

Green curve uses statistics to generate variability knowing only 1-hour average
Radiant Solutions predicts sub-hourly variability

White curve = measured

Green curve uses statistics to generate variability knowing only 1-hour average

Big dip and wild fluctuations
Radiant Solutions predicts sub-hourly variability

White curve = measured

Green curve uses statistics to generate variability knowing only 1-hour average
Risk-Parity Dispatch

Advantages:

• Explicitly incorporates probabilistic information into dispatch process.
• Reduced solve time compared to full stochastic dispatch.
• Takes into account both the meteorological and power system states.
• Does not produce overly conservative solutions such as robust dispatch.
A map view displays data for solar plants, planning regions, transmission lines, and forecast values.

Visual cues alert users when situations arise that require attention.

Aggregated regions can be selected to view details.
SolarView

Alternatively, individual sites can be selected for comparison.

Advanced forecast analysis tools enable probability visualization and detailed assessments.
Validation - FESTIV Capabilities

- Steady-State power system operations simulator (i.e. UCED + AGC).
- Simulates all temporal resolutions of the scheduling process:
  - DA, HA, RT, AGC
- All models are interconnected (output of one serves as input to next):
  - Interconnected nature allows FESTIV to capture the real nature of forecasts.
  - Allows for impact of forecast accuracy to be studied.
- Simulates scheduling **AND** deployment of reserves.
- Provides **BOTH** economic metrics (production costs, LMPs, etc.) and reliability metrics (ACE, CPS2, etc.).
Validation and Implementation - ERCOT iTest System

- Probabilistic forecasts will be ingested into the iTest system operationally
- Adaptive reserves and risk parity dispatch will be implemented in the iTest system
- iTest System:
  - Replica of ERCOT’s production environment, including hardware, software, and interfaces
  - Last stop for changes to be implemented in operations
  - Utilizes real system data in real-time

Source: GE Grid Solutions
Algorithm Development
[15 months]
1. Probabilistic Solar Power Forecasts
2. Adaptive Reserves
3. Risk-Parity Dispatch
4. SolarView

Validation and Verification
[12 months]

Implementation and Demonstration
[9 months]
Thank you!
Questions?

www.nrel.gov
## Consideration of Key FOA Topics

<table>
<thead>
<tr>
<th>Important Topic</th>
<th>Proposed Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partnership with at least one balancing authority</td>
<td>ERCOT is a committed project partner receiving more than 20% of project funding, and they will be heavily involved in all phases of the project.</td>
</tr>
<tr>
<td>Probabilistic format of numerical and visualized output</td>
<td>MDA is committed to providing probabilistic solar power forecasts, and the SolarView platform will be developed for visualization and situational awareness.</td>
</tr>
<tr>
<td>Development of decision-making process for unit commitment and economic dispatch using probabilistic forecast as input</td>
<td>The adaptive reserves will be utilized at multiple timescales, including unit commitment and economic dispatch, and the risk-parity dispatch will be used in the dispatch time frame.</td>
</tr>
<tr>
<td>Demonstration of solar power forecasts integrated in development environment</td>
<td>The project team will utilize two development environments to demonstrate the value and robustness of the forecasts and tools developed: NREL’s FESTIV model and ERCOT’s iTest environment.</td>
</tr>
<tr>
<td>Compliance with validation guidelines of test framework</td>
<td>The project team will work closely with the awardee in Topic Area 1 to meet the validation guidelines.</td>
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</table>

**Going above and beyond the FOA topics:**

- This project spans the full range of technology readiness levels and upon completion will be able to see the solutions put into practice with the flip of a switch.
- Open source nature of the tools will create benefits beyond the ERCOT area.
Work Breakdown Structure and Task Description

Budget Period 1. Algorithm Development — 15 months

- **Task 1.1:** Develop Probabilistic Solar Power Forecasts (M1–M15)
  - *Subtask 1.1.1:* Create Probabilistic Solar Power Forecasting Algorithms for Utility-Scale PV Plants and Balancing Area-Level Solar Generation (M1–M12)
  - *Subtask 1.1.2:* Create Probabilistic Behind-the-Meter Solar Power Forecasts (M3–M15)

- **Task 1.2:** Develop Adaptive Reserve Algorithms (M1–M15)
  - *Subtask 1.2.1:* Grid Condition Clustering (M1–M6)
  - *Subtask 1.2.2:* Grid Condition Forecasting (M5–M12)
  - *Subtask 1.2.3:* Develop Adaptive Reserve Algorithm (M3–M15)

- **Task 1.3:** Develop Risk-Parity Dispatch Algorithm (M1–M15)
  - *Subtask 1.3.1:* Determine Dynamic Costs (M1–M9)
  - *Subtask 1.3.2:* Develop Risk-Parity Algorithm (M1–M15)

- **Task 1.4:** Develop Situational Awareness Tool, SolarView (M9–M15)
Budget Period 1 Milestones

- **Milestone 1.1:** Demonstrate ability to produce the full spectrum of forecast probabilities at multiple timescales, including day-ahead and sub-hourly.

- **Milestone 1.2:** Demonstrate that the adaptive reserve algorithms can reduce total reserves by more than 25%.

- **Milestone 1.3:** Demonstrate that the risk-parity algorithm consistently converges to the optimal solution in less than 4 minutes for a small utility system.

- **Milestone 1.4:** Complete solar-specific features in the software, and successfully demonstrate the SolarView capabilities to the solar program manager.

- **Budget Period 1 Go/No-Go Decision Point:** All Year 1 milestones completed. (15 months)
Budget Period 2. Verification and Validation — 12 Months

- **Task 2.1**: Validate Probabilistic Solar Power Forecasts (M16–M27)
  - **Subtask 2.1.1**: Ground Truth Collection & Produce Operational Utility-Scale Probabilistic Forecasts (M16–M27)
  - **Subtask 2.1.2**: Provide Probabilistic Behind-the-Meter Solar Power Forecasts Operationally (M16 – M27)
  - **Subtask 2.1.3**: Coordinate with Validation Team (M16–M27)

- **Task 2.2**: Ingest Probabilistic Forecasts into ISO Energy Management System (M16–M27)

- **Task 2.3**: Estimate Adaptive Reserve Economic and Reliability Impacts (M16–M27)
  - **Subtask 2.3.1**: Create Adaptive Reserve Time-Series Data (M16–M19)
  - **Subtask 2.3.2**: FESTIV 118-Bus Simulations of Adaptive Reserve Impacts (M18–M23)
  - **Subtask 2.3.3**: FESTIV ISO Simulations of Adaptive Reserve Impacts (M20–M27)

- **Task 2.4**: Estimate Risk-Parity Dispatch Economic and Reliability Impacts (M16–M27)
  - **Subtask 2.4.1**: Incorporate Risk-Parity Algorithm into FESTIV (M16–M21)
  - **Subtask 2.4.2**: FESTIV Simulations of Risk-Parity Dispatch Impacts (M20–M27)
Budget Period 2 Milestones

• **Milestone 2.1:** Complete successful validation of the probabilistic forecasts according to the standards adopted by the Topic Area 1 awardee.

• **Milestone 2.2:** Successfully ingest probabilistic solar power forecasts into the ISO’s system with more than 95% reliability during a 1-month period.

• **Milestone 2.3:** Reduce total production costs when compared to the case without adaptive reserves. This will be assessed using case study simulations of the IEEE 118-bus and the ISO’s realistic test system with FESTIV.

• **Milestone 2.4:** Increase reliability scores when compared to the case with standard economic dispatch and deterministic forecast. This will be assessed using case study simulations of the IEEE 118-bus test system and the ISO’s realistic test system with FESTIV.

• **Budget Period 2 Go/No-Go Decision Point:** All Year 2 milestones completed. (27 months)
Budget Period 3. Implementation and Demonstration—9 Months

- **Task 3.1**: Provide Operational Probabilistic Forecasts (M28–M36)
  - **Subtask 3.1.1**: Provide and Ingest Operational Forecasts (M28–M36)

- **Task 3.2**: Incorporate Adaptive Reserves into ISO Test Environment (M28–M36)
  - **Subtask 3.2.1**: Implement Adaptive Reserves (M28–M36)

- **Task 3.3**: Incorporate Risk-Parity Dispatch into ISO Test Environment (M28–M36)
  - **Subtask 3.3.1**: Analyze Historical Data to Determine Risk Parameters (M28–M33)
  - **Subtask 3.3.2**: Demonstrate Risk-Parity Implementation (M32–M36)

- **Task 3.4**: Provide the ISO Operator Training on Situational Awareness Tool (M33–M36)
  - **Subtask 3.4.1**: Develop SolarView Training (M28–M30)
  - **Subtask 3.4.2**: Deliver SolarView Training (M30–M33)
Project Management Plan

- The PI has extensive experience with similarly sized projects with external collaborators
- Extensive ongoing joint work between team members
- Dedicated project manager and NREL’s project milestone tracking system

- Bi-weekly team meetings to gauge progress and coordinate joint tasks
- Deep dive meetings held as necessary on particular technical topics
- Asynchronous collaboration tools, i.e. GitHub and Slack, for coordination
- Biannual in-person team meetings
# Project Team, Experience, and Qualifications

<table>
<thead>
<tr>
<th>Key Participant</th>
<th>Organization</th>
<th>Background and Expertise</th>
</tr>
</thead>
</table>
| Bri-Mathias Hodge, Ph.D., PI | NREL                | • Manager of the Power System Design and Studies group.  
• Expertise in the area of grid planning and operations with high levels of renewable energy, particularly the impact of renewable energy (RE) forecasting on power system planning and operations.  
• Published more than 100 peer-reviewed papers on RE integration.  
• Served as PI on projects totaling $11.5M+ in the last five years.  
• Work package leader for Advanced Usage of Probabilistic Forecasts in the IEA Task 36 on Forecasting for Wind Energy. |
| Sandip Sharma, Co-PI    | ERCOT                | • Manager of the Operations Planning group.  
• Focus on RE integration, frequency response, and ancillary services.  
• Member of the NERC Resources subcommittee and previously of the NERC Frequency Response Standard drafting team. |
| Stephen Jascourt, Ph.D., Co-PI | MDA            | • Senior scientist who created the MDA solar forecasting system based on first principles, including a large volume of research-quality observations worldwide.  
• Works on product development and improvement projects bridging between scientific research and operational applications.  
• Worked for the University Corporation for Atmospheric Research’s COMET Program, and trained weather forecasters on complex calculations behind numerical weather prediction models. |
| Jie Zhang, Ph.D., Co-PI | University of Texas at Dallas (UTD) | • Assistant professor with expertise in the forecasting of wind power, solar power, and load; grid integration of renewable energy; and the modeling, design, and optimization of complex energy systems.  
• PI or co-PI on several wind, solar, and electricity projects funded by the DOE Grid Modernization Initiative and SunShot Initiative.  
• Published 80+ peer-reviewed journal and conference publications. |
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<td>ERCOT</td>
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<td>$118,200</td>
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<td>PROJECT TOTALS</td>
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<td><strong>Total Costs</strong> (Federal + Cost Share)</td>
<td>$911,605</td>
<td>$776,601</td>
<td>$515,378</td>
<td>$2,203,584</td>
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<td></td>
<td>Cost Share</td>
<td><strong>6.29%</strong></td>
<td><strong>20.26%</strong></td>
<td><strong>22.76%</strong></td>
<td><strong>15.06%</strong></td>
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</tbody>
</table>

Total Costs: $2,203,584

Cost Share Percentages:
- NREL: 15.06%
- ERCOT: 22.76%
- MDA Information Systems: 20.26%
- University of Texas at Dallas: 6.29%

**Note:** The Federal vs. Cost Share percentages for the different performers are calculated as shown.
Budget Period 3 Milestones

- **Milestone 3.1:** Successfully deliver probabilistic solar power forecasts to the ISO’s system with more than 98% reliability during the demonstration period.

- **Milestone 3.2:** Demonstrate robust utilization of the adaptive reserve algorithms in the iTest system for a continuous period of 1 month.

- **Milestone 3.3:** Demonstrate robust utilization of the risk-parity dispatch in the iTest system for a continuous period of 1 month.

- **Milestone 3.4:** Conduct a minimum of two training sessions for the ISO’s operators.
What is ERCOT?

The Texas Legislature restructured the Texas electric market in 1999 and assigned ERCOT four primary responsibilities:

- **System Reliability**
- **Competitive Wholesale Market**
- **Open Access to Transmission**
- **Competitive Retail Market**

ERCOT is a nonprofit organization and regulated by the Public Utility Commission of Texas, with oversight by the Texas Legislature.

ERCOT is not a market participant and does not own generation or transmission/distribution wires.
The interconnected electrical system serving most of Texas, with limited external connections

- 90% of Texas electric load; 75% of Texas land
- 71,110 MW peak, August 11, 2016
- More than 46,500 miles of transmission lines
- 570+ generation units

**ERCOT connections to other grids are limited to ~1250 MW of direct current (DC) ties, which allow control over flow of electricity**
ERCOT Current Records

Peak Demand Record: 71,110 megawatts (MW)
- Aug. 11, 2016, 4-5 p.m.

Weekend Record: 66,921 MW
- Sunday, Aug. 7, 2016, 5-6 p.m.

Winter Peak Record: 59,650 MW
- Jan. 6, 2017, 6-7 p.m.

Wind Generation Records (instantaneous)
- Output: 16,141 MW
  - March 31, 2017, 8:56 p.m.
- Penetration (load served): 50%
  - March 23, 2017, 3:50 a.m.
  - Total Load = 28,780 MW

Recent Monthly Peak Demand Records

2017
- January: 59,650 MW (Jan. 6, 6-7 p.m.)

2016
- August: 71,110 MW (All-time record)
- September: 66,949 MW (Sept. 19, 4-5 p.m.)
- October: 59,864 MW (Oct. 5, 4-5 p.m.)
- December: 57,932 MW (Dec. 19, 7-8 a.m.)

2015
- July: 67,650 MW (July 30, 4-5 p.m.)
ERCOT Annual Energy and Peak Demand (2005-2016)
• Steady growth continues, with some spikes.
• Largest annual increase: 3,294 MW in 2015 (A close second: 3,220 MW in 2008)
• Incentives, uncertainty and other factors affect construction decisions and schedules.
• Not all planned projects will get built.
• Texas continues to lead U.S. in wind capacity.
Registered and Unregistered Distributed PV: Number of Installations (6702 total)

Registered: 9
Unregistered: 6693
Total: 6,702

Source: DREAM TF Dec 14, 2015
ERCOT Solar Forecasting


Hour Ahead MAPE: 4.21%  Day Ahead MAPE: 4.62%
Hours counted: 13
(Only hours above 1 MW are counted)  Current Installed Capacity: 484MW*

Solar Output vs. Forecasts

![Graph showing solar output and forecasts.](image-url)
Solar Forecast Example: East Coast Solar Farm

Solar farm power (MW) measured (red) vs. estimated (blue) every 15 minutes. MDA estimate is based on short-range forecast. No site data available for previous 5 weeks!
Solar Forecasting Web Display

GERMANY over 1,000,000 sites: Bavaria over 300,000 sites
Aggregate total including behind the meter

Map of regional variation vs locations
Last 10 days official estimate vs. 24-h forecast
Solar Forecasting Web Display

Best forecast and 80% probability of exceedance

RTO total and two of the farms selected to show different:

- Capacity
- Location, thus sunny or cloudy at different times
- Tracking, thus different shapes of daily profile
MDA is current solar forecast provider for multiple RTOs – after competitive multi-month trials against other vendors

- Fixed tilt and single axis and dual axis tracking sites
- Sites in areas of variable cloudiness and storminess, others in seasonally sunny/arid locations
- Some sites had well-established history, others were new
- Service includes retrieving real-time site data from RTO
- Trial included aggregate distribution system (behind the meter) forecasts for zones covering several counties
- Trial included 80% probability of exceedance as conservative guidance for ensuring adequate resources when solar generation is low or uncertain
Solar Forecasting Skill vs. Other Vendors

- Daily importance parameter assigned to each day, separately each site.
- Days ranked more important if actual power was low (cloudy day) or highly variable.
- Forecast hourly MAE was calculated for the 20% of “most important” days at each site.
Solar Forecasting Skill – Day ahead

Skill varies by site and weather:

• Mostly sunny = easier to predict

• Sun tracking arrays rest flat overnight → morning/evening ramps require knowledge of panel motion
Solar Forecasting Skill – Aggregate best

Skill at 7 farms and aggregate (orange).

Aggregate has much better skill

Sample=hourly for 6 months
Solar Forecasting Skill – Behind-the-meter

California 160,000+ sites
Comparison: Aggregate all sites with exact orientations/tracking vs. select samples

- sunny summer day
- variable clouds summer day
Example of site issues MDA can detect and handle:

PV site with irradiance monitoring

Small shadow fell across irradiance monitor
Wind power forecast models provide operators with information helpful in determining future production output and potentially disruptive events.

A map view displays data for wind farms, planning regions, transmission lines, and forecast values.

Visual cues alert users when situations arise that require attention.
WindView

Map views provide tools for a variety of scenarios and time-frames.

An abundance of visual data is made available via the map.

Settings for alert thresholds, forecast settings, and more provide a customizable experience.

Data is navigable in both time and space.
FESTIV Flowchart

Start

System and generator data, day-ahead forecasts of load and solar power generation

Interval $t^{DU}$?

NO

Initial commitment status and start-up decisions of generators

Interval $t^{RU}$?

NO

NO

YES

Run day-ahead security-constrained unit commitment

YES

YES

Run real-time security-constrained unit commitment

YES

Initial commitment status and start-up decisions of generators

Interval $t^{RE}$?

NO

Run real-time security-constrained economic dispatch

YES

Dispatch schedules and reserve schedules of generators

Run AGC/ACE calculation

End

Absolute area control error in energy: $\text{AACEE}$

Standard deviation of raw $\text{ACE}$: $\sigma_{\text{ACE}}$

METRICS

Percentage of intervals without violations:

$$CPS2_{\text{score}} = \left(1 - \frac{N_v}{N_T - N_U}\right) \times 100$$

CPS2 violation value:

$$N_v = \sum_{\tau \in \mathcal{H}_{\text{DC}}} f_{\tau}$$

Scheduling horizon $< \mathcal{H}_{\text{DU}}$?

NO

Store flag variable

$$f_{\tau} = \begin{cases} 
1, & \text{if } ACE_{\text{CPS2}, \tau} > 50 \\
0, & \text{if } ACE_{\text{CPS2}, \tau} \leq 50 
\end{cases}$$

Interval $T_{\text{CPS2}} > 10\text{min}$?

NO

Raw $\text{ACE}$

YES
## Project Schedule

<table>
<thead>
<tr>
<th>Task 1.1</th>
<th>Develop Probabilistic Solar Power Forecasts</th>
</tr>
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<tbody>
<tr>
<td>1.1.1</td>
<td>Create Probabilistic Solar Power Forecasting Algorithms</td>
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<td>1.1.2</td>
<td>Create Probabilistic Behind-the-Meter Solar Power Forecasts</td>
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<td>Demonstrate ability to produce the full spectrum of forecast probabilities at multiple timescales, including day-ahead and sub-hourly</td>
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<td>Task 1.2</td>
<td>Develop Adaptive Reserve Algorithms</td>
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<td>1.2.1</td>
<td>Grid Condition Clustering</td>
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<tr>
<td>G/NG-1</td>
<td>All Year 1 milestones completed</td>
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<tr>
<td>Task 2.1</td>
<td>Validate Probabilistic Solar Power Forecast</td>
</tr>
<tr>
<td>2.1.1</td>
<td>Collect Ground Truth Data and Produce Utility-Scale Probabilistic Forecasts Operationally</td>
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<td>2.1.3</td>
<td>Coordinate with Validation Team</td>
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<tr>
<td>M2.1</td>
<td>Completed successful validation of the probabilistic forecasts according to the standards adopted by the Topic Area 1 awardee</td>
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<td>Task 2.2</td>
<td>Ingest Probabilistic Forecasts into ISO Energy Management System</td>
</tr>
<tr>
<td>M2.2</td>
<td>Successfully ingest probabilistic solar power forecasts into the ISO’s system with more than 95% reliability during a 1-month period</td>
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<tr>
<th>Budget Period 1</th>
<th>Budget Period 2</th>
<th>Budget Period 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
</tr>
</tbody>
</table>

Legend: Triangle = Milestone; Circle = Go/No-Go
## Project Schedule (2)

<table>
<thead>
<tr>
<th>Task 2.3</th>
<th>Estimate Adaptive Reserve Economic and Reliability Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.3.1</td>
<td>Create Adaptive Reserve Time-Series Data</td>
</tr>
<tr>
<td>2.3.2</td>
<td>FESTIV 118-Bus Simulations of Dynamic Reserve Impacts</td>
</tr>
<tr>
<td>2.3.3</td>
<td>FESTIV ISO Simulations of Adaptive Reserve Impacts</td>
</tr>
</tbody>
</table>

- **M2.3**: Reduce total production costs when compared to the case without adaptive reserves.

<table>
<thead>
<tr>
<th>Task 2.4</th>
<th>Estimate Risk-Parity Dispatch Economic and Reliability Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4.1</td>
<td>Incorporate Risk-Parity Algorithm into FESTIV</td>
</tr>
<tr>
<td>2.4.2</td>
<td>FESTIV Simulations of Risk-Parity Dispatch Impacts</td>
</tr>
</tbody>
</table>

- **M2.4**: Increase reliability scores when compared to the case with standard economic dispatch and deterministic forecast.

<table>
<thead>
<tr>
<th>Task 3.1</th>
<th>Provide Operational Probabilistic Forecasts</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1.1</td>
<td>Provide and Ingest Operational Forecasts</td>
</tr>
</tbody>
</table>

- **M3.1**: Successfully deliver probabilistic solar power forecasts to the ISO’s system with more than 98% reliability during the demonstration period.

<table>
<thead>
<tr>
<th>Task 3.2</th>
<th>Incorporate Adaptive Reserves into ISO Test Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2.1</td>
<td>Implement Adaptive Reserves</td>
</tr>
</tbody>
</table>

- **M3.2**: Demonstrate robust utilization of the adaptive reserve algorithms in the iTest system for a continuous period of 1 month.

<table>
<thead>
<tr>
<th>Task 3.3</th>
<th>Incorporate Risk-Parity Dispatch into ISO Test Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3.1</td>
<td>Analyze Historical Data to Determine Risk Parameters</td>
</tr>
<tr>
<td>3.3.2</td>
<td>Demonstrate Risk-Parity Implementation</td>
</tr>
</tbody>
</table>

- **M3.3**: Demonstrate robust utilization of the risk-parity dispatch in the iTest system for a continuous period of 1 month.

<table>
<thead>
<tr>
<th>Task 3.4</th>
<th>Provide the ISO Operator Training on Situational Awareness Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.4.1</td>
<td>Develop SolarView Training</td>
</tr>
<tr>
<td>3.4.2</td>
<td>Deliver SolarView Training</td>
</tr>
</tbody>
</table>

- **M3.4**: Conduct a minimum of two training sessions for the ISO’s operators.
# Project Team, Experience, and Qualifications

<table>
<thead>
<tr>
<th>Name</th>
<th>Organization</th>
<th>Experience and Qualifications</th>
</tr>
</thead>
</table>
| Qin Wang, Ph.D.          | NREL         | • Research engineer in the Power System Design and Studies group.  
                          |              | • Worked as a market operation engineer at Midcontinent Independent System Operator prior to joining NREL.  
                          |              | • Expertise in the area of power system operations, electricity market design, and renewable energy integration.  
                          |              | • Published more than 30 peer-reviewed papers and has been involved in multiple projects funded by DOE and industry. |
| Pengwei Du, Ph.D.        | ERCOT        | • Lead engineer for renewable integration with expertise in the area of grid operations, RE integration, and renewable forecasting.  
                          |              | • Previously a senior research engineer at PNNL. |
| Anthony R. Florita       | NREL         | • Research engineer for the Power System Design and Studies group.  
                          |              | • Specializes in data science, statistical methodology, and the modeling and simulation of multi-physics systems.  
                          |              | • Published 50+ peer-reviewed papers in the areas of solar energy, model predictive control, and building-to-grid modeling. |
| Jonathan Duckworth       | NREL         | • Analyst and developer in the Geospatial Data Science Group focusing on spatial application development and interactive data visualization.  
                          |              | • Primary developer for the OpenCarto platform, a web framework creating online geographic information system applications focused on data visualization. |
| Christopher Cassidy      | MDA          | • Principal data engineer responsible for the operation and maintenance of the renewable power forecasts for wind and solar generation. |