**PROJECT TITLE: COPING WITH COLD WEATHER IN MINNESOTA WIND ENERGY**

**I. PROJECT STATEMENT**

**Wind plants are growing rapidly in Minnesota**

Wind power has become one of the main renewable energy sources in Minnesota, accounting for nearly 18% of the total electricity production in the state and it continues to grow. The strength of wind energy in Minnesota is one of the reasons why we are on track to meet its “25 percent by 2025” renewable portfolio standard.

**Extreme winter weather condition pose challenges for wind farms**

Minnesota is one of the three coldest states in the U.S. and is in the top 10-15 states for annual snowfall. Our average monthly temperatures in winter are below 15°F. Extreme cold events, well below average, often occur in the winter when polar air sweeps across the upper Midwest. The most recent polar vortex event, which occurred at the end of January 2019, reached 20-year low temperatures between -13°F to -56°F. Many wind farms were not able to operate in these conditions.

**Impact of cold weather on wind turbines**

A primary challenge for wind turbines during cold weather is ice accumulation on blades. Ice forms under certain weather and precipitation conditions and often results in the need to shut down the turbine. The exact processes and conditions leading to ice accumulation, the hazards resulting from the ice, and possible mitigation strategies are not well understood. We know that ice build-up results in uneven loading on turbine blades and tower, increasing wear and tear on the turbine. Ice shedding during operation or “ice throw” is a major safety hazard for wind farm operators yet we know very little about the processes involved. Shut down of turbines because of detected ice accumulation results in revenue losses, which are estimated to be between 0.5% and 50% of annual production. Our ability to predict ice formation and, indirectly, the prediction of when wind energy farms may need to be shut down due to ice, is poor and this research seeks to improve capabilities.

**Objectives of project**

This project aims to investigate ice accumulation on wind turbine blades and develop predictive tools to help manage this hazard. We propose to: 1) measure air velocity, temperature, and moisture near wind turbines to reveal the icing process on wind turbine blades under various cold weather conditions; 2) develop an accurate model for the momentum, heat, and moisture transport of air in wind plants that affects the ice formation on turbine blades; 3) quantify the ice formation process on wind turbine blades; 4) investigate the amounts of ice accretion and the ice shapes on wind turbine blades; and 5) develop a mitigation strategy for minimizing the impact of ice on power production using a combination of forecasting, detection, and mitigation methods.

**II. PROJECT ACTIVITIES AND OUTCOMES**

**Activity 1: Laboratory measurements in wind tunnel and field measurements at wind research field station**

SAFL is equipped with a large wind tunnel that allows control and measurement of air speed and temperature around wind turbine models. Humidity sensors will be used to measure the moisture transport near model wind turbines. Ice formation on the blades of wind turbine models will be measured, and the shape and mass of the ice deposits will be quantified, together with the lift and drag forces of the iced turbine blades. Field data will be collected during the winter at the UMN wind research field station, located in Rosemount, MN, using our 2.5 MW wind turbine and 130 m metrological tower. Data will also be collected from wind farms in Minnesota through collaboration with industry partners.

**ENRTF BUDGET: $156,691**

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| **Outcome** | **Completion Date** |
| 1. A unique dataset of air velocity, temperature, and moisture near wind turbines. | March 31, 2021 |
| 2. A complete characterization of the icing process on the blades of wind turbines | March 31, 2022 |

**Activity 2: Develop modeling and prediction tools for air flows and ice formation on turbine blades**

We will develop a computational model to describe the air flows in wind farms and near turbine blades. The model will compute heat and moisture transport along the blade surface, and will describe both “rime icing” due to fog droplets and “glaze icing” due to precipitation. Based on the model, two engineering prediction tools will be developed. One will describe how wind turbines interact with the local atmosphere in cold weather. The other will quantify the ice formation process on wind blades. The computational model and the engineering prediction tools will be calibrated via the comparisons with the laboratory and field measurements data obtained in Activity 1.

**ENRTF BUDGET: $147,355**

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| **Outcome** | **Completion Date** |
| 1. A computational model to simulate the momentum, heat, and moisture transport of air in wind plants and the ice on turbine blades | June 30, 2022 |
| 2. An engineering prediction tool to describe cold air flows around turbines | Sept. 30, 2022 |
| 3. An engineering prediction tool to describe ice formation on turbine blades | Dec. 31, 2022 |

**Activity 3: Develop strategies for coping with low temperature for wind turbines**

Based on the measurement data obtained in Activity 1 and using the engineering tools developed in Activity 2, we will assess the various methods for anti-icing and de-icing of wind turbines, including heating blades internally, special coatings added during manufacturing, and de-icing spray after construction. The sensitivity of ice accumulation to meteorological variables will be studied, and the model predictions will be compared to data from icing wind tunnel experiments in SAFL and from the field study of wind turbine icing at the UMN station. A Minnesota site-specific database indicating wind speed, heat transfer, moisture transport, and ice formation will be created for wind turbines. Specific guidelines for site suitability evaluation of future wind plants in extreme cold weather will be provided based on the database.

**ENRTF BUDGET: $95,516**

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| **Outcome** | **Completion Date** |
| 1. Assessment and recommendation of methods for anti-icing and de-icing of wind turbines | Sept. 30, 2022 |
| 2. Minnesota site-specific database for wind speed, air temperature and humidity, and ice formation for wind turbines | Mar 31, 2023 |
| 3. Environmental report for wind turbines under low temperature and icy conditions to provide guidelines for existing and future wind plants | June 30, 2023 |

**III. PROJECT PARTNERS AND COLLABORATORS:**

The proposed study will be carried out in collaboration with the Minnesota energy industry. We have ongoing collaborations with local consultants, Xcel Energy, and DOE national laboratories and will incorporate these same partners into this new project.

**IV. LONG-TERM- IMPLEMENTATION AND FUNDING:**

This project will be completed within three years. The knowledge generated on the formation of ice on blades is information sought worldwide but especially applicable to MN and upper Midwest wind farms. We believe the research products generated (e.g. computation tools, site-specific database, and mitigation strategies) are a substantial contribution to wind energy with benefits for our regulated utilities and citizens of the state. The project will also establish Minnesota as a leader in cold regions wind energy research and development.

**V. SEE ADDITIONAL PROPOSAL COMPONENTS:**

**A. Proposal Budget Spreadsheet**

**B. Visual Component or Map**

**F. Project Manager Qualifications and Organization Description**