Environment and Natural Resources Trust Fund
2017 Request for Proposals (RFP)

Project Title: **ENRTF ID: 136-E**

Development of Efficient and Reliable Wind Turbine Transmission

Category: E. Air Quality, Climate Change, and Renewable Energy

Total Project Budget: $ 414,839

Proposed Project Time Period for the Funding Requested: 3 years, July 2017 - June 2020

Summary:

A reliable and efficient hydrostatic wind power transmission with advanced controls and energy storage will be tested at the University of Minnesota.The design will ultimately be demonstrated at Morris.

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Sponsoring Organization: U of MN

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Location

Region: Central, Metro

County Name: Hennepin, Stevens

City / Township: Minneapolis, Morris

Alternate Text for Visual:

The visual has five areas: 1) Challenge and solution, 2) Task 1: Advanced wind turbine control, 3) Task 2: Hydraulic hybrid drivetrain, 4) Task 3: Design of hydrostatic transmission for a wind turbine at Morris, MN and 5) 105 kW power regenerative wind turbine test platform at the University of Minnesota.

_____ Funding Priorities _____ Multiple Benefits _____ Outcomes _____ Knowledge Base

_____ Extent of Impact _____ Innovation _____ Scientific/Tech Basis _____ Urgency

_____ Capacity Readiness _____ Leverage _______ TOTAL ______%

PROJECT TITLE: Development of Efficient and Reliable Wind Turbine Transmission

PROJECT STATEMENT

In this project we will demonstrate a more reliable and efficient transmission for a wind turbine. A Hydrostatic Transmission (HST) is smaller, cheaper and more reliable than the currently used mechanical gearbox. The efficiency of the HST will be increased with advanced controls and energy storage. The improvements will be verified with experiments conducted on the existing 105 kW regenerative hydrostatic wind power research test stand in the Powertrain Lab of the Mechanical Engineering Department at University of Minnesota. A hydrostatic wind turbine will be designed for future field testing at Morris, MN.

A conventional wind turbine uses a heavy, fixed ratio mechanical gearbox transmission. Wind turbulence and gusts create impact loading on the gearbox and generator, causing early failure. A turbine is designed for 20 to 25 year life, but the gearbox typically fails in 6 to 7 years. A Department of Energy (DOE) study shows that premature gearbox failure significantly increases the cost of the energy because of turbine downtime, unplanned maintenance, increased warranty reserves, and replacement of heavy gearboxes using special machinery. Expensive power electronics are also required, since with a fixed gear ratio, the generator is unable to produce a constant 60 Hz. output.

An HST is a proven solution that is widely used in construction, agriculture and mining equipment because of its high power density and durability. Unlike a fixed-ratio gearbox, an HST has a variable ratio allowing the generator to run at 60 Hz regardless of the wind speed. Since the hydraulic fluid is slightly compressible, the transmission and generator are protected from mechanical shock, considerably improving turbine reliability.

Wind energy is a free and abundant source of renewable electricity that does not emit greenhouse gases. Minnesota's wind industry has been growing rapidly in recent years. Minnesota generates 3,235 MW of its electricity from wind, 16% of the state's total. Environmental benefits to Minnesota include saving 574 million gallons of water and reducing 4.9 million metric tons of CO_2 emissions annually. This is equivalent to removing one million cars from the road.

II. PROJECT ACTIVITIES AND OUTCOMES

The hydrostatic transmission for wind turbine proposed in this project consists of a fixed displacement pump and a variable displacement motor. The rotor drives the fixed displacement pump and the variable displacement motor drives the generator. Taking the availability of commercial hydraulic components, control simplicity, transmission efficiency and cost into consideration, this choice is the most practical solution. The wind power research test stand is equipped with sensors to measure the performance of the components and system. It also can simulate the rotor torque from the wind in real time using a fast acting hydrostatic drive. The energy production of the turbine can be increased with advanced turbine control and hybrid drivetrain. The performance of the proposed methods will be verified on the research test stand. Informed with these results, an experimental HST wind turbine will be designed for field testing at Morris.

Activity 1: *Development and validation of advanced wind turbine control* **Budget: $156,222**

The conventional wind turbine control strategy is simple and effective, but not optimal since rotor speed is used instead of instantaneous wind speed, adding a delay. A new advanced control method using instantaneous wind speed will be developed to overcome this weakness. The new method is expected to improve efficiency of the wind turbine.

Outcome	Completion Date
1. Demonstration of conventional control performance with simulation and experiment	*Sep 30, 2017*
2. Development of advanced control theory	*Mar 31, 2018*
3. Demonstration of advanced control performance with simulation and experiment	*Aug 31, 2018*

Activity 2: Design and testing of *hydraulic hybrid drivetrain* **Budget: $165,847**

The use of a hydrostatic transmission in a wind turbine, creates the possibility of adding energy storage to the turbine using a hydraulic accumulator. When the wind speed is above the rated speed, some of the excess wind energy can be stored in the hydraulic accumulator. This excess wind energy is released to the system when the wind speed is below the rated speed. This will increase the energy capture by maximizing the generator operating time at maximum output power.

Outcome	Completion Date
1. Design and optimization of hydraulic hybrid transmission	*Nov 30, 2018*
2. Development of a control and energy management approach for the hybrid transmission	*Mar 31, 2019*
3. Modification of the research test stand to include accumulator	*June 30, 2019*
3. Performance testing of hybrid transmission on research test stand	*Oct 31, 2019*

Activity 3: *Design of a hydrostatic transmission wind turbine for field testing* **Budget: $92,770**

A design will be developed up to a 1 MW hydrostatic wind turbine to be located at the West Central Research and Outreach Center in Morris, MN. The design will be the first step towards a field test and commercialization of the new wind turbine technology. The design will include a study of scaling the hydrostatic transmission technology as well as the specific site characteristics. Cost justification is required to understand the benefits. Costs will be compared based on the levelized cost of wind energy, a metric used by the DOE and others to evaluate the relative costs of electric-generating systems and the impact of technology design changes. The cost analysis will guide us to find the best design.

Outcome	Completion Date
1. Design of a hydrostatic wind turbine for the Morris location	*March 31, 2020*
2. Cost comparison of the of this wind turbine with alternatives	*June 30, 2020*

III. PROJECT STRATEGY

A. Project Team/Partners

Prof. Kim Stelson brings unique expertise in wind power, fluid power systems and advanced controls design. The team will be led by Prof. Stelson. Two graduate students and one undergraduate student will be participated in the project. Dr. Qing-Hui Yuan of Eaton Corporation, a leading hydraulic components manufacturer, will assist us in development and testing of the hydrostatic transmission. Dan Juhl, Director of Juhl Energy, a leader in the development of community wind, will guide us in developing suitable technology for community wind. Michael Reese, Director of Renewable Energy at WCROC will advise on the suitability of the hydrostatic wind turbine design for the Morris, MN site. Prof. Stelson and all student will be funded on the project. Dr. Yuan, Mr. Juhl and Mr. Reese will serve as volunteers on the project.

B. Project Impact and Long-Term Strategy

The development and demonstration of more reliable and cost-effective hydrostatic transmissions for wind energy will attract industry and investors to renewable energy, leading to the expansion of the green economy by enabling the practical use of hydrostatic powertrains in wind turbines. Accelerating the development of renewable energy and reducing the emissions of greenhouse gasses will provide jobs in the green economy and lead to a healthy environment for future generations. Hydrostatic transmissions are very suitable for community wind and can be retrofitted on existing turbines. The results of this project will stimulate the fluid power industry to develop more efficient hydraulic components for wind applications.

C. Timeline Requirements

The project will begin on July 1, 2017, and require 36 months to complete.

2017 Detailed Project Budget

Project Title: Development of Efficient and Reliable Wind Turbine Transmission

IV. TOTAL ENRTF REQUEST BUDGET : 3 years (07/01/2017-06/31/2020)

BUDGET ITEM *(See "Guidance on Allowable Expenses", p. 13)*	**AMOUNT**
Personnel:	
Project Investigator: Kim A Stelson (75% salary, 25% benefits) 1 month/yr for each year (0.25 FTE)	$ 78,791
Two Graduate Research Assistances (60% salary, 40% benefits) 2 students/yr each year (3.0 FTE)	$ 287,923
One summer undergraduate student @ 100%/ yr (0.58 FTE)	$ 15,000
Two academic year REU students @ 25%/yr (0.58 FTE)	$ 15,000
Professional/Technical/Service Contracts:	$ -
Equipment/Tools/Supplies:	$ -
Hydraulic Accumulator	$ 5,200
Hydraulic components and sensors to modify the regenerative test platform	$ 4,425
Materials and Suppllies (Hydraulic oil and maintenace of the test bed)	$ 5,000
Acquisition (Fee Title or Permanent Easements):	$ -
Travel:	
Trips to UMN Morris, MN campus for hydrostatic wind turbine site investigation (@2 trips/yr)	$ 3,500
Additional Budget Items:	$ -
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$ 414,839

V. OTHER FUNDS *(This entire section must be filled out. Do not delete rows. Indicate "N/A" if row is not applicable.)*

SOURCE OF FUNDS	**AMOUNT**	**Status**
Other Non-State $ To Be Applied To Project During Project Period: *Indicate any additional non-state cash dollars secured or applied for to be spent on the project during the funding period. For each individual sum, list out the source of the funds, the amount, and indicate whether the funds are secured or pending approval.*	N/A	*Indicate: Secured or Pending*
Other State $ To Be Applied To Project During Project Period: *Indicate any additional state cash dollars (e.g., bonding, other grants) secured or applied for to be spent on the project during the funding period. For each individual sum, list out the source of the funds, the amount, and indicate whether the funds are secured or pending approval.*	N/A	*Indicate: Secured or Pending*
In-kind Services To Be Applied To Project During Project Period: *Indicate any additional in-kind service(s) secured or applied for to be spent on the project during the funding period. For each type of service, list type of service(s), estimated value, and indicate whether it is secured or pending. In-kind services listed must be specific to the project.*	N/A	*Indicate: Secured or Pending*
Funding History:		
Equipment donations from industry (Bosch Rexroth, Danfoss, Donaldson, Eaton, ExxonMobil, and Linde)	$ 55,000	
Post-Doc funded by CCEFP, University of Minnesota matching funds	$ 141,500	
Remaining $ From Current ENRTF Appropriation: .	$ -	

Development of Efficient and Reliable Wind Turbine Transmission

Prof. Kim A Stelson, University of Minnesota

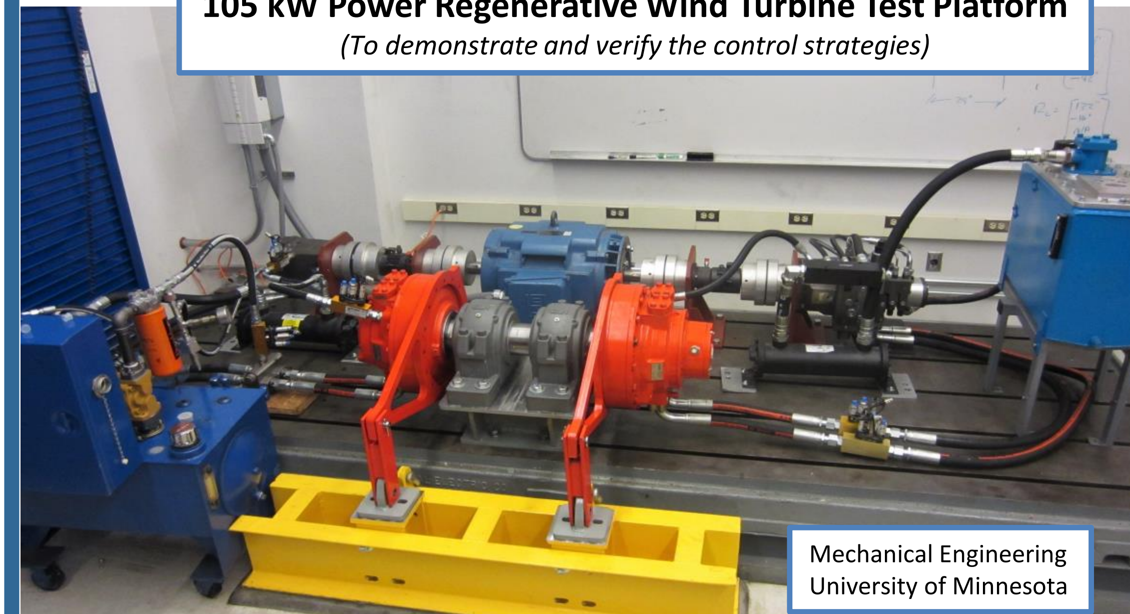
Challenge: Need an improved wind turbine transmission that is **Efficient, Reliable** and **Cost Effective**

Solution: Hydrostatic transmission

- **Efficient** because of continuously variable ratio, advanced controls and hybridization.
- **Reliable** because the slight compressibility of the hydraulic fluid protects the turbine from shock loading
- **Cost effective** because a heavy precision mechanical gearbox is replaced with smaller and commercially available hydraulic components and the power converter is eliminated.

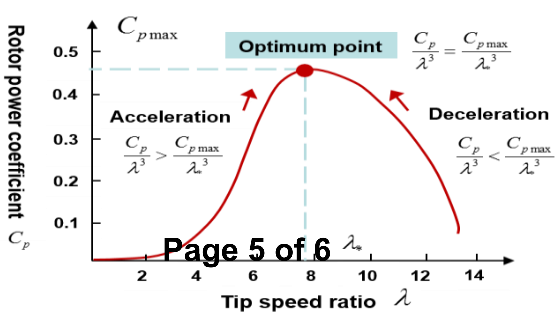
105 kW Power Regenerative Wind Turbine Test Platform

(To demonstrate and verify the control strategies)



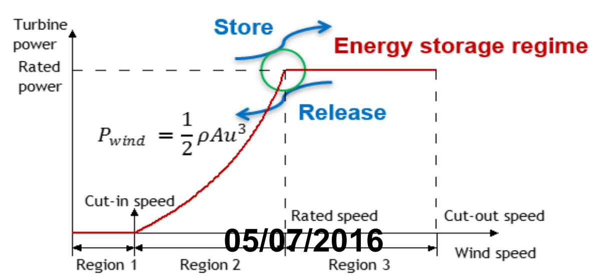
Advanced Wind Turbine Control

- Conventional control uses rotor speed.
- Advanced control will use estimated wind speed, improving efficiency
- Compare both methods using simulation and experiments



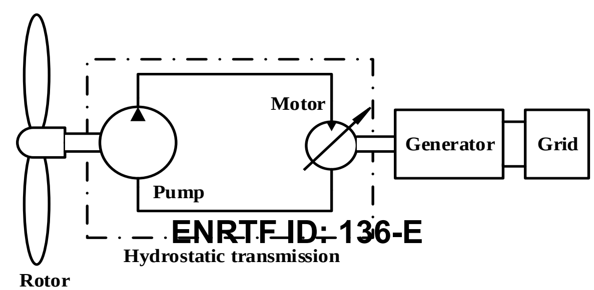
Hydraulic Hybrid Drivetrain

- Add an accumulator to the hydrostatic transmission to store energy.
- Hybrid and non-hybrid transmission will be compared using simulation and experiments



Design a Hydrostatic Transmission for a Wind Turbine at Morris, MN

- Cost comparison will be used to guide the design and compare with other solution
- Design will be field tested in the future at Morris, MN



Project Manager Qualifications

Kim A. Stelson is College of Science and Engineering Distinguished Professor at the University of Minnesota where he has been a member of the mechanical engineering faculty since 1981. He is also Director of the Center for Compact and Efficient Fluid Power (CCEFP). Stelson obtained his bachelor's degree from Stanford University and his master's and doctoral degrees from Massachusetts Institute of Technology. He has published prolifically in the areas of mechanical design, manufacturing, system dynamics and control, fluid power, hydraulic hybrid vehicles and wind energy. He has received many honors and awards and is a Fellow of American Association for the Advancement of Science (AAAS). Stelson will have overall responsibility for all phases of the project including administration, finance, progress reporting, research planning, supervision of graduates students and consultation with outside experts.

Organization Description

The project will be located at the Center for Compact and Efficient Fluid Power (CCEFP) in the Mechanical Engineering Department of University of Minnesota-Twin Cities. CCEFP is a National Science Foundation Engineering Research Center founded in 2006 (see www.ccefp.org for more information). CCEFP is the leading academic research center in the world for fluid power. The mission of the CCEFP is to "change the way fluid power is researched, and taught." CCEFP is a network of seven universities and seventy companies. Technologies developed by CCEFP are demonstrated on six test beds. Wind power is one of the six CCEFP test beds. The CCEFP headquarters is at the University of Minnesota.