CENTER FOR COMPACT AND EFFICIENT FLUID POWER

A National Science Foundation Engineering Research Center

IREE INSTITUTE ON THE ENVIRONMENT

UNIVERSITY OF MINNESOTA
Driven to Discover

Hydrostatic Transmission for Wind Power Generation RS-0008-09

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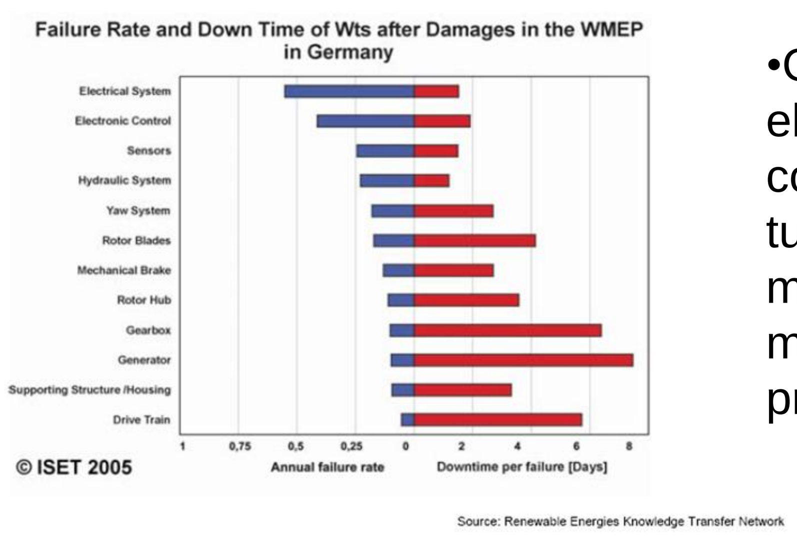
Motivation

• DOE goal of 20% of U.S. energy from wind by 2030

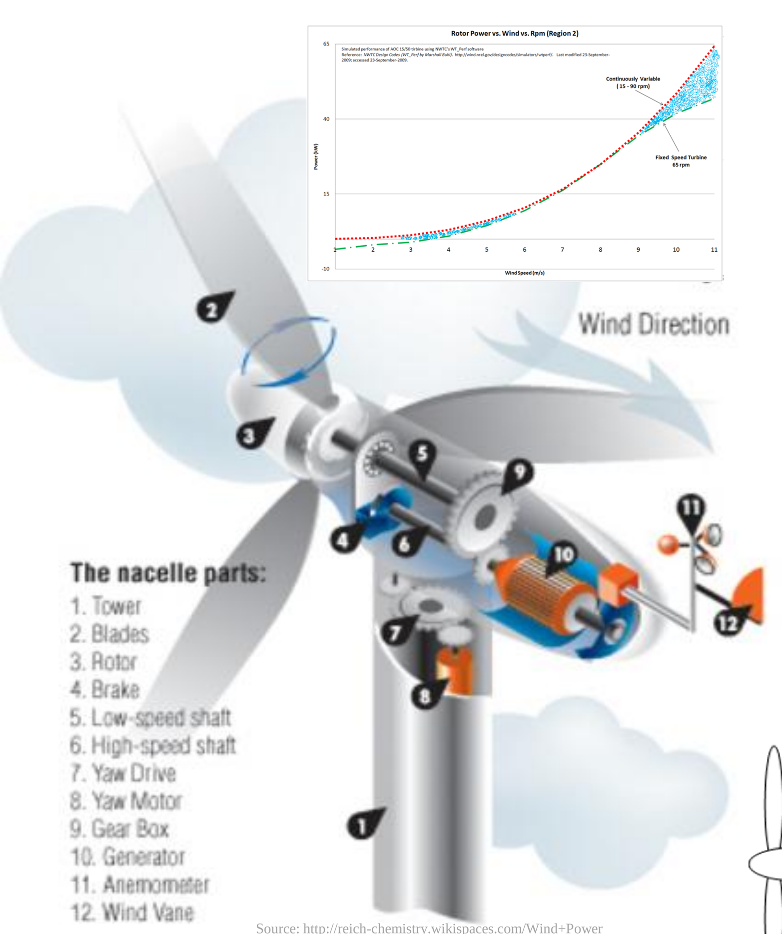


•Gearboxes and power electronics used in most conventional wind turbines have been a major cause of maintenance and premature failure

•Mid-size wind turbines (100– 1000 kW) are an underserved market niche that aligns well with the current state of the art in hydrostatic transmissions

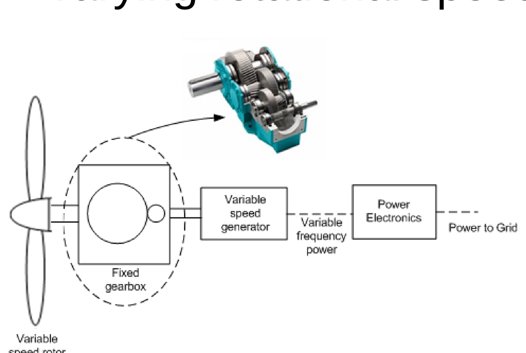
•The need of the hour is to design turbines that are simple yet reliable and robust and at the same time reduce the lifetime cost of energy

Conventional Wind Turbine

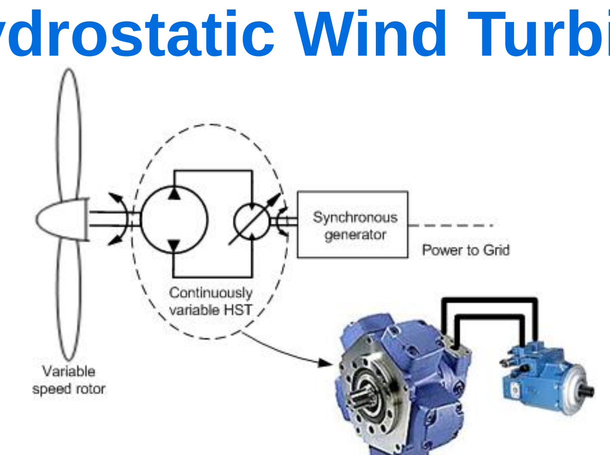


•Conventional utility scale wind turbines are mostly variable speed machines since a variable speed machine produce more energy than a fixed speed turbine

•Variable speed wind turbines require power electronics to allow the generator to operate at varying rotational speed



Hydrostatic Wind Turbine



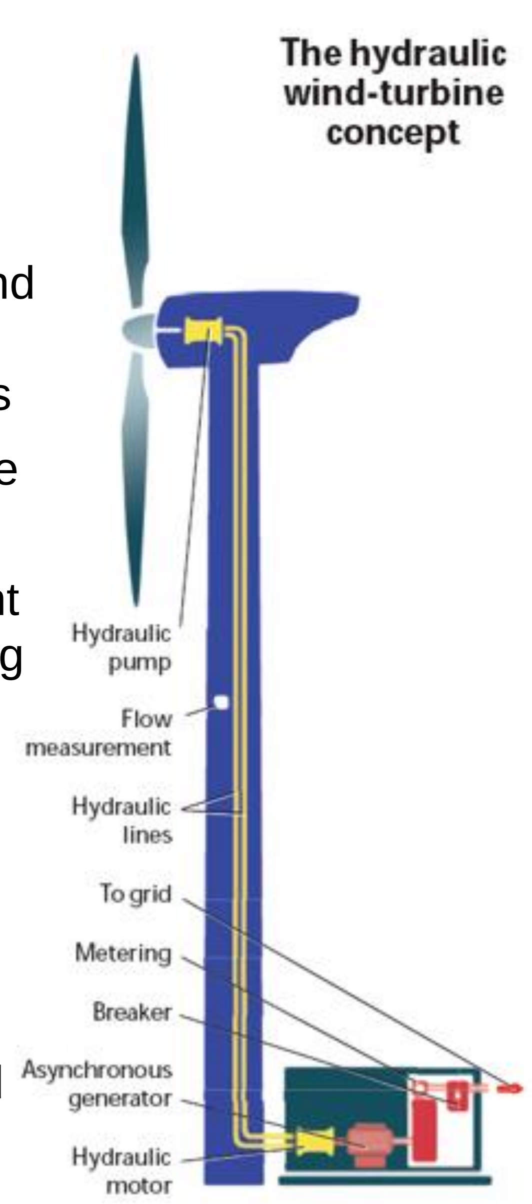
• Fluid link between turbine blades and generator in an HST wind turbine allows for more flexible layout options

• Generator can be removed from the nacelle and placed at ground level

• An HST is inherently more compliant and damped than a gearbox, reducing high stress transients through the system

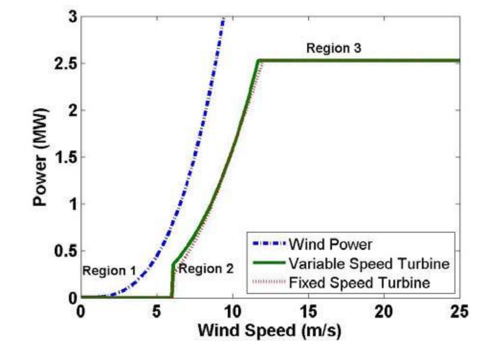
•The HST decouples the wind power from the generator, allowing power spikes from the wind to be better controlled

• Loads within an HST can be carried by a fluid film, allowing theoretical infinite life

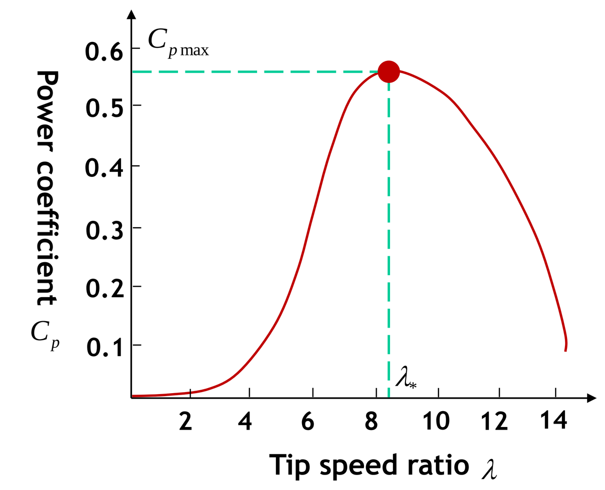


Background

• The objective of wind turbine power generation control for different wind speeds can be divided into four regions



• Wind power coefficient (Cp) is the ratio of wind power captured by the rotor, which is limited by the Betz Limit at 0.593.



$$P_{wind} = \frac{1}{2}\rho A \upsilon_{wind}^{3}$$

$$C_p = \frac{P_{rotor}}{P_{wind}}$$

• Cp is determined by the tip speed ratio of the rotor (TSR)

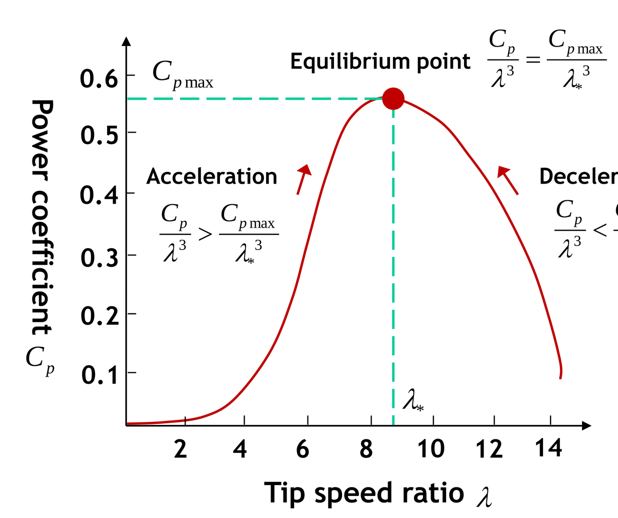
$$\lambda = \frac{\omega_{rotor} R}{\upsilon_{wind}}$$

• The objective of a controller design in region 2 is to make the rotor always work at the optimal TSR, which allows for maximum wind energy captured.

• To maintain the optimal TSR, the rotor speed needs to be adjusted in real-time given the different input wind speeds.

Control Strategy

• A control law for region 2 operation is to let the control torque (rotor shaft reacting torque) be given by



$$\tau_c = K\omega_{rotor}^{2}$$

where the gain K is given by

$$K = \frac{1}{2}\rho A R^3 \frac{C_{p\max}}{\lambda_*^3}$$

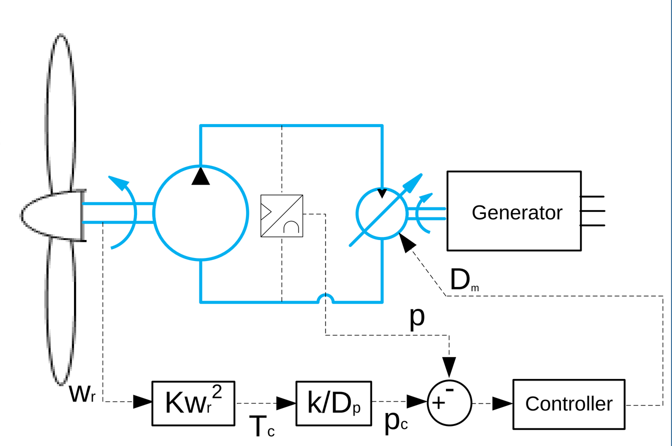
The rotor dynamic equation

$$\dot{\omega} = \frac{1}{J}(\tau_{aero} - \tau_c)$$

$$= \frac{\rho A R^3 \omega^2}{2J}\left(\frac{C_p}{\lambda^3} - \frac{C_{p\max}}{\lambda_*^3}\right)$$

• For hydrostatic wind turbine, the control strategy is to convert control torque command to pressure command, which is governed by

$$p_c = \tau_c \cdot \frac{\eta_p}{D_p}$$

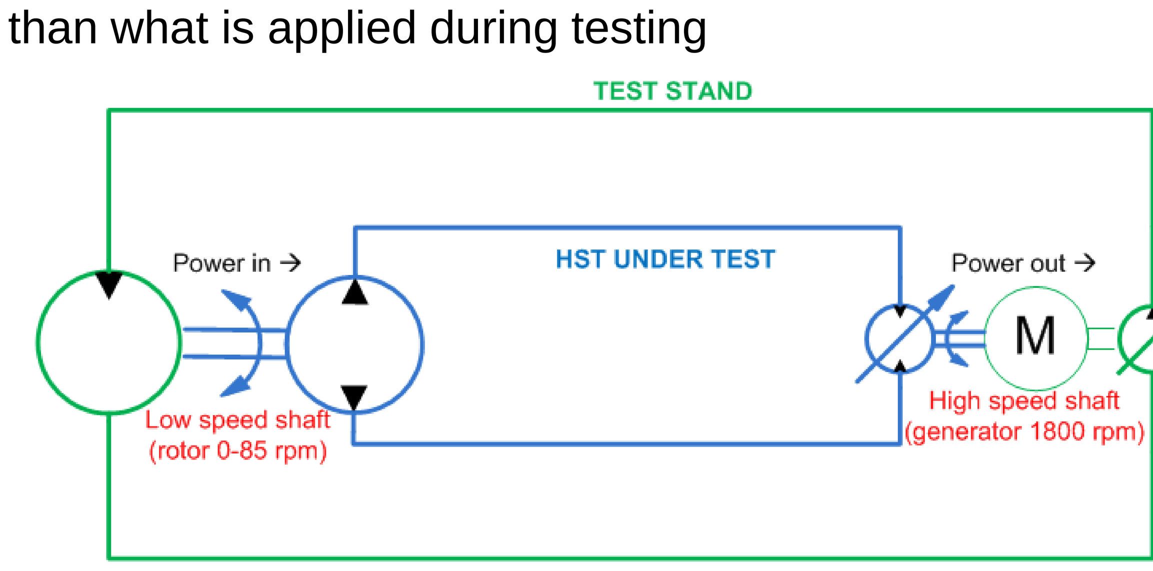


Test Stand

• In order to run repeatable tests to analyze system design and control strategy options, a test stand is being built to replicate wind turbine loads in the laboratory

•80,000 $ worth of in kind hardware donations and 10,000$ in cash donations have been sanctioned by collaborating industries

•The test stand is regenerative, so it consumes less power than what is applied during testing



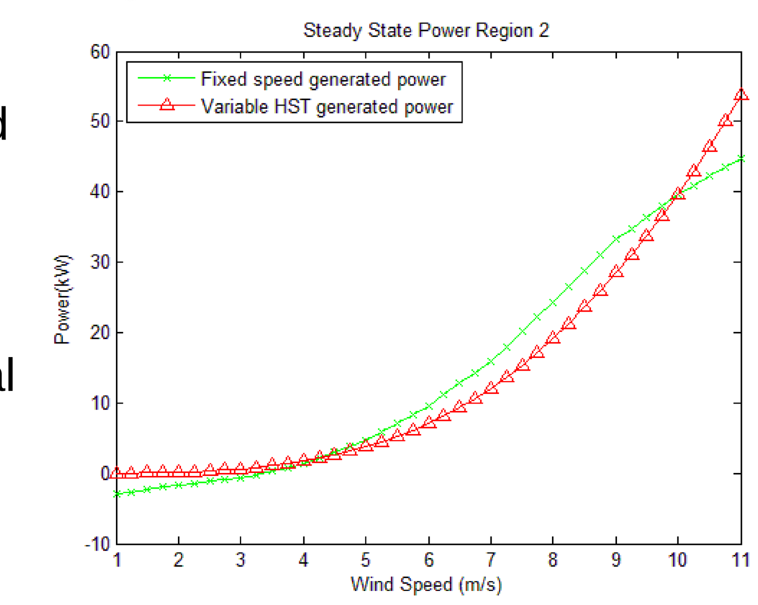
Simulation Results

•Simulations were conducted by interfacing NREL's NWTC design code softwares with Matlab/Simulink model of continuously variable hydrostatic transmission

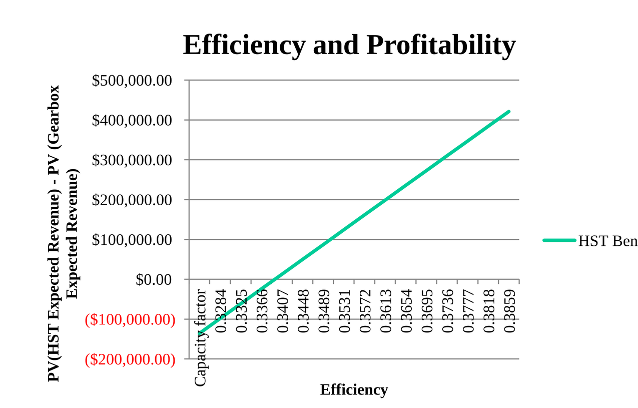
•AOC 15/50 50KW fixed speed turbine was chosen as a baseline turbine for this investigation

• HST using typical components modeled and simulated to steady state for range of wind speed through region 2

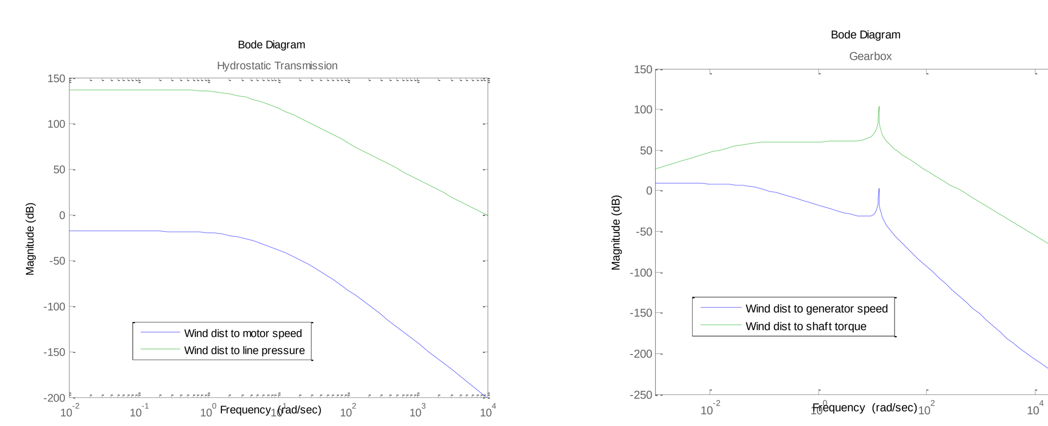
• Variable HST with typical component efficiencies compared with a fixed speed gearbox



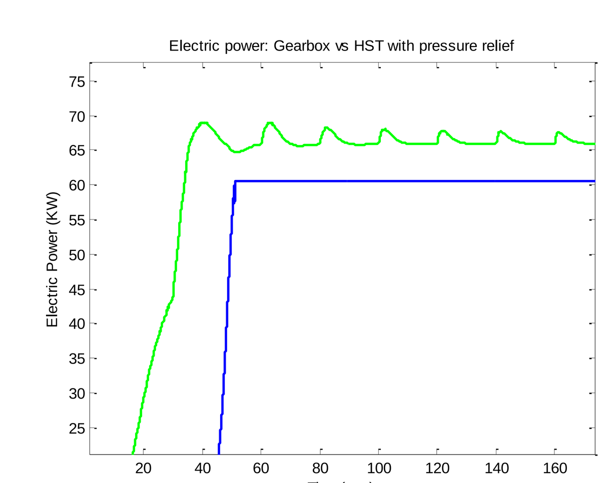
•Economic analysis conducted at University of Minnesota Morris indicate that HST technology is commercially viable given a capacity factor greater than 34.3%, which is achievable



• Inherent damping of HST provides smoother output torque than a rigid gearbox in dynamic conditions



•Use of pressure relief valve could make it possible to produce smoother power output for near or above rated turbulent wind conditions



Next Steps

• Develop advanced controls to optimize power generation by analyzing trade-offs between aerodynamic and mechanical efficiency

• Investigate tandem pump/motor configurations to eliminate low-efficiency displacement requirements and explore storage ideas to capture more energy

• Currently we are working on a DOE grant with a major hydraulic company and a leading wind turbine manufacturer to develop HST for off shore wind turbine applications

Industry and university collaborators

University of Minnesota Driven to Discover; University of Minnesota Morris; RFI Racine Flow Meter Group; Rexroth Bosch Group; Eaton Powering Business Worldwide; IREE Institute on the Environment, University of Minnesota; St. Anthony Falls Laboratory