CENTER FOR COMPACT AND EFFICIENT FLUID POWER

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Hydrostatic Transmission for Wind Power Generation RS-0008-09

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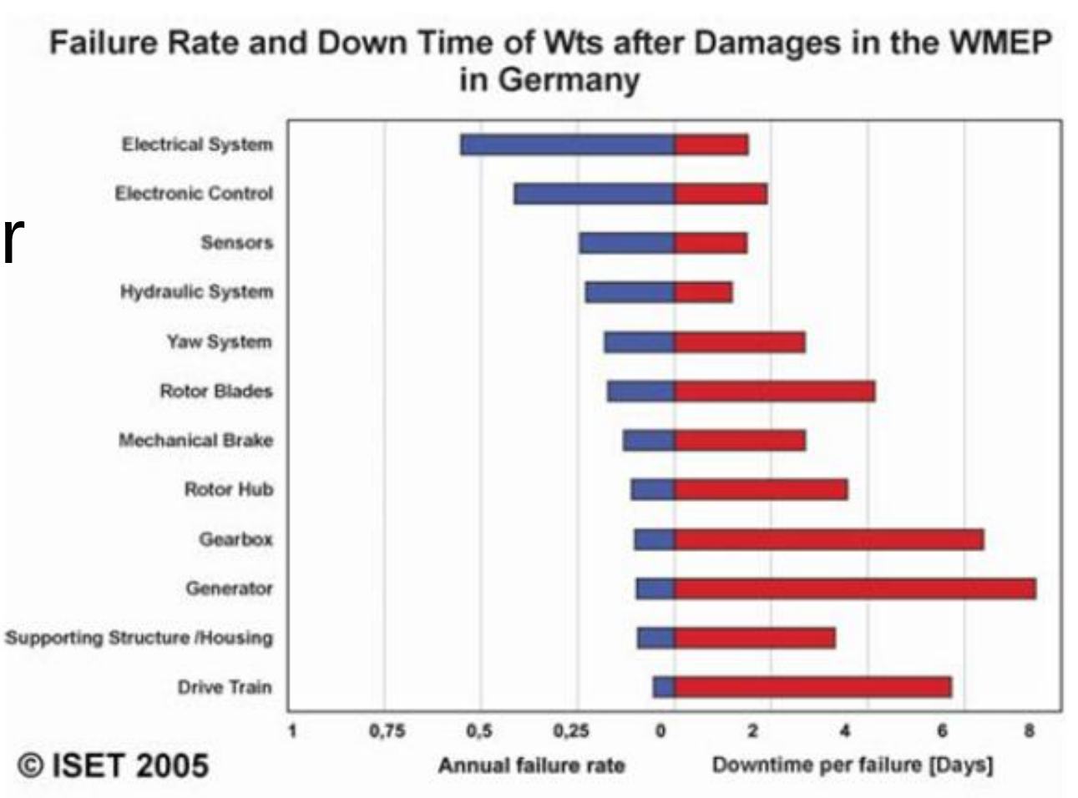
Motivation

- DOE goal of 20% of U.S. energy from wind by 2030
- Gearboxes used in most conventional wind turbines have been a major cause of maintenance and premature failure
- Wind turbines should be made as simple as possible while achieving high reliability and power quality
- Conventional variable speed wind turbines require power electronics to allow the generator to operate at varying rotational speed

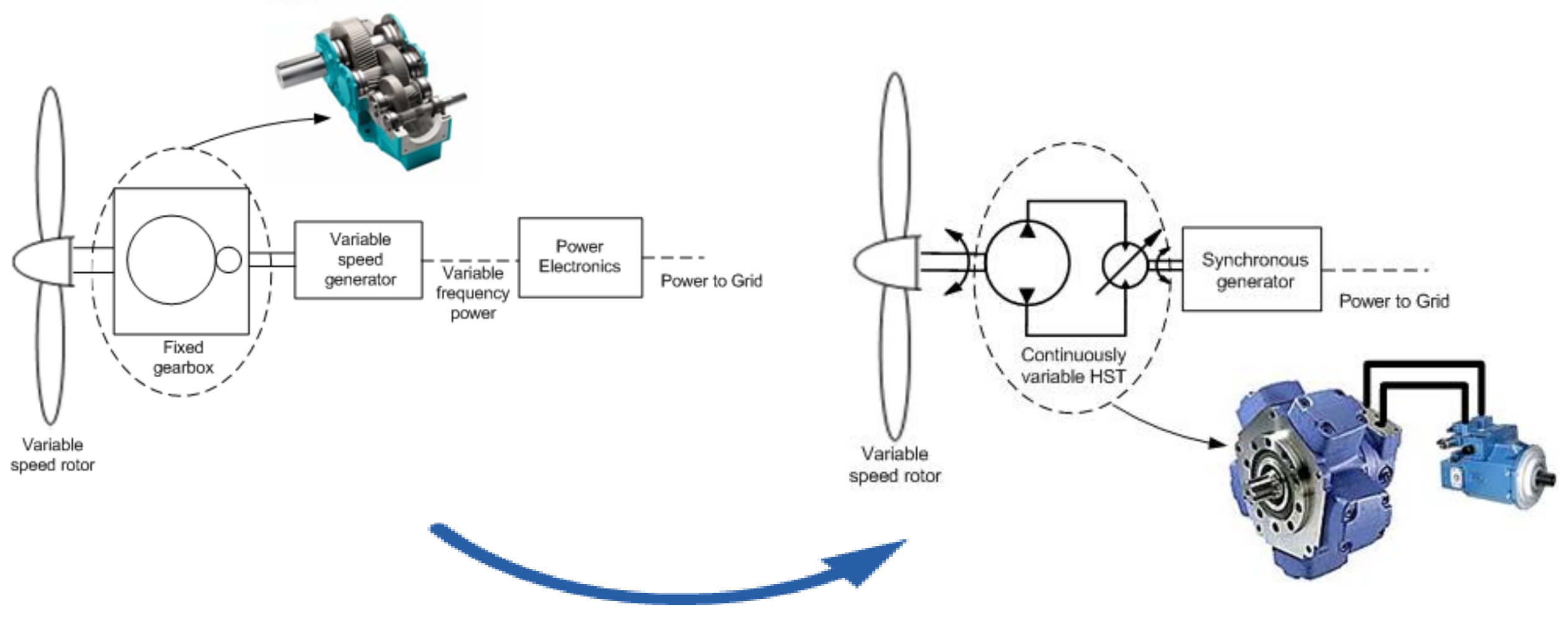


Source: Renewable Energies Knowledge Transfer Network

- Power electronics also contribute to system unreliability as well as overall cost and complexity
- It would be ideal if the functions of the gearbox and power electronics could be performed by a single, robust system
- Mid-size wind turbines (10 – 1000 kW) are an underserved market niche that aligns well with the current state of the art in hydrostatic transmissions

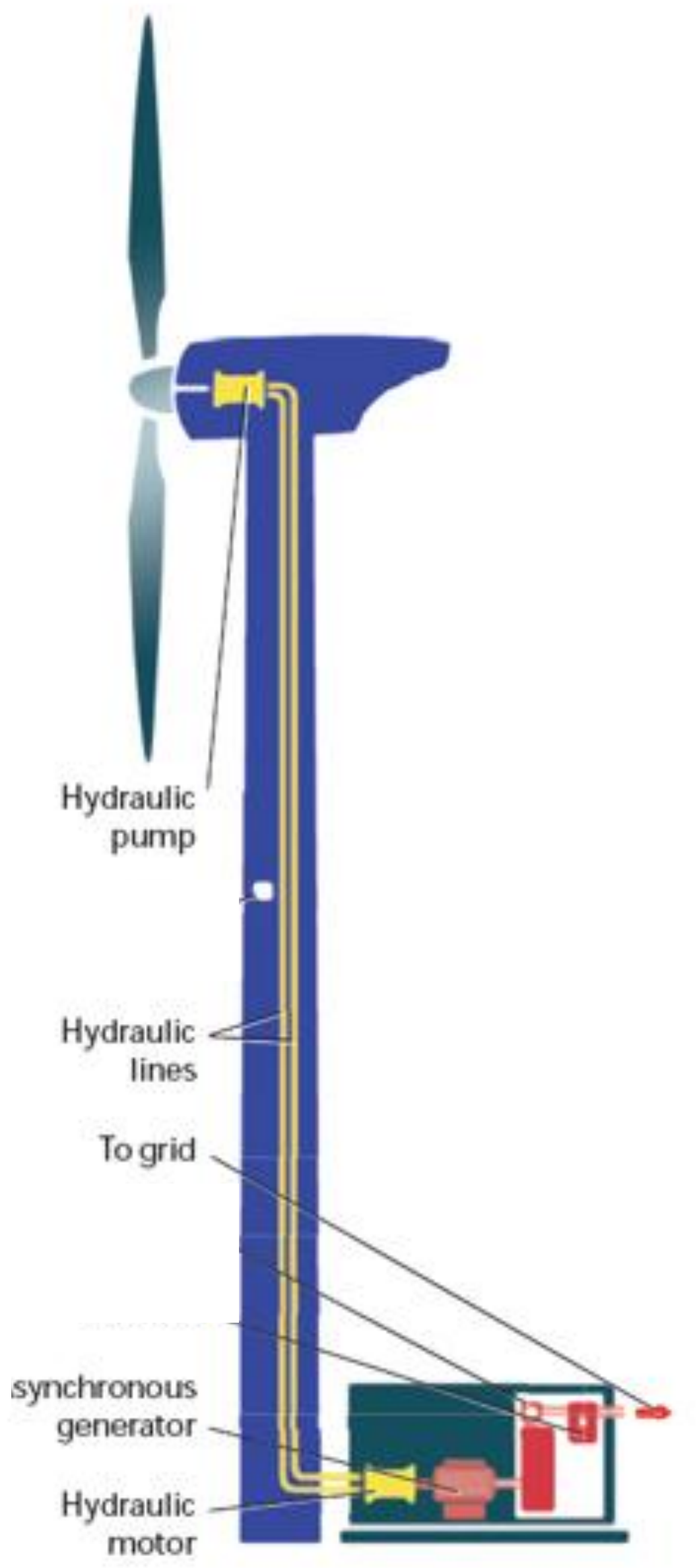
Goals

- Design a continuously variable hydrostatic transmission (HST) capable of improving reliability and productivity of mid-size wind turbines
- Build a test stand to allow for system and component testing as well as development of controls for optimized performance



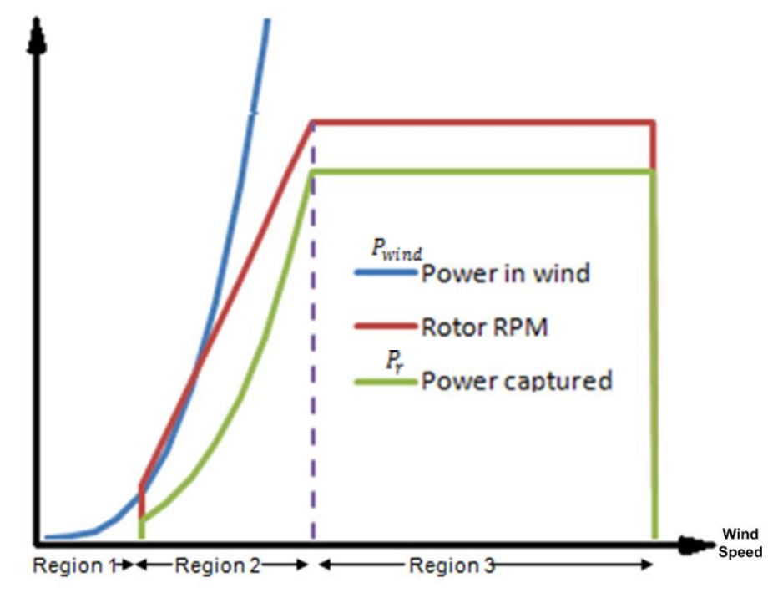
Additional Benefits

- 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 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

- Variable speed wind turbines are capable of generating more power than fixed speed wind turbines
- A specific blade design has an optimal tip speed ratio (TSR) which allows for maximum power coefficient (Cp)
- Cp is limited by the Betz Limit at 0.593
- The rotor speed must be able to vary with wind speed to maintain TSR and optimum Cp, maximizing power captured



$$TSR = \frac{v_{tip}}{v_{wind}} = \frac{\omega r}{v_{wind}}$$

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

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

- Power electronics control the generator torque in conventional variable speed wind turbines proportional to the rotor speed squared to achieve optimum Cp and TSR

$$P_r = T_r \omega_r$$

$$P_{r\,max} = P_{wind} C_{p\,max} = \frac{1}{2}\rho_{air} A {v_{wind}}^3 C_{p\,max}$$

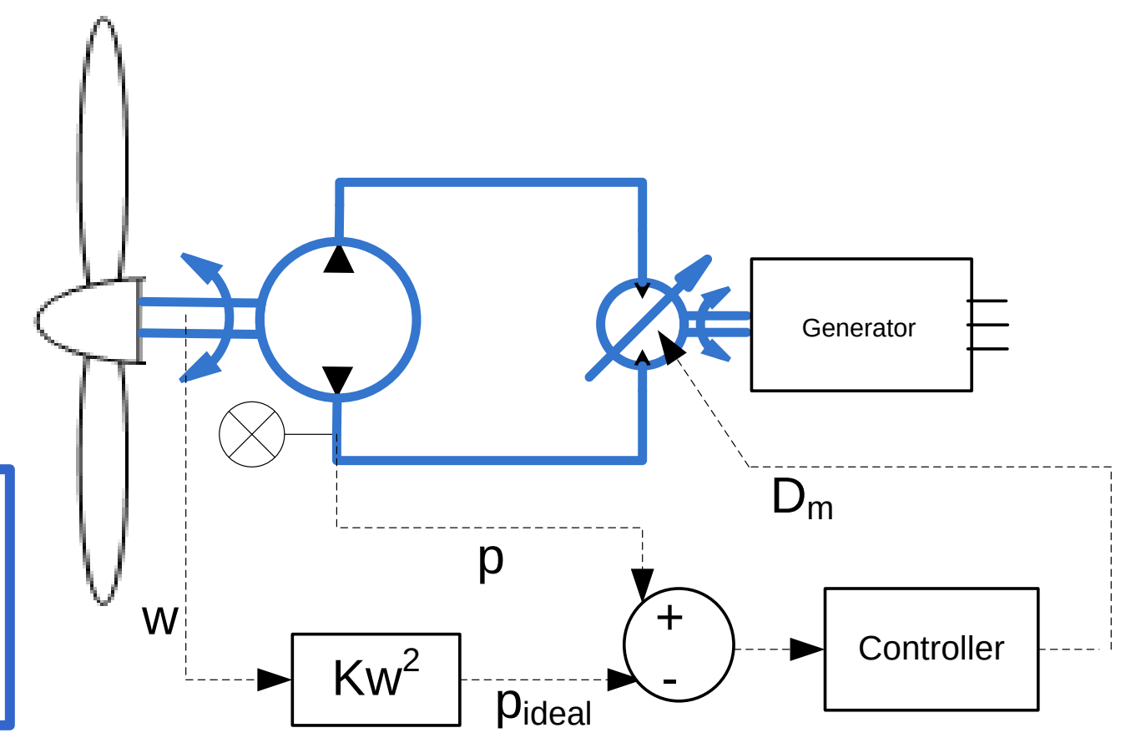
$$\boxed{T_{r\,ideal} = \frac{1}{2}\rho_{air} A \frac{{\omega_r}^2}{{TSR_{ideal}}^3} C_{p\,max} = K{\omega_r}^2}$$

Schematics/Control Strategy

- The HST will control the pressure which directly relates to rotor torque

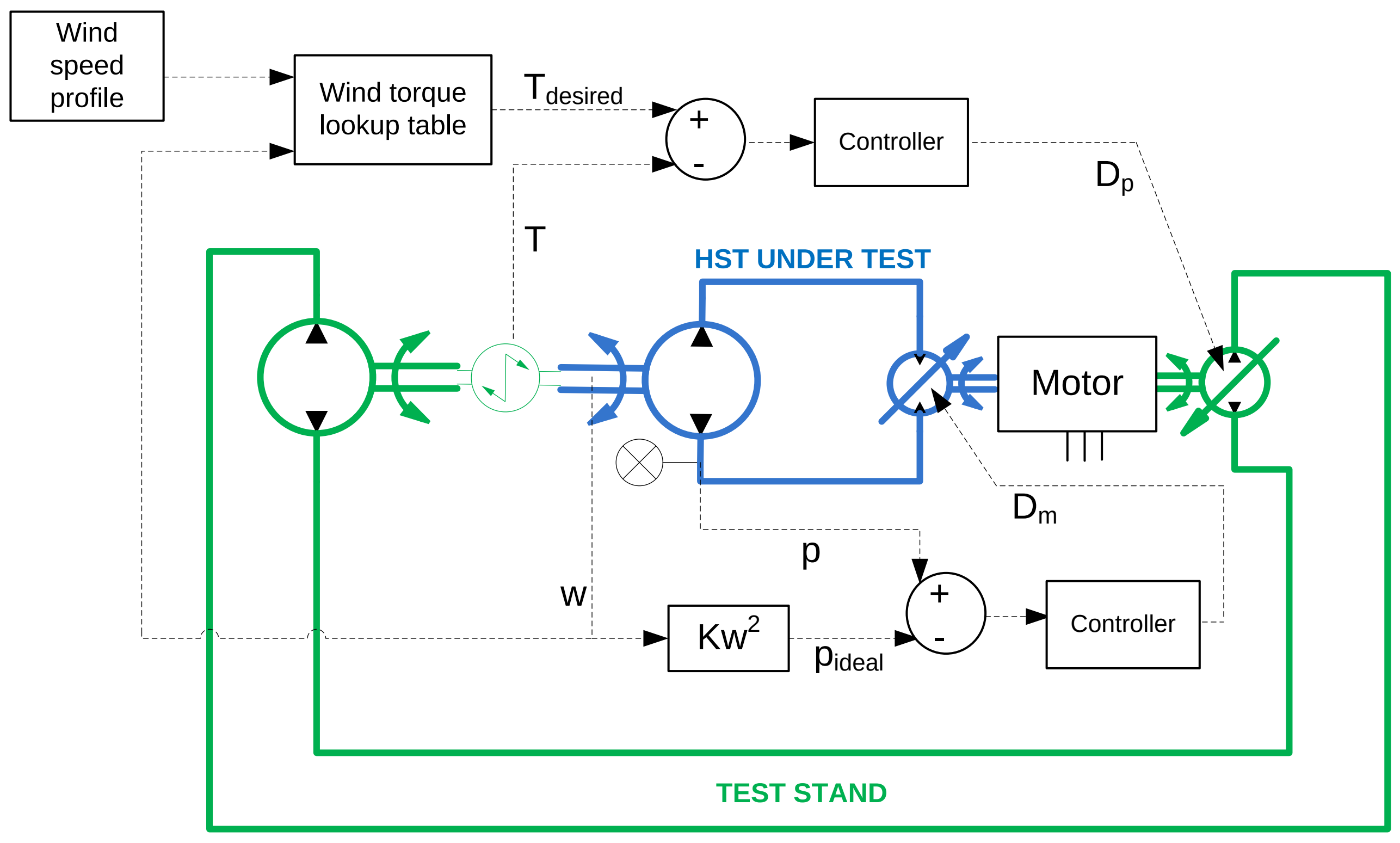
$$T_{r\,ideal} = \frac{p_{ideal} D_p}{2\pi \eta_{p\,mech}}$$

$$\boxed{p_{ideal} = \frac{\frac{1}{2}\rho_{air} A {\omega_r}^2 C_{p\,max} 2\pi}{D_p \eta_{pmech} {TSR_{ideal}}^3} = K_2 {\omega_r}^2}$$



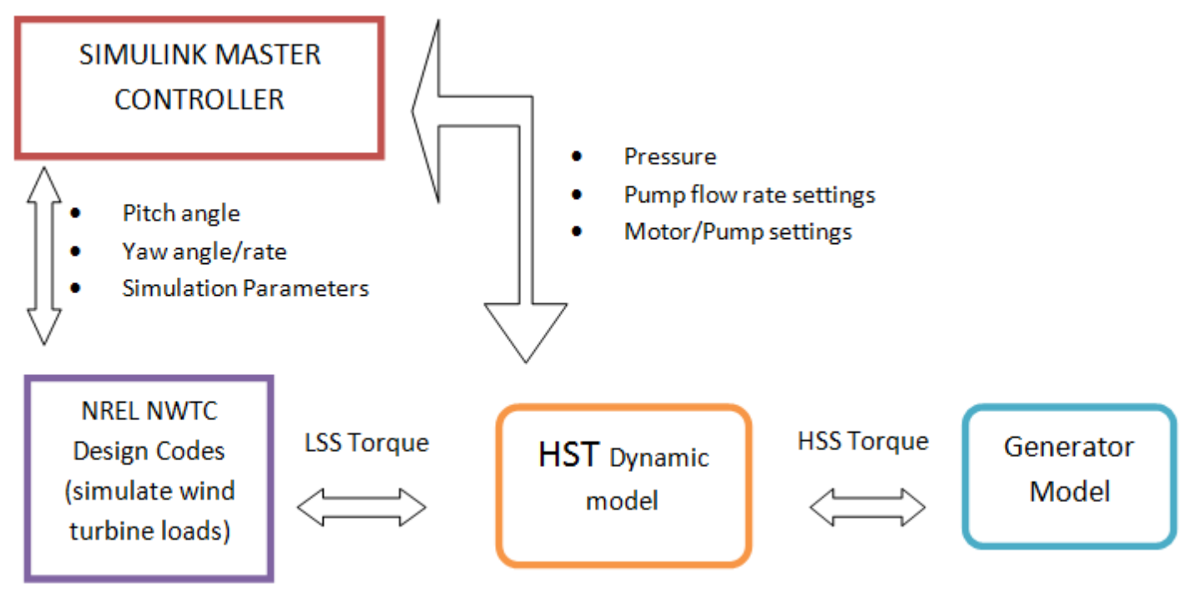
Test Stand

- In order to run repeatable tests to analyze system design and control strategy options, a test stand will be built to replicate wind turbine loads in the laboratory
- Software will calculate the ‘wind torque’ for a specified wind profile and controls the test stand to apply that torque to the transmission under test
- The test stand is regenerative, so it consumes less power than what is applied during testing



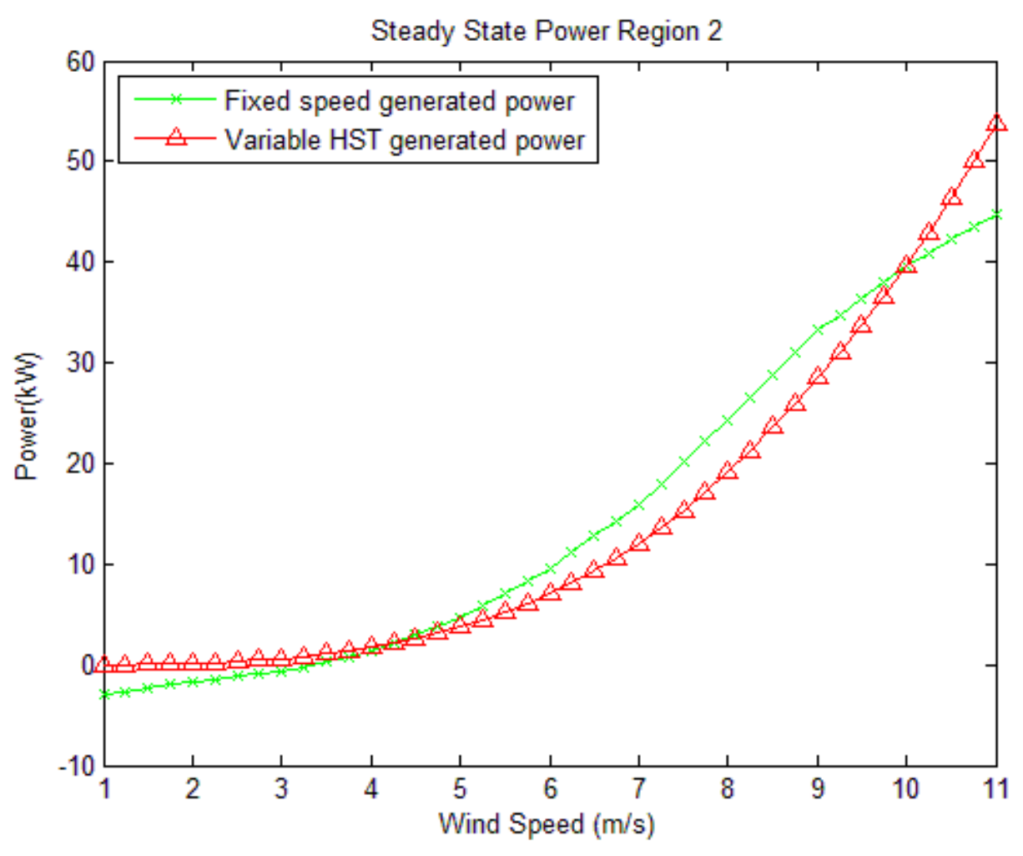
Simulation

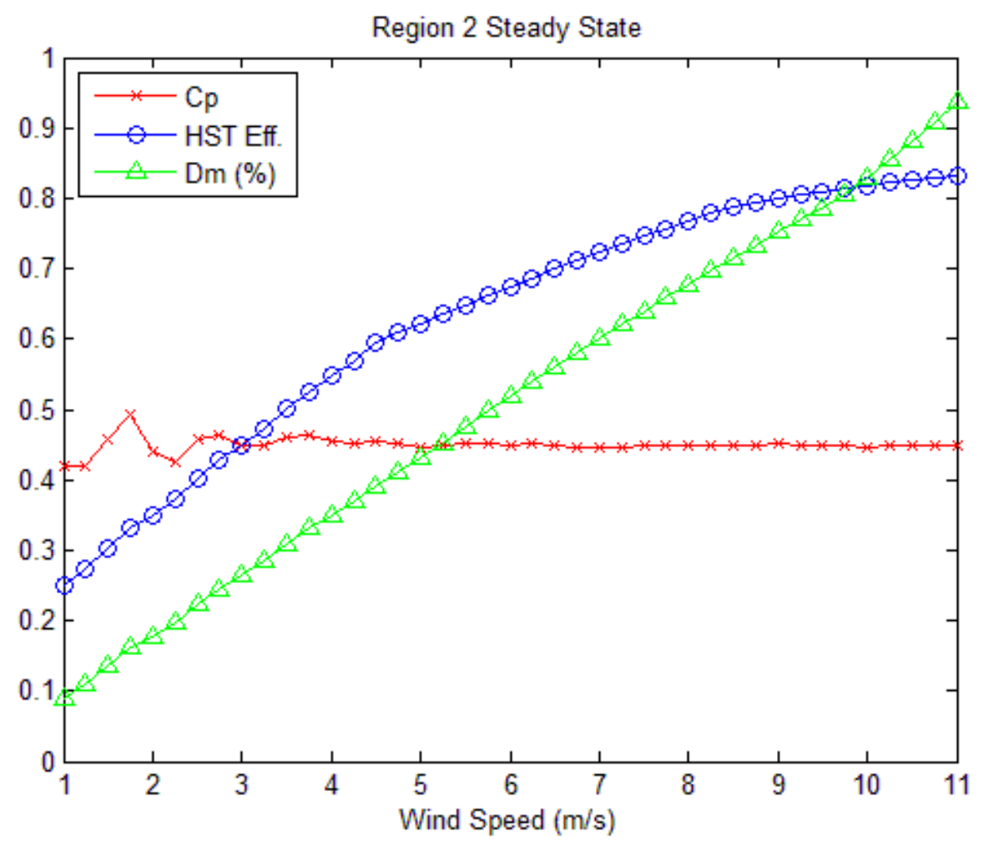
- Interface NREL’s NWTC design code software with Matlab/Simulink model of continuously variable hydrostatic transmission
- Use available aerodynamic blade performance data for the AOC 15/50 50 kW wind turbine



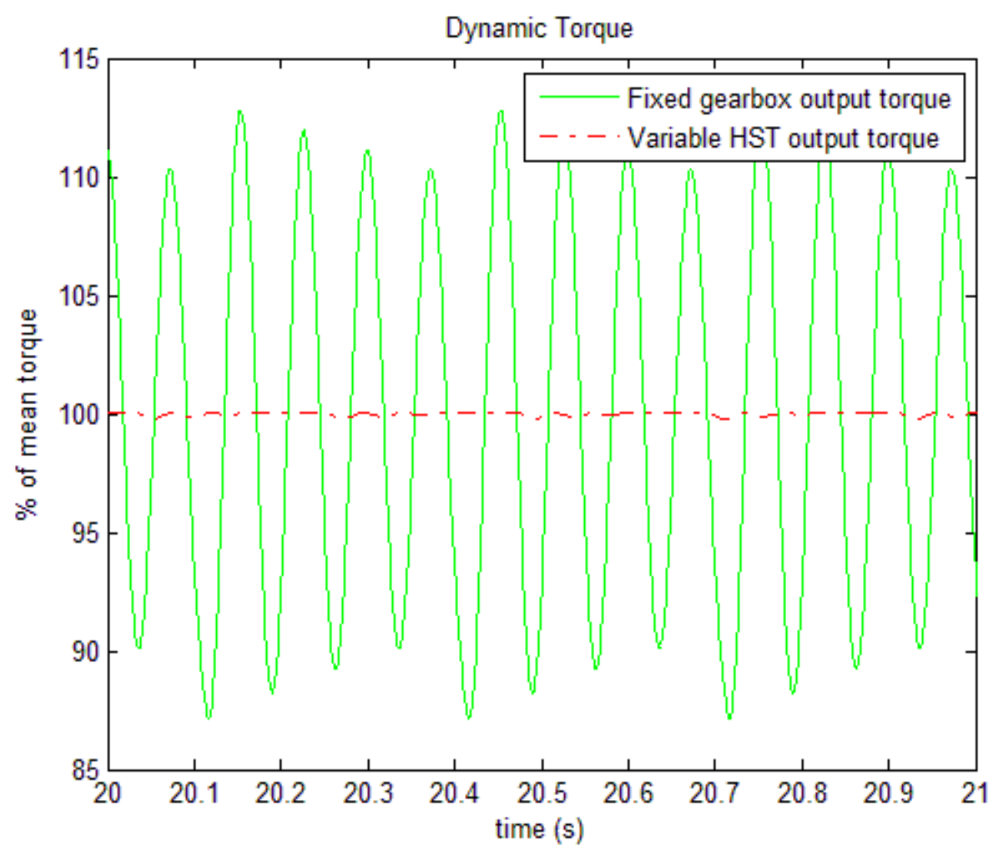
Preliminary Findings

- 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





- Typical hydrostatic pump/motors have low efficiency at low displacement settings
- Despite low efficiency at low wind speeds, higher power is achieved near rated wind speed
- Nearly constant Cp
- Control and natural damping of HST provides smoother output torque than a rigid gearbox in dynamic conditions
- Analysis included a 10% input (wind) torque fluctuation at 4.5 Hz, equal to the frequency of the tower shadow effect at rated speed



Next Steps

- Develop advanced controls to optimize power generation by analyzing trade-offs between aerodynamic, electrical and mechanical efficiency
- Investigate tandem pump/motor configurations to eliminate low-efficiency displacement requirements
- Development of high efficiency pumps and motors will be driven by this new application

Industry and university collaborators

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