Active Drivetrain Control to Improve Energy Capture of Wind Turbines

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Abstract

At its core, the generation of electrical power from mechanical energy sources requires the careful matching of the source characteristics with those of the electrical grid. Wind energy presents additional challenges in that the source is highly variable. Current solutions to this problem, including active blade pitch control and power conditioning, have proven to be effective, but with additional course. If wind is to supply 20% of the nation's power, more of this energy must be harvested.

A Differential Continuously Variable Transmission (DCVT) is introduced to control the effective speed ratio between the turbine rotor and the generator under computer control. Two controllers are presented: one designed to maintain constant generator speed; the second to maintain a specific tip speed ratio (TSR).

The controllers are implemented in a dynamic simulation of the CART wind turbine with pitch control disabled. Simulation results indicate that increased energy capture is possible due to dynamic response to rapidly changing winds. The simulation also indicates that steady state performance is improved by allowing the rotor to seek it's optimal rotational speed through a wider range of operation, without the additional costs associated with active blade pitch control.

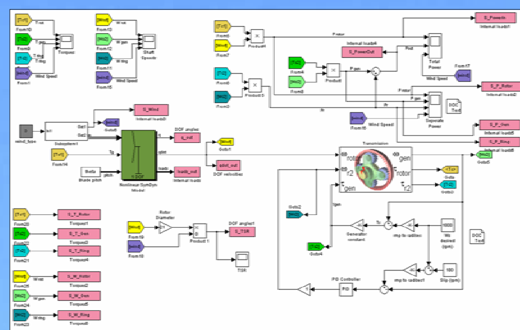
Objectives

Assess and quantify the advantages of a variable speed, fixed mesh drive train for mid-size wind turbines without active blade pitch control. Two control laws are investigated in this study:

1)Generator speed control: maintain constant generator rotational speed.

2) TSR control: achieve target tip speed ratio in an attempt to maximize power capture.

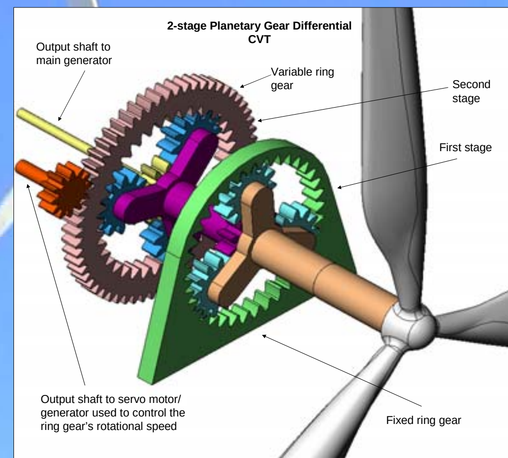
The simulation results reveal variations in torque transients experienced in the gearbox as a result of the combination of wind variations and controller objectives.



Schematic representation of the two-stage planetary differential continuously variable transmission

System Description

- In low wind speeds, the servo motor routes power through the system, via the ring gear, onto the grid by the main generator
- In higher winds, the servo motor operates as a generator, capturing additional power from the wind, which can either be stored for later use or routed onto the grid

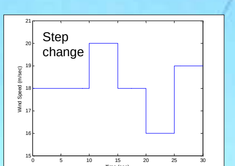


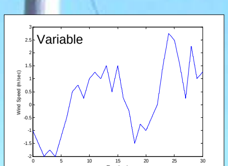
Methods

All simulations were implemented in Simulink, utilizing SymDyn as the aeroelastic model, where the only DOF enabled was generator azimuth. We modeled the system with the CART turbine since data is publicly available, but this simulation is easily adaptable to other turbines.

A kinematic transmission model was used, but a complete inertial model could easily be implemented in this modeling structure.

Three different wind types were modeled:
- Constant wind speed
- Step-changing wind
- Variable wind





Two different control schemes were implemented using the following control laws:
- Constant generator speed

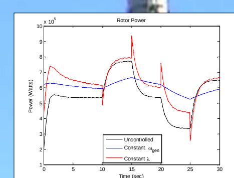
$$\omega_R = k_P\left(\overline{\omega}_{desired} - \omega_{gen}\right) + k_I\int\left(\overline{\omega}_{desired} - \omega_{gen}\right)dt$$

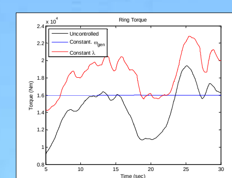
- Constant TSR

$$\omega_R = k_P\left(\overline{\lambda}_{desired} - \frac{R\omega_{rot}}{v_{wind}}\right) + k_I\int\left(\overline{\lambda}_{desired} - \frac{R\omega_{rot}}{v_{wind}}\right)dt$$

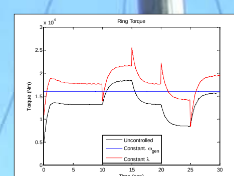
Results

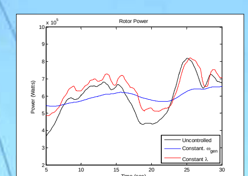
Step-change wind speed results:
- The constant generator speed controller had smallest transient response.
- The Constant TSR system resulted in the largest control torques.
- The constant TSR system had large torque transients.





Variable wind speed results
- On average, both systems increased power.
- Constant generator controller reduced torque transients.
- Constant TSR system increased torque transients.





	Uncontrolled		Constant ω_{gen}		Constant TSR	
	Ring Gear Torque (kNm)	Fluctuation (kNm)	Ring Gear Torque (kNm)	Fluctuation (kNm)	Ring Gear Torque (kNm)	Fluctuation (kNm)
Max	19.4	4.9	16.0	0.0	22.8	4.3
Mean	14.5		16.0		18.5	
Min	9.2	-5.3	16.0	0.0	14.3	-4.3

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Conclusions

Control for constant generator speed:
- Main generator (standard grid-coupled induction generator) produces 90% of total power, eliminating power conditioning electronics for main interconnect.
- 10% of total power flows through controller motor/generator
  - Rectify and invert, or
  - Store for later use
- Torque transients are greatly reduced

Control for constant Tip Speed Ratio
- Power capture increased
- Torque transients are increased
- Leads to large power fluctuations, requiring more power electronics to support auxiliary motor/generator

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