Modeling and Control of Wind Energy and Microgrid Systems

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WIND ENERGY SYSTEM

Research Goals

- Improve wind energy capture
- Reduce maintenance cost
- Overcome wind intermittency and unpredictability

Wind Turbine Basics

$$\begin{cases} \dot{\omega} = -\frac{B}{J_r}\omega + \frac{B}{G_r J_r}\omega_g - \frac{K}{J_r}\varphi + \frac{\pi}{8J_r}\rho_{air} D_r^2 (V_w - v)^3 C_p / \omega \\ \dot{\omega}_g = \frac{B}{G_r J_g}\omega - \frac{B}{G_r^2 J_g}\omega_g + \frac{K}{G_r J_g}\varphi - \frac{1}{J_g}\tau \\ \dot{\varphi} = \omega - \frac{1}{G_r}\omega_g \\ \dot{x} = v \\ \dot{v} = -\frac{K_{twr}}{M_{twr}} x - \frac{B_{twr}}{M_{twr}} v + \frac{1}{8M_{twr}}\rho_{air} D_r^2 \left(V_w - v\right)^2 C_t \end{cases}$$

States:

Turbine rotor speed ω

Generator speed ω_g

Low speed shaft torsional deflection φ

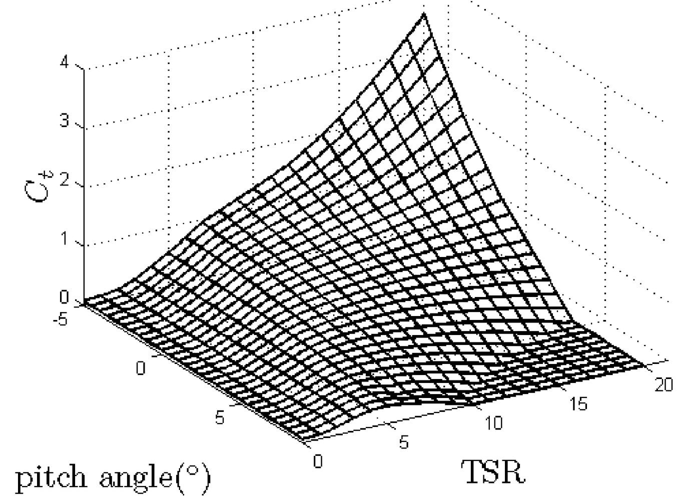
Tower top fore-aft displacement x

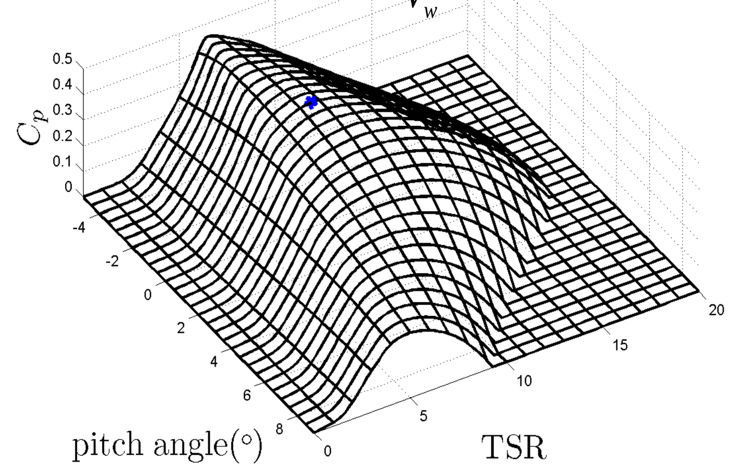
Tower top fore-aft velocity v

Manipulated variables:

- Generator torque τ
- Blade pitch angle β

$$TSR = \frac{\omega D_r / 2}{V_w}$$





Challenge 1: Modeling Uncertainty

- Model oversimplification
- Aero-elastic response of the turbine blades or the stochastic non-uniform wind inflow
- Manufacturer error (e.g. blades are asymmetric)

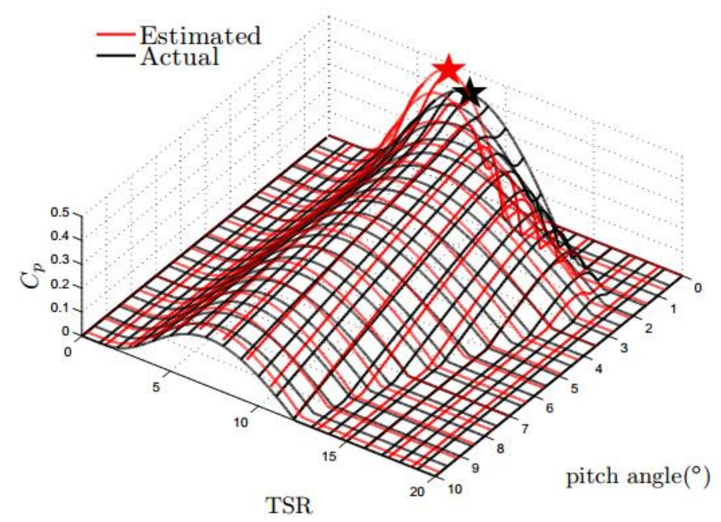
Solution:

- Data driven adaptive controller

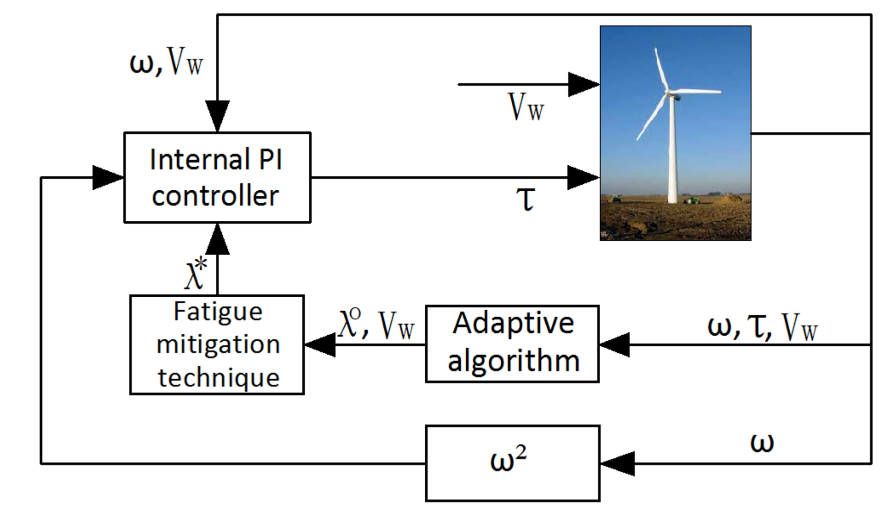
$$\tau = \left[K_{STC} + K_p(\lambda - \lambda^*) + K_i \int (\lambda - \lambda^*) dt\right]\omega^2$$

$$\lambda^* = \begin{cases} \lambda^o & (\frac{2\lambda^* V_w}{D_r} > \omega_{\min}) \\ \frac{k\sqrt{K_{twr}/M_{twr}} D_r}{2V_w N} & (\frac{2\lambda^* V_w}{D_r} \le \omega_{\min}) \end{cases}$$

$$\begin{cases} \lambda^o(k+1) = \lambda^o(k) + \eta\, sign[\sum_{i=1}^{n} w_i (x_i - \bar{X})(y_i - \bar{Y})] \\ \eta = \alpha \left| \frac{\sum_{i=1}^{n} w_i (x_i - \bar{X})(y_i - \bar{Y})}{\sum_{i=1}^{n} w_i (x_i - \bar{X})^2} \right| \\ \eta_{\min} \le \eta \le \eta_{\max}, \end{cases}$$



Comparison of actual estimated power coefficient curves



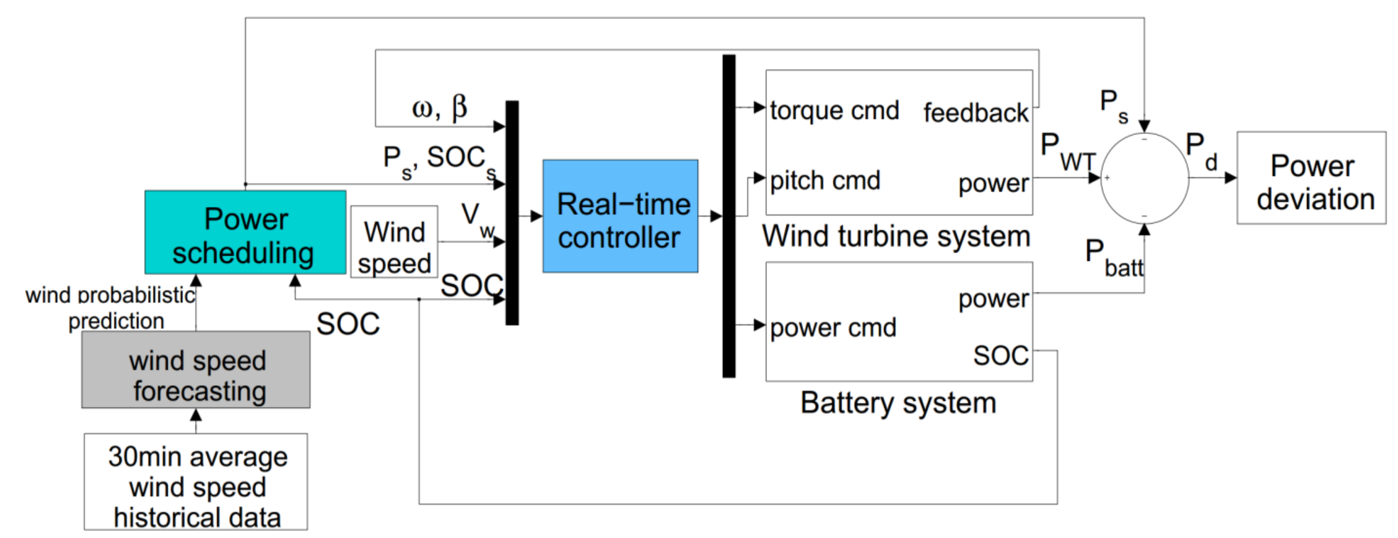
A simplified block diagram of a wind turbine system with the adaptive controller

Challenge 2: Wind Unpredictability

- Wind power is highly intermittent and non-dispatchable
- Conservative output power scheduling

Solution:

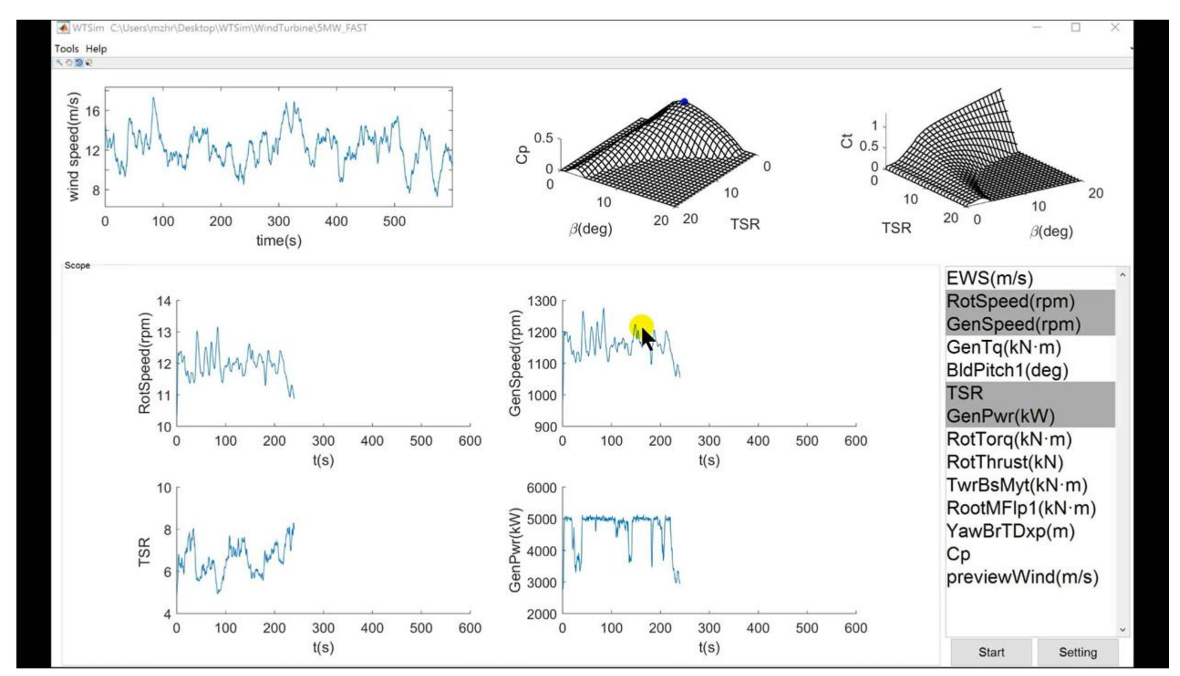
- Battery energy storage system is integrated with a wind turbine
- Store extra wind energy that cannot be absorbed by the grid
- Autoregressive and moving average (ARMA) wind forecast, model predictive power scheduling and H2-optimized active power control



Integrated wind turbine and battery system

WTSIM: A wind turbine simulator

- Aero-elastic of wind turbine model
- Auto extracted control oriented reduced order model
- Traditional and newly developed controllers
- Wind profile generation, frequency analysis, fatigue analysis etc.

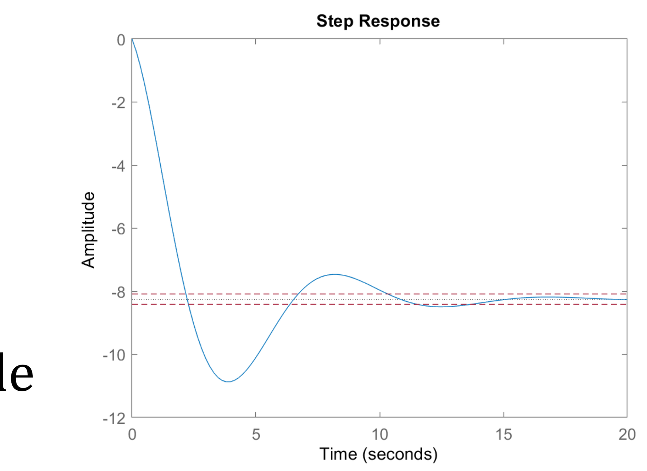


MICROGRIDS

Small power networks that can operate autonomously from the main grid by using distributed energy generation.

Research Goals

- Maintain power quality
- Decentralized control for distributed generators
- Robustness to topology changes, generator disconnection, renewable intermittency



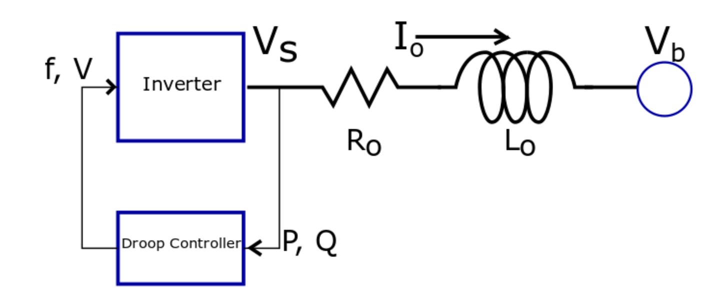
Grid disturbance response

Challenge: Decentralized Control

- Microgrids are comprised of independent generators
- Communication between generators may be slow, costly: how do we coordinate control?
- Using only local data is desirable, but then instability or poor performance may result when generators interact

Solution:

- Decentralized H-infinity control
- Full microgrid model is used for controller design (to implement system-level costs for individual controller performance)
- Only local data is used for controller operation

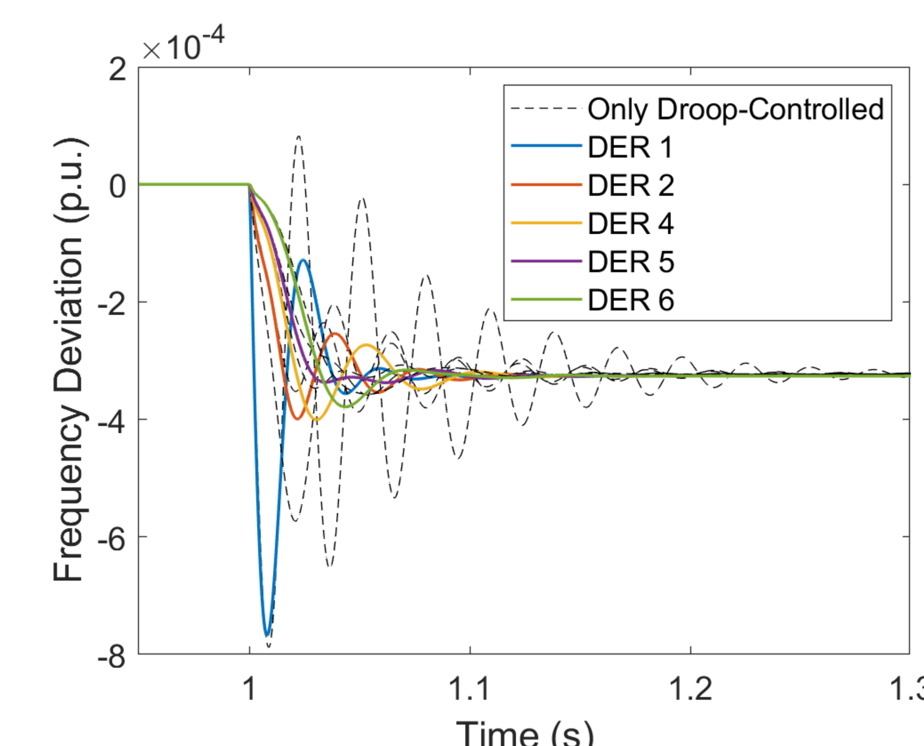


$f = f^0 - m\Delta P$
$V_s = V_s^0 - n\Delta Q$

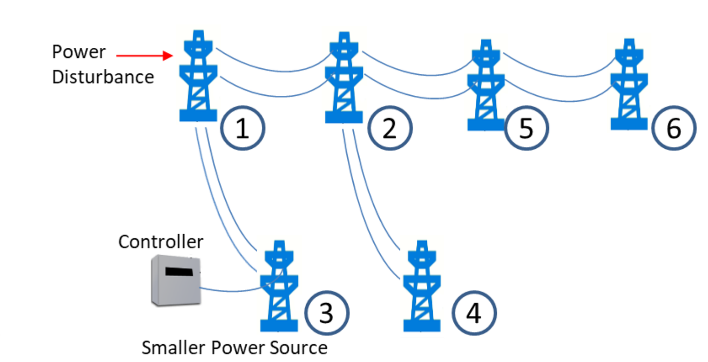
Droop Control

$f = f_{grid}$
$V_s = V_s^0 - Kx$

H-Infinity Control



Adjacent controller response comparison



Microgrid network layout for simulations utilizing control on a reduced power source adjacent to power disturbance

Cockrell School of Engineering

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