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Transient Stability and Control of Wind Turbine Generation Based On Hamiltonian Surface Shaping and Power Flow Control

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OBJECTIVES:

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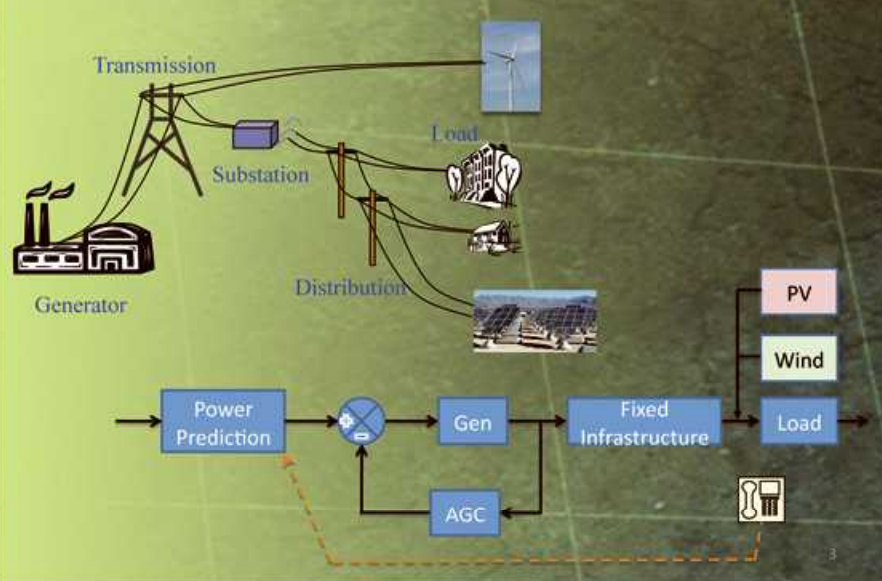
What is the optimal performance of an energy storage system (Unified Power Flow Controller - UPFC, diesel, etc.) to balance a wind turbine on a microgrid system?

Investigate nonlinear control HSSPFC technique to allow us to simultaneously optimize the performance of variable generation (wind turbine) including adaptive blades and the performance requirements of an energy storage system to smooth the power supply with a combination of conventional generation and storage, etc.

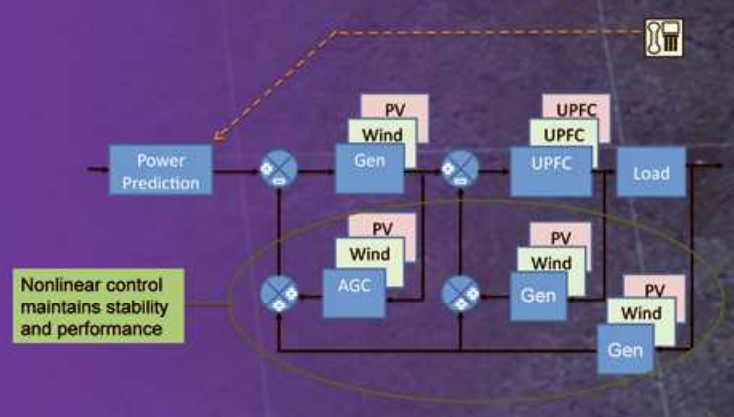
BACKGROUND:

BACKGROUND: Today's Stochastic Renewables Sources are Treated as Negative Loads.



DISTRIBUTED:

Distributed Nonlinear Control Enables Stability and Transient Performance.



Unified Power Flow Control (UPFC) increases flexibility and provides critical link to renewables

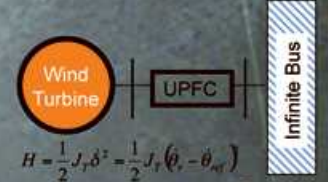
VARIABLE:

Variable Generation and UPFC Connected to Infinite Bus

Model:

$$J_T\dot{\omega}_r = -K_T\omega_r + T_a - T_g$$
$$\omega_r = \dot{\theta}_r$$
$$\delta = \theta_r - \theta_{ref}$$
$$T_a = M\dot{\theta}_r^2$$
$$T_g = u_m + T_e$$
$$u_m = u_{m_{ref}} + \Delta u_m$$
$$u_{m_{ref}} = -J_T\ddot{\theta}_{ref} - K_T\dot{\theta}_{ref} + M\dot{\theta}_r^2$$

Variable (no longer constant)



Hamiltonian: $H = \frac{1}{2}J_T\dot{\delta}^2 = \frac{1}{2}J_T(\dot{\theta}_r - \dot{\theta}_{ref})$

Power Flow: $\dot{H} = \left[-K_T\dot{\theta}_r + T_a - T_g - J_T\ddot{\theta}_{ref}\right]\dot{\theta}_r$

$\dot{H} = \left[-K_T\dot{\delta} - \Delta u_m - T_e\right]\dot{\delta}$

Select wind generation and UPFC nonlinear PID controllers from HSSPFC:

$$\Delta u_m = K_{P_m}\delta + K_{I_m}\int_0^t \delta d\tau + K_{D_m}\dot{\delta}$$
$$T_e = T_{e_{max}}\left[(1+u_{e_1})\sin\delta - u_{e_2}\cos\delta\right]$$

$$u_{e1} = K_{P_e}\cos\delta_s + K_{D_e}\sin\delta\dot{\delta} + K_{I_e}\sin\delta\int_0^t(\delta - \delta_s)d\tau$$
$$u_{e2} = K_{P_e}\cos\delta_s - K_{D_e}\cos\delta\dot{\delta} - K_{I_e}\cos\delta\int_0^t(\delta - \delta_s)d\tau$$

Static stability condition:

$$H = \frac{1}{2}J_T\dot{\delta}^2 + \frac{1}{2}K_{P_m}\delta^2 + T_{e_{max}}(1 + K_{P_e})(1 - \cos\delta)$$

Dynamic stability condition:

$$\int_0^t\left[K_T + K_{D_m} + T_{e_{max}}K_{D_e}\right]\dot{\delta}^2 dt > -\int_0^t\left[K_{I_m}\int_0^t \delta d\tau_1 + T_{e_{max}}K_{I_e}\int_0^t \delta d\tau_1\right]\dot{\delta}dt$$

RESULTS:

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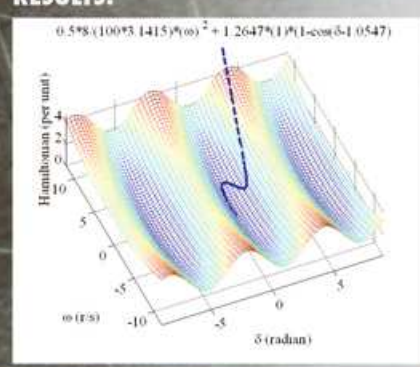
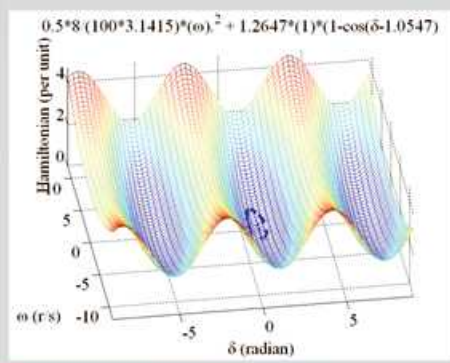
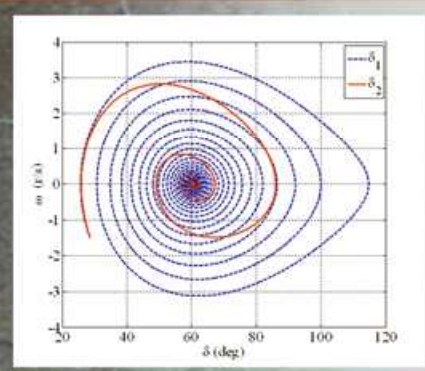
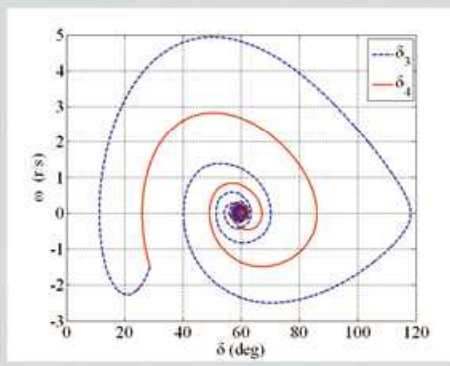
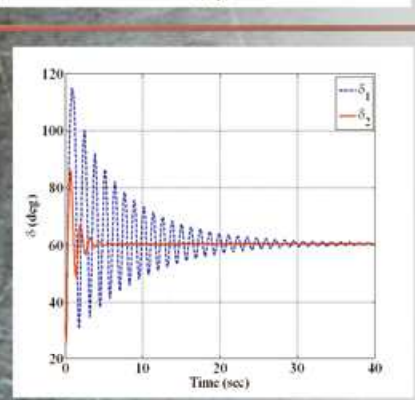
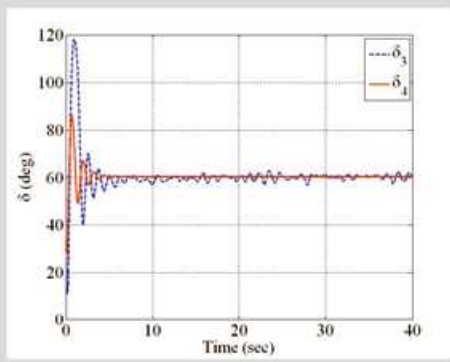


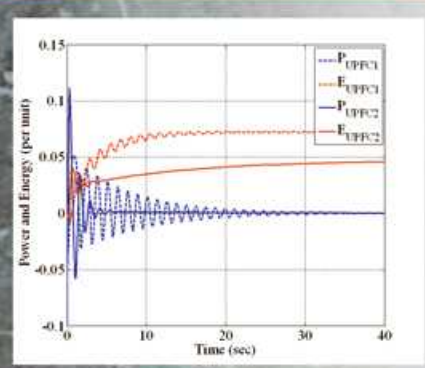


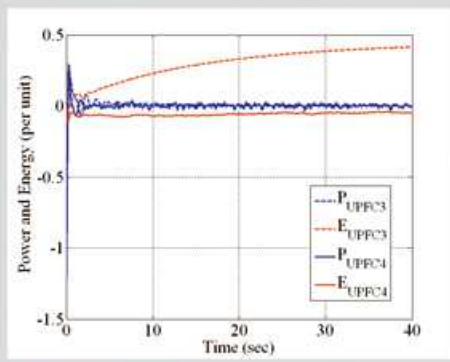




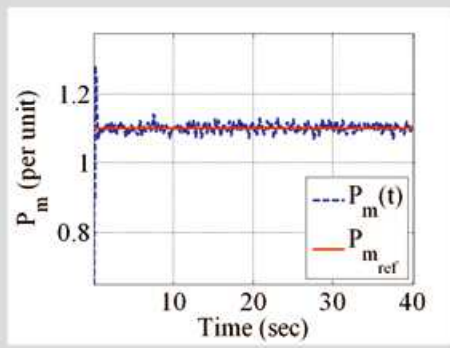








- Wind Turbine stochastic input approximated initially with simple random input
- Feedforward used to predict random process and help to provide desired constant power reference input



$$u_{e_1} = u_{e_1} - \left[\left(P_{m_{ref}} - P_m(t)\right)P_{max}\right]\sin\delta$$
$$u_{e_2} = u_{e_2} + \left[\left(P_{m_{ref}} - P_m(t)\right)P_{max}\right]\cos\delta$$

CONCLUSIONS:

NEXT STEPS, SUMMARY, AND CONCLUSIONS:

- Next Steps
  - Continue to refine models/controls (aeroelastic, power stability)
  - Further numerical simulations
  - Baseline microgrid system analysis
  - Experimental validation (real-time, HIL, scaled)
- Summary
  - Renewables bring technical and operational challenges
  - We cannot continue to treat stochastic renewables as negative loads
  - Energy storage is not a silver bullet
- Conclusions
  - Microgrids can effectively align renewable energy resources with mission needs
  - Applied HSSPFC two-step process to analyze feedback controllers
  - Optimize UPFC with variable generation requirements

9th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plants
18-19 October 2010
Quebec, Canada

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