Tuning criteria for converter connected PMSG wind turbine guaranteeing large signal stability

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Objective: Design a control with scalable large signal stability certificate for a windfarm

→ a windfarm that is guaranteed to have uninterrupted operation

Philosophy:

- Challenge the traditional power system operational conventions,
  - Not compatible with large integration of unpredictable renewable sources
  - Todays control is based upon linearization or case specific numerical computations and simulations
  - As the grid is expanded by interconnecting rapidly changing renewable sources, these computations becomes close to impossible to perform
- Replace with decentralized control with scalable large signal stability certificates
  - Scales with the system automatically, as the system is expanded
  - Stability is preserved as the system expands

This Work:

- Create such a control alternative for a wind power system according to the mentioned philosophy
- Our goal is to ensure that wind parks safely can be interconnected to the power system.
  - We will focus on a permanent magnet synchronous generator in a wind energy conversion system

Mathematical concepts and tools used to achieve the stability certificate

- Energy modeling and control
  - Energy does not differentiate between linear and non-linear systems
    - We can avoid linearization, and thus small signal studies
  - Suited to analyzing complex systems
    - Energy is additive
- Passivity (Energy control)
  - A restatement of energy conservation principles
    - useful starting point for nonlinear control design for complex systems

- Port-Hamiltonian modelling formalism (Energy modeling)
  - Highlights interconnection patterns, dissipation and the energy’s role in the system
    - … which are the main ingredients for energy control
  - Unified framework for systems existing in different physical domains
  - Suited for complex system analysis by focusing on interconnection of smaller subsystems

- Lyapunov stability theory
  - Lyapunov's direct method
  - Conditions investigated to check for stability

Port-Hamiltonian model of the PMSG wind energy conversion system

$$\underbrace{\begin{bmatrix} \dot{\Phi}_d \\ \dot{\Phi}_q \\ \dot{p} \end{bmatrix}}_{\dot{x}} = \left(\frac{p}{2}\Phi \underbrace{\begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & -1 & 0 \end{bmatrix}}_{J_0} + \frac{p}{2}L \underbrace{\begin{bmatrix} 0 & \omega_m & 0 \\ -\omega_m & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}}_{J(\omega_m)} - \underbrace{\begin{bmatrix} r & 0 & 0 \\ 0 & r & 0 \\ 0 & 0 & d - \frac{T_m(\omega_m)}{\omega_m} \end{bmatrix}}_{R(\omega_m)} \right) \underbrace{\begin{bmatrix} i_d \\ i_q \\ \omega_m \end{bmatrix}}_{\nabla H(x)} + \underbrace{\begin{bmatrix} -1 & 0 \\ 0 & -1 \\ 0 & 0 \end{bmatrix}}_{G} \underbrace{\begin{bmatrix} v_d \\ v_q \end{bmatrix}}_{u} + \underbrace{\begin{bmatrix} 0 \\ 0 \\ d\omega_{ref} \end{bmatrix}}_{E}$$

Differential equations describing the wind energy conversion system

$$L\dot{i}_d = -ri_d + Li_q \frac{P}{2}\omega_m - v_d$$

$$L\dot{i}_q = -ri_q - Li_d \frac{P}{2}\omega_m + \phi \frac{P}{2}\omega_m - v_q$$

$$J\dot{\omega}_m = T_m - \frac{3}{2}\frac{P}{2}\phi i_q + d(\omega_f - \omega_m)$$

Applying the procedure of [1] that is for a general machine to a system analyzed in [2] which uses a different energy modeling formalism, and we include the nonlinearities in the torque generated from the wind, we attain the condition in (1)

The torque generated by the wind is given as:

$$T_m = \frac{1}{2}\rho A V^3 C_p \frac{1}{\omega_m}[Nm],$$

where wind power coefficient Cp is given as:

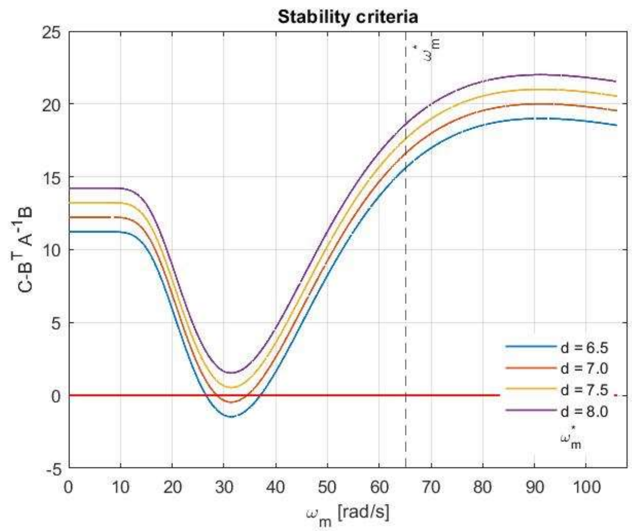
$$C_p = C_1(C_2\eta - C_5)e^{-C_6\eta}$$

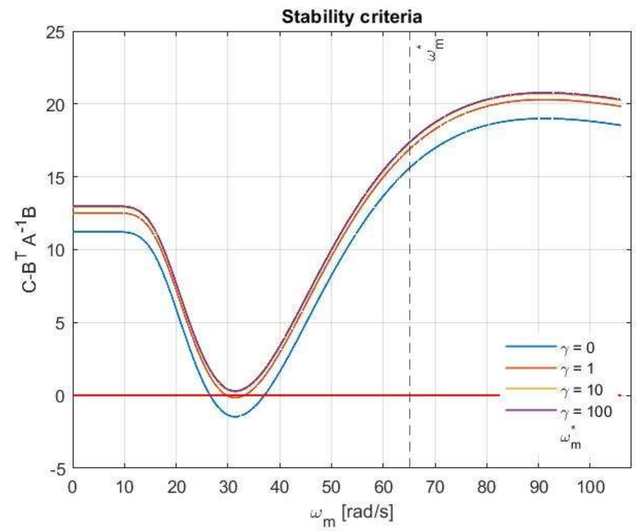
Condition for stability:

$$\underbrace{d}_{1.\text{term}} - \underbrace{\frac{\partial T_m(\omega_m)}{\partial \omega_m}}_{2.\text{term}} - \underbrace{\frac{(\bar{i}_q \frac{p}{2} L)^2}{4(r+\gamma)}}_{3.\text{term}} \geq 0 \quad (1)$$

Condition for stability:

$$\underbrace{d}_{1.\text{term}} - \underbrace{\frac{\partial T_m(\omega_m)}{\partial \omega_m}}_{2.\text{term}} - \underbrace{\frac{(\bar{i}_q \frac{p}{2} L)^2}{4(r+\gamma)}}_{3.\text{term}} \geq 0 \qquad (1)$$

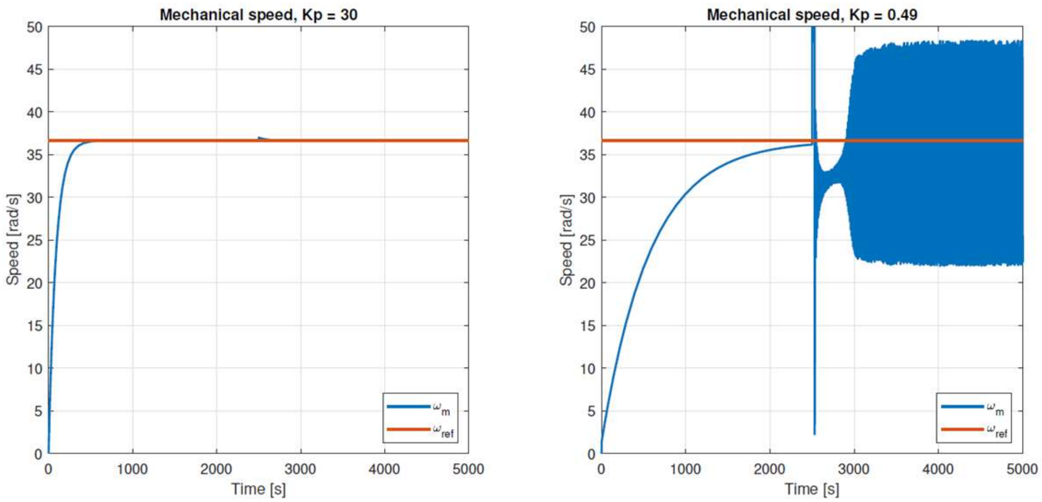




Observations:

- Electromechanical damping is needed to guarantee stability.
- When the machine is accelerating or decelerating the risk of instability is the greatest and the damping must be designed for this condition
- At the nominal working point, the nonlinear system can be ensured to be stable by use of linear PI-controllers for the currents

Simulations result when the tuning criteria is met compared to when the criteria is not fulfilled



Future Work:

- Include nonlinear converters
- Expand the certificate to a windpark
- Robustness challenges

Refrences:

[1] N. Monshizadeh et al. 'Conditions on Shifted Passivity of Port-Hamiltonian Systems'. In: Syst. Control. Lett. 123 (2019), pp. 55-61.

[2] Rafael Cisneros et al. `An adaptive passivity-based controller for a wind energy conversion system'. In: (2019), pp. 4852-4857.