Fault-Tolerant Control of Wind Turbine Systems

A. Tasdighi, A. A. Suratgar, M. B. Menhaj

Dept. of Electrical Engineering, Amirkabir University of Technology

INTRODUCTION

Wind turbines are used to generate electricity from the kinetic power of the wind. Historically, they were frequently used as a mechanical device to turn machinery. In general, wind generators are classified into two primary types based on the axis direction which can be either vertical or horizontal. Wind turbines have the potential to generate large amounts of electricity in wind farms both onshore and offshore.

ADVANTAGES OF WIND POWER

- Clean fuel source
- Domestic source of energy
- Sustainable
- Cost-effective
- Compatibility with existing farms or ranches

CHALLENGES OF WIND POWER

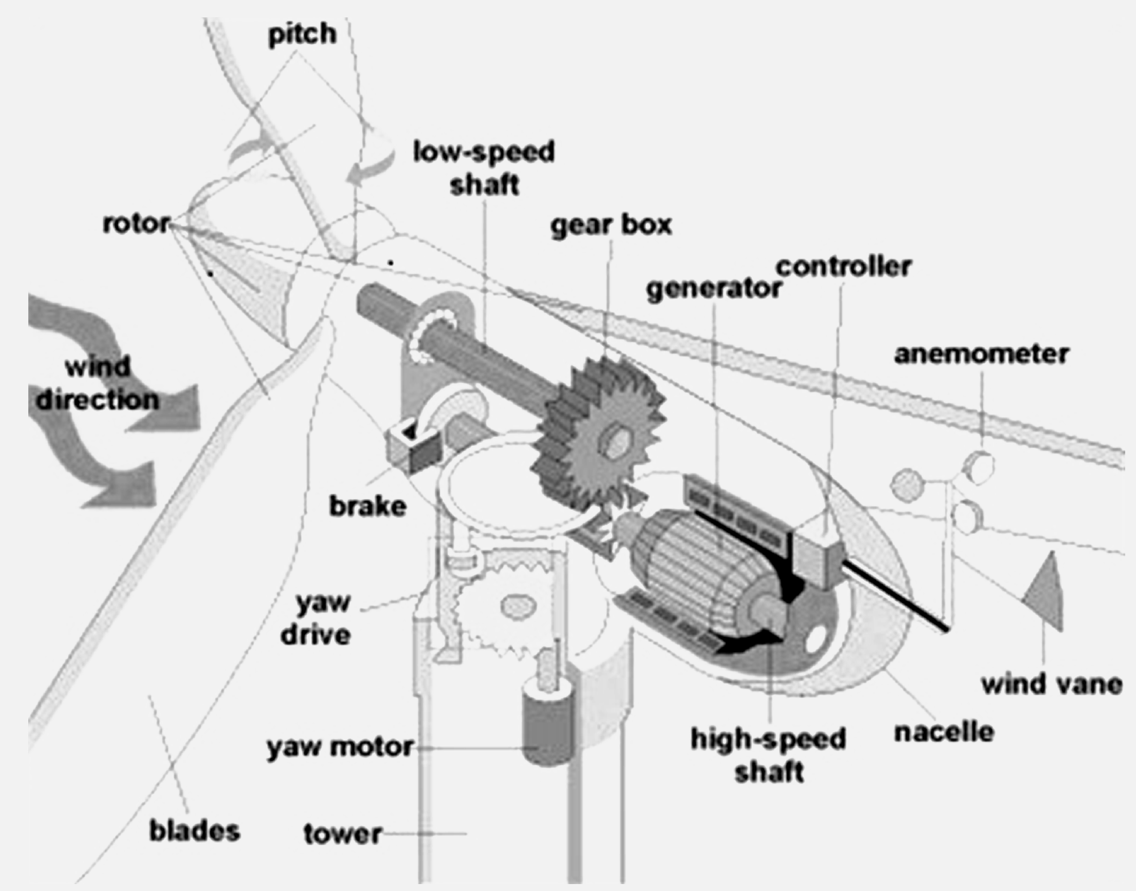
- Wind power must still compete with conventional generation sources on a cost basis
- Good wind sites are often located in remote locations, far from cities where the electricity is needed
- Wind resource development might not be the most profitable use of the land
- Turbines might cause noise and aesthetic pollution

NEED FOR FAULT-TOLERANCE AND BENEFITS

- Heavy, complex and remotely installed wind turbines
- Problems of stochastic wind disturbances and gravitational and gyroscopic loads
- Non-linear, unsteady and complex aerodynamics of wind turbines
- To prevent catastrophic failures and faults deteriorating other parts of the wind turbine by early fault detection and accommodation
- To reduce maintenance costs, provide diagnostic details to the maintenance staff by remote diagnosis and at the same time, to increase energy production

SYSTEM MODEL

In our study, we are interested in fault tolerant control of wind turbines.



STATE VARIABLES

- Generator speed
- Generator torque
- Speed of low-speed shaft
- Speed of high-speed shaft
- Angle between two shafts

CONTROL OUTPUTS

- Generator torque
- Blade angle

SYSTEM OUTPUT

- Wind turbine electrical power

To perform fault detection, isolation and identification

- Recursive least square (RLS) algorithm is applied to accommodate faults
- Model predictive controller (MPC) is used to provide control signals for the faulty system

PROBLEM FORMULATION

$$x' = f(x,u,w,v)$$
$$y = g(x)$$

$$f(x,u,w,v) = \begin{pmatrix} \frac{1}{I_r}(T_a - K_d\theta - B_d(\omega_r - \frac{\omega_g}{N_g}) - B_r\omega_r) \\ \frac{1}{I_g}(-T_g + \frac{K_d}{N_g}\theta + \frac{B_d}{N_g}(\omega_r - \frac{\omega_g}{N_g}) - B_g\omega_g) \\ \omega_r - \frac{\omega_g}{N_g} \\ \frac{1}{\tau_g}(\frac{P_{ref}}{\omega_g} - T_g) \\ \frac{1}{\tau_\beta}(\beta_{ref} - \beta) \\ \tilde{v}' \\ -\frac{1}{\tau_1\tau_2}\tilde{v} - \frac{\tau_1+\tau_2}{\tau_1\tau_2}\tilde{v}' + \varepsilon \end{pmatrix}$$

RLS EQUATIONS

$$\hat{\theta}(t) = \hat{\theta}(t-1) + P(t)\varphi(t)(y(t) - \varphi^T\hat{\theta}(t-1))$$

$$P(t) = \frac{1}{\lambda}\left[P(t-1) - \frac{P(t-1)\varphi(t)\varphi^T(t)P(t-1)}{\lambda + \varphi^T(t)P(t-1)\varphi(t)}\right]$$

MPC EQUATIONS

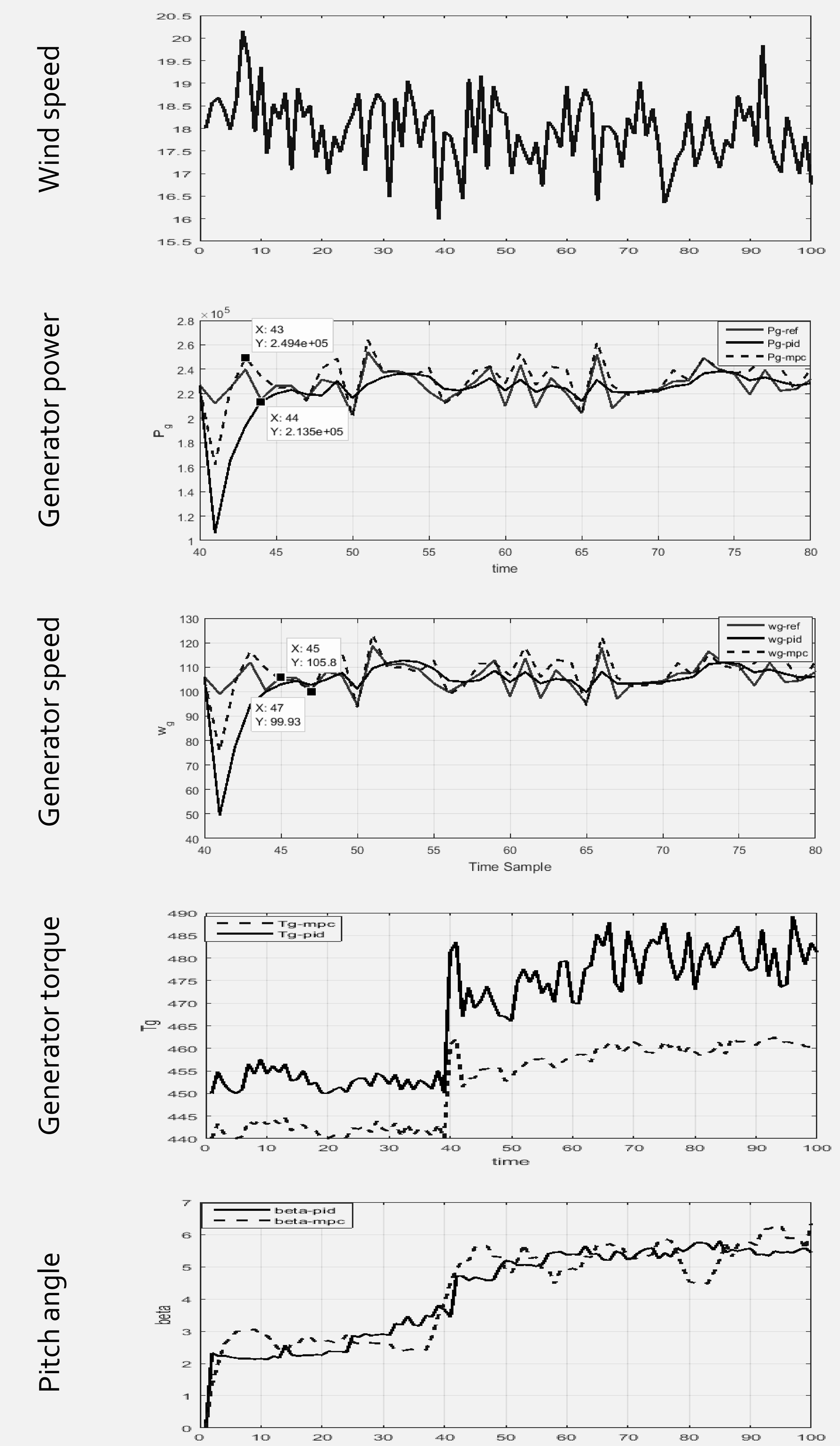
$$X(k_i+1|k_i) = AX(k_i) + B\Delta u(k_i)$$
$$X(k_i+2|k_i) = A^2X(k_i) + AB\Delta u(k_i) + B\Delta u(k_i+1)$$
$$\vdots$$
$$X(k_i+N_p|k_i) = A^{N_p}X(k_i) + A^{N_p-1}B\Delta u(k_i) + \cdots + A^{N_p-N_c}B\Delta u(k_i+N_c-1)$$

$$y(k_i+1|k_i) = CAX(k_i) + CB\Delta u(k_i)$$
$$y(k_i+2|k_i) = CA^2X(k_i) + CAB\Delta u(k_i) + CB\Delta u(k_i+1)$$
$$\vdots$$
$$y(k_i+N_p|k_i) = CA^{N_p}X(k_i) + CA^{N_p-1}B\Delta u(k_i) + \cdots + CA^{N_p-N_c}B\Delta u(k_i+N_c-1)$$

$$\Delta U = (\Phi'\Phi + \bar{R})^{-1}\Phi'(\bar{R}_s r(k_i) - FX(k_i))$$
$$K_y \cong (\Phi^T\Phi + \bar{R})^{-1}\Phi^T R_s, K_{mpc} \cong (\Phi^T\Phi + \bar{R})^{-1}\Phi^T F$$
$$\Delta U(k_i) = K_y r(k_i) - K_{mpc}X(k_i)$$

SIMULATION RESULTS

The simulation scenario is set so that a fault occurs in the actuator of wind turbine one minute past the reference time. The purpose is to maintain all the previous set points while the system is faulty. Form the results, it can be seen that the system succeeds in reaching all the set points just after five seconds.



Amirkabir
University of Technology