

# Blade-pitch Control System Degradation Model

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# Outline

- 1 Background
- 2 Framework – Blade-pitch control system life time prediction
- 3 Stochastic process application on wind turbine pitch control system
  - Model description
  - Deterioration process of actuator
  - Healthy indicator
  - Case study
  - Conclusions

## Background introduction



- Cost expensive
- Located off-shore or at remote place
- Unattended working condition
- Effected by wind behavior

## Background introduction

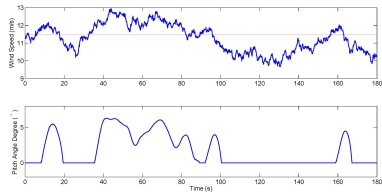
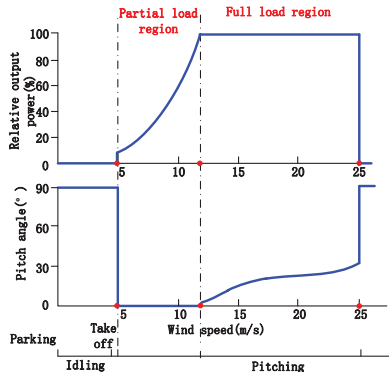


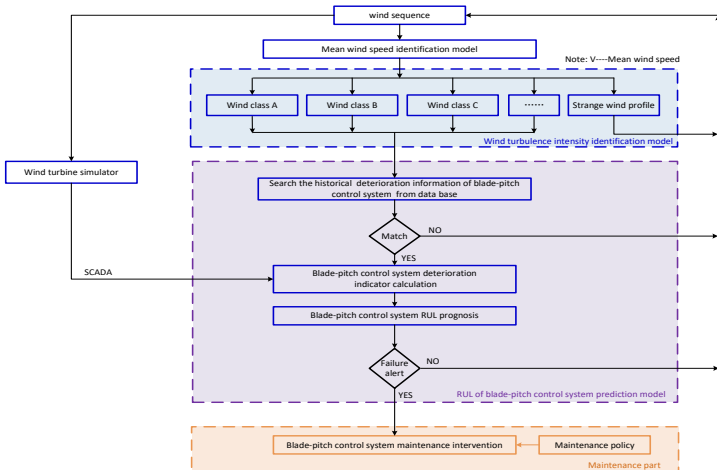
FIGURE – Pitch behavior

FIGURE – Changes of power and pitch angle over wind speed

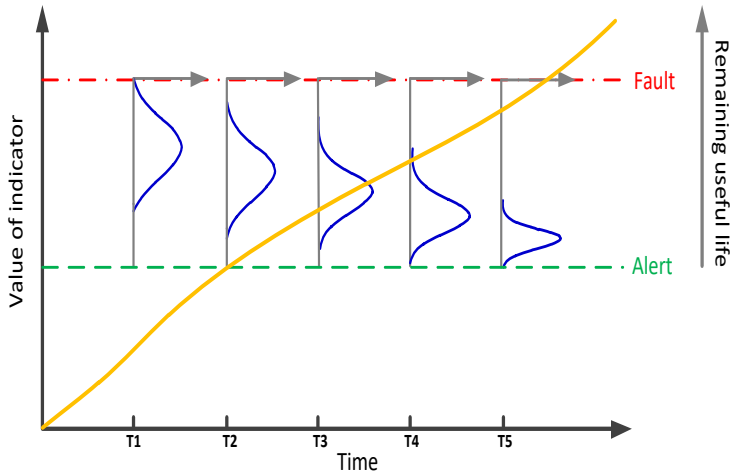
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# Framework – Life time prediction of blade-pitch control system



## Framework – Blade-pitch control system degradation model



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## Control system of wind turbine

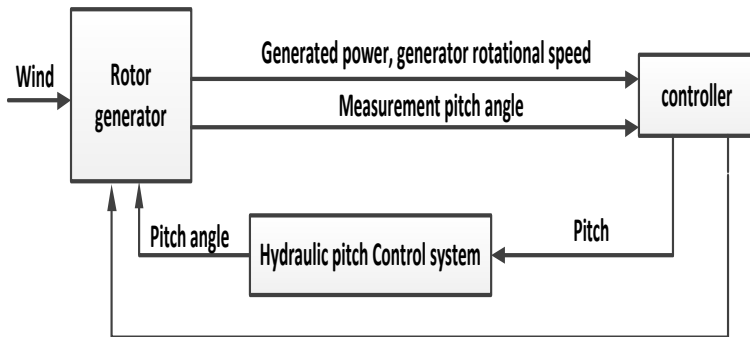


FIGURE – Control system of wind turbine

## Model description - Wind speed model\*

Wind speed sequence  $u(t)$  can be considered as the combination of its 10 min's mean value  $\bar{u}(t)$  and its fluctuation  $u_f(t)$ .

$$u(t) = \bar{u}(t) + u_f(t)$$

$$du_f(t) = a(u_f, t)dt + b(u_f, t)dw_t$$

- $a(u_f, t) = -\frac{u_f}{\Lambda}$
- $b(u_f, t) = \left(\frac{2\sigma^2}{\Lambda}\right)^{\frac{1}{2}}$
- $\sigma$  is the standard deviation
- $\Lambda$  is the integral time scale

\*Calif, R. (2012). PDF models and synthetic model for the wind speed fluctuations based on the resolution of Langevin equation. Applied energy, 99, 173-182.

## Model description - Blade pitch actuator model

A fault-free hydraulic pitch system is a piston servo system which can be modelled by a seconde order dynamic equation\*

$$\ddot{\beta} + 2\zeta\omega_n\dot{\beta} + \omega_n^2\beta = \omega_n^2\beta_r$$

- $\beta$  - measurement blade-pitch angle
- $\beta_r$  - reference blade-pitch angle from pitch control system
- $\omega_n$  - natural frequency
- $\zeta$  - damping ration

The deterioration is considered in the hydraulic pitch actuator, it can be modeled by changing  $\omega_n$  and  $\zeta$ .

- failure free case :  $\zeta = 0.6$ ,  $\omega_n = 11.11 \text{ rad/s}$ .
- High air content in the oil :  $\omega_n = 3.42 \text{ rad/s}$ .
- Hydraulic leakage :  $\zeta = 0.9$ ,  $\omega_n = 5.73 \text{ rad/s}$ .

\*Merritt, H. E. (1967). Hydraulic control systems. John Wiley & Sons.

## Model description - Blade pitch controller model

The blade-pitch angle commands are computed by using a proportional-integral (PI) control on the speed error between rated generator speed and the filtered generator speed.

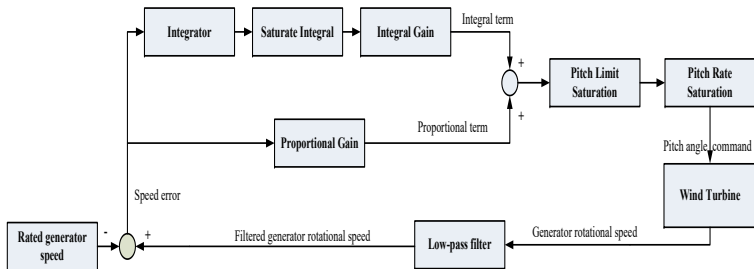


FIGURE – Flow chart of blade-pitch controller

## Model description – Wind Turbine simulator

The blade-pitch actuator and blade-pitch controller are implemented within Matlab/Simulink environment.

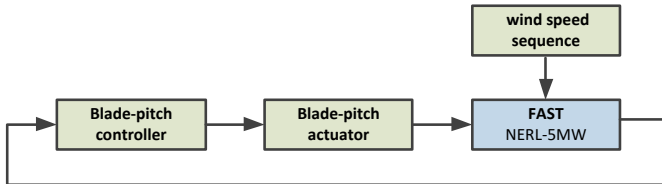


FIGURE – FAST/Simulink-based wind turbine simulator coupled blade-pitch actuator deterioration model

FAST - The Fatigue, Aerodynamics, Structures and Turbulence software is a wind turbine simulator designed by the US National Renewable Energy Laboratory.

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## Deterioration process of actuator

The deterioration of actuator can be modelled by a stochastic process. A Compound Poisson Process is a good candidate to model the deterioration.

- Blade-pitch system carries out instructions only when wind speed exceeds the rated wind speed
- Deterioration appears uniquely when blade-actuator implements the action
- The increase deterioration level is independent of the past level of the deterioration and it is random

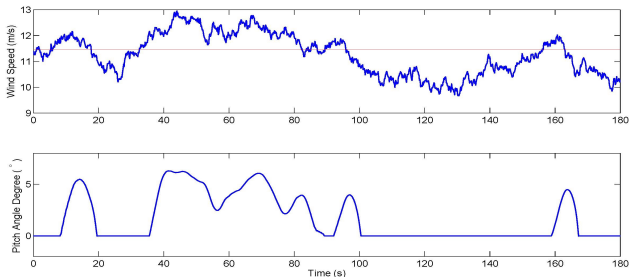


FIGURE – Blade-pitch action simulation

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## Healthy indicator

By considering the operational conditions of variable wind speed and uncertainty, a dynamic healthy indicator based on real time operational data is proposed.

$$PitInd_{t_0} = \frac{\sum_{t=t_0}^{T+t_0} |\Omega_t - \Omega_{t_{Ref}}| / \Omega_{t_{Ref}}}{T}$$

- $\Omega_t$  is turbine's rotational speed at time  $t$
- $\Omega_{t_{Ref}}$  is the fault-free turbine's rotational speed at time  $t$
- $T$  is the calculation interval

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## Case study

### Actuator's deterioration simulation

- excessive air/oil ratio can reduce the natural frequency of pitch actuator
- the nature frequency of actuator  $\omega_n$  decreases to  $3.42\text{rad/s}$
- the deterioration range of  $\omega_n$  is  $[0, 7.69]$

$$X(t) = \sum_{i=0}^{N(t)} Y_i, t \geq 0$$

- $\{N(t), t \geq 0\}$  - a Poisson process
- $Y_1, Y_2, \dots$  - independent, identically distributed random variables independent of  $\{N(t), t \geq 0\}$
- assume that  $Y_i, i = 1, 2, \dots$  follows a uniform distribution
- $X(t)$  represents the accumulated deterioration at time  $t$  on  $\omega_n$ .

## Case study

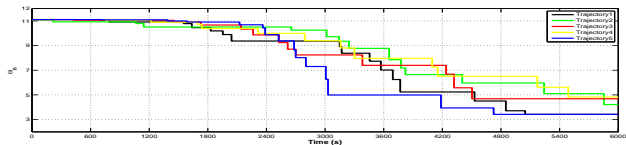


FIGURE – Deterioration trajectories of  $\omega_n$

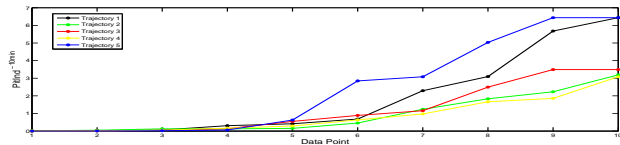


FIGURE – Health indicator  $PitInI$  calculated per 10 min for each deterioration trajectory

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## Conclusions

- A model of hydraulic blade-pitch system considering controller's deterioration has been implemented in a wind turbine simulator based on FAST software
- A health indicator based on wind turbine operational real data is proposed to estimate the deterioration of hydraulic blade-pitch actuator.
- This indicator can well reflect the deterioration.



Thank you for your attention !