Model-Based Detection for Ice on Blade

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Introduction

This study focuses on determine the most efficient linearized wind turbine model for ice on blade detection. The modeling error in respect to the number of degree of freedoms and operation points are studied. The performance of wind turbine under different ice conditions is investigated and the ice detection method is applied for both below rated and above rated wind speed. The ice detection accuracy with different modeling parameters and different ice conditions is determined.

Modeling

The modeling error is related to the number of degree of freedoms (DOF) ans operation points. Some quantities are dominated by the number of DOFs such as rotor speed. Some quantities are more influenced by DOFs, such as rotor thrust.

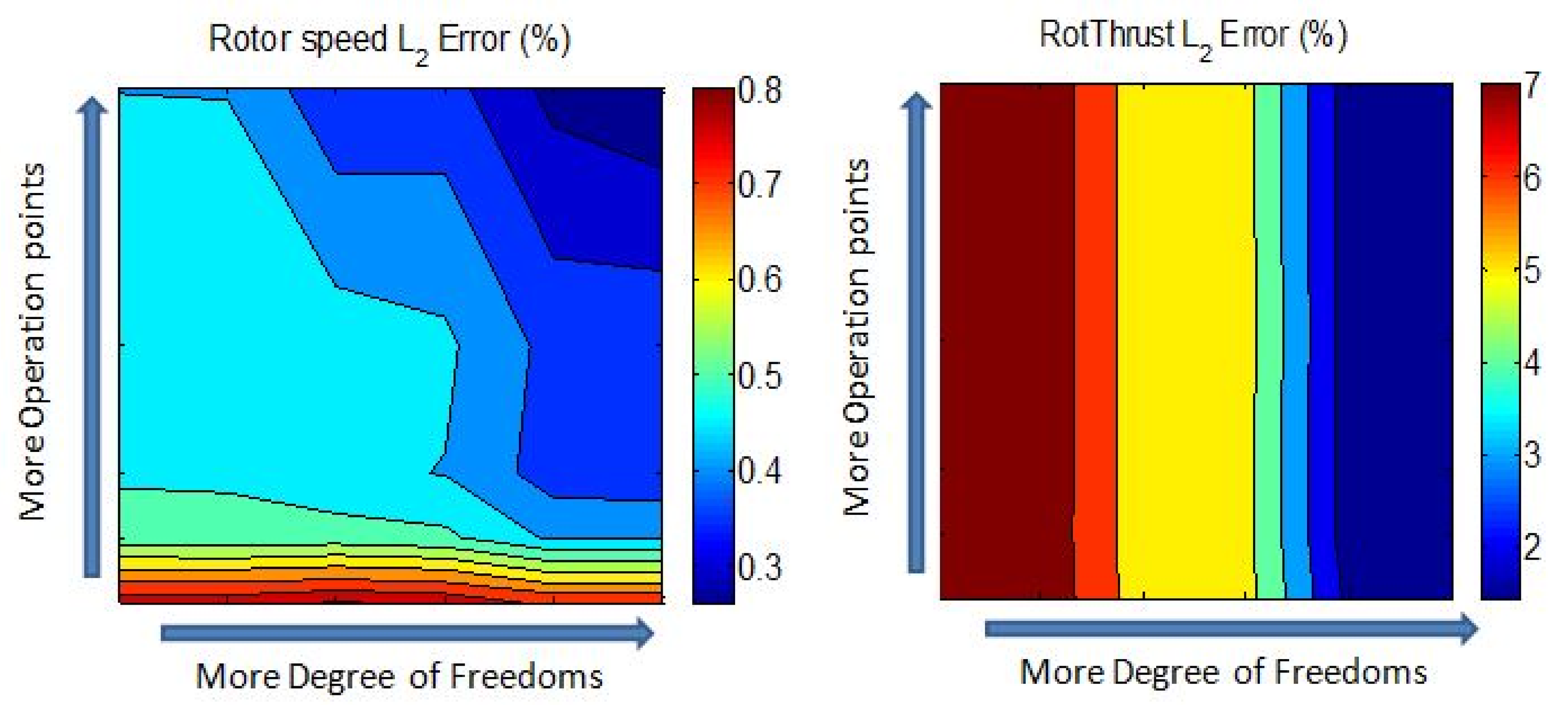

Fig. 1: Modeling error of rotor speed and rotor thrust

Ice Detection

The concept of model-based ice detection is as follows: Firstly ice on blade changes the aerodynamics and the blade mass. Therefore it can be considered as one wind turbine system changed to a different system. That means the outputs of the two systems, with ice and without ice, are different, even the inputs are exactly the same. From the ice detection point of view, if the difference of outputs between iced system and cleaned one is much larger than modeling error, ice on blade can be detected.

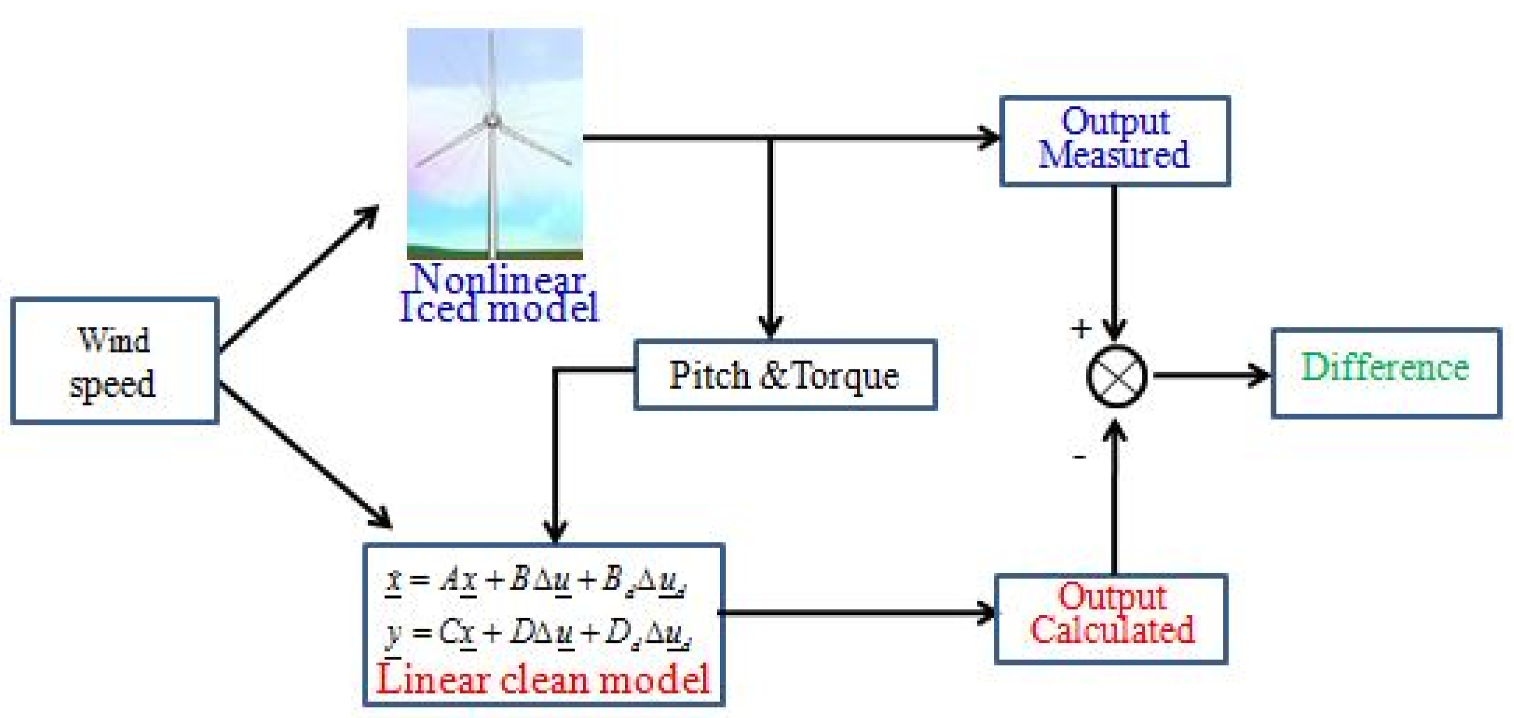

Fig. 2: Flow chart of ice detection concept

The ice detection capability is defined as

$$\text{Capability} = \frac{\text{Difference}}{\text{Modeling Error}}$$

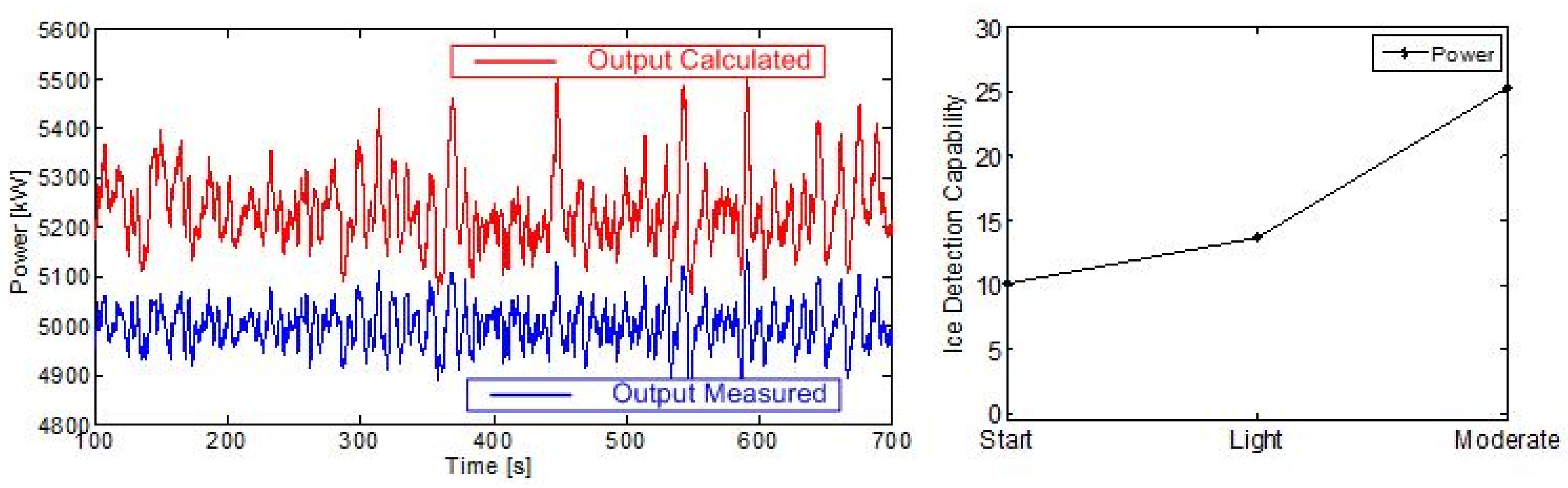

Fig. 3: Ice detection capability and time series

Ice detection for above rated wind speed

The ice detection capability of some quantities are more related with operation points, such as power. While other quantities are more related with DOFs, such as blade root bending moment, shown in Fig 4. The table shows the ice detection ability of different quantities. The ice detection capability is roughly defined as low, middle and high.Moreover, some quantities cannot be used as detection criteria for certain ice conditions.

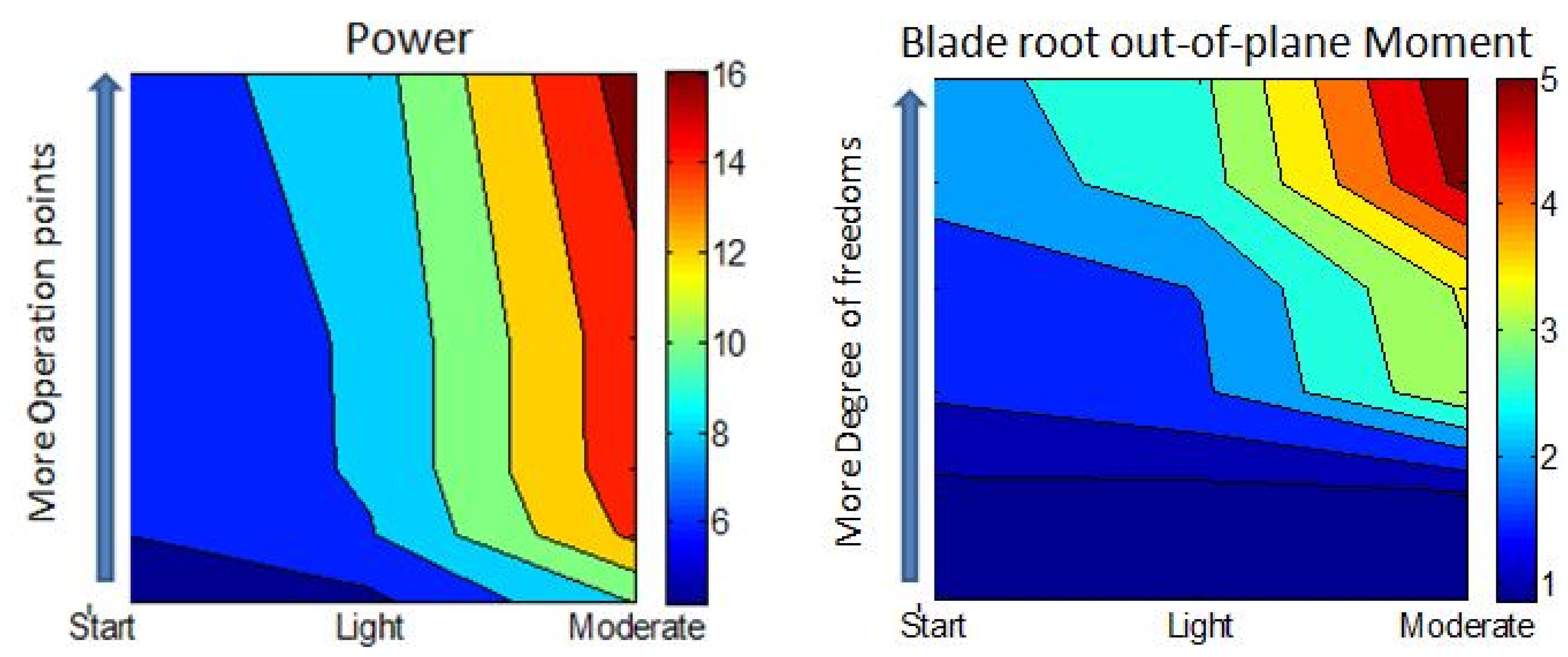

Fig. 4: Ice detection capability of power and blade root moment

Ice	Start	Light	Moderate
Power	Middle	High	High
Rotor Speed	Middle	High	High
Blade out-of-plane deflection	No	No	Low
Blade in-plane deflection	No	No	Low
Tower side-side moment	No	Low	Low
Tower fore-aft moment	No	Middle	High
Tower torsion moment	No	Low	Middle

Table 1: Ice detection capability of above rated wind speed

Ice detection for below rated wind speed

For below rated wind speed cases, although the results are different with above rated wind speed,the trends are similar.

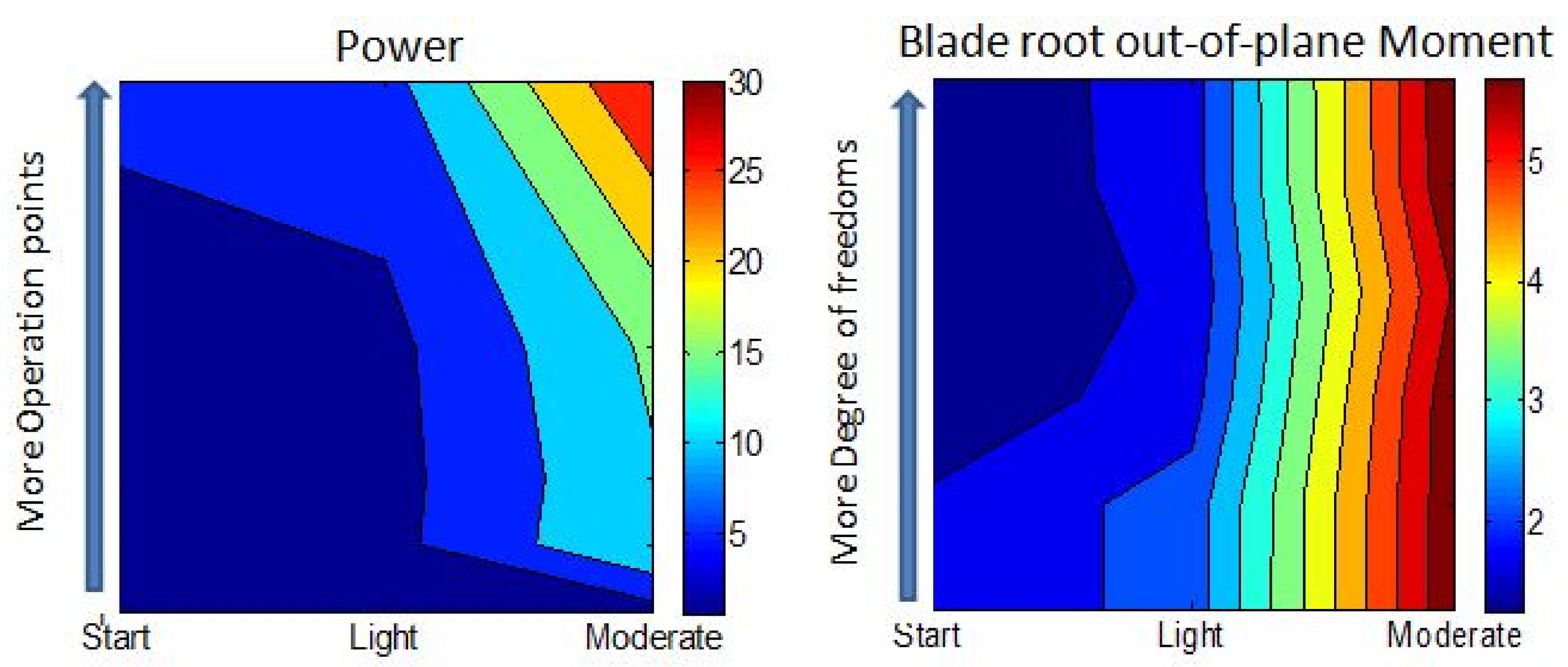

Fig. 5: Ice detection capability of power and blade root moment

Ice	Start	Light	Moderate
Power	Middle	High	High
Rotor Speed	Middle	High	High
Blade out-of-plane deflection	No	Low	Middle
Blade in-plane deflection	No	Low	Middle
Tower side-side moment	No	Low	Low
Tower fore-aft moment	No	No	No
Tower torsion moment	No	Low	Middle

Table 2: Ice detection capability of below rated wind speed

Conclusions

Not all quantities can be applied for ice detection. Power and rotor speed are good criteria, while blade deflections and tower bending moment can be used with some limitations.