Algorithm to Prevent Wind Turbine Blade Fatigue from Icing Condition

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Abstract*-One of the upcoming technology is installation of hybrid energy systems, where the cost of grid connectivity is greatly reduced and cost of fuel increases drastically due to remoteness of the location. On one hand hybrid system has tremendously reduced the total cost of installing stand alone grid system, on other hand it provides a reliable supply of electricity. Due to non linear characteristics of Wind hybrid system, it becomes impractical to develop a mathematical model and to obtain simple and practical controller. Neural Networks and Artificial intelligence techniques have provided an alternative approach where in conventional mathematical model are being replaced with Artificial Neural Networks (ANN), which provides flexibility, easy to handle incomplete data & noise, are able to handle non linear characteristics, above it can be used to create a model which can predict change in load demands, wind speed, weather forecast, derive a meaningful conclusion from complicated data, which are too complex for humans to understand and extract information or pattern from it. ANN along with Fuzzy control when blended in a control algorithm provides better results than conventional mathematical controllers, in term of robustness, response time, etc. The main focus in this research proposal is to create or develop power control algorithm for smart wind turbine, which is used to control icing conditions.

Keywords— HAWT, icing, Wind Turbine, ANN.

I. INTRODUCTION

For many northern regions of the world, the best locations for the placement of wind energy stations are along coastal areas or on the tops of hills and mountains. These locations, however, are susceptible to atmospheric icing events during the winter months. Icing is an important issue when operating wind turbines in elevated or arctic areas as it can cause significant production losses and represent a safety risk [1]. In 2014, a 1.3 kW wind turbine with integrated blade heating was installed in central Switzerland, at 2300 m. Performance degradation of horizontal axis wind turbines (HAWTs) due to ice accretion has been investigated on a number of machines at different locations [2]. Power output can be negligible for a wind turbine operating under extreme icing conditions. Furthermore, random shedding of ice from the rotating turbine blades can cause severe out-of-balance loads on the wind turbine. These added load increases material fatigue, reducing the operational life of the turbine and causing nonproductive downtimes for repair. Icing concerns regarding wind turbine operation are not limited to, extreme icing conditions but start at the first sign of surface roughness on the blades. It has been shown that even the slightest amount of surface roughness has the potential to reduce energy output from a wind turbine by 20 percent [3-4].

Setting up icing system only on the outer part of the blade would enable a significant decrease of heating energy costs. For smaller wind turbine. The problem of ice prevention is even more severe because of the lower potential power output as compared with a larger turbine. For more severe icing events, stopping the turbine may be the most logical solution owing to the energy required for ice prevention and wear on the machine. Stopping a wind turbine during the presence of every icing conditions, however, would be nonproductive. For slight to moderate icing events, where the turbine continues to operate, but at reduced levels of efficiency, it may be beneficial to continue operation with or perhaps, heating element in place. The determination of the best option to maximize energy output from the turbine operating at mountains requires a knowledge of the performance loss that can be expected during the icing event. To predict the degradation in wind turbine performance due to icing, an algorithm is proposed.

II. ICE EFFECT ON WIND TURBINE

Wind turbines (WT) operating at high altitudes are frequently facing icing conditions during winter operation. At the same time, the best sites for wind farm installation are located at higher altitudes, as wind speed generally increases by 0.1m/s per 100m of altitude for the first 1000m. In regions with cold climate, available wind power is approximately 10% higher than in other regions due to increased air density at lower temperatures [5]. Therefore, wind farms installed in some of the best wind sites around the world are facing possible icing events. Icing affects the wind assessment and the operation of wind farms. The following problems are directly related to icing and cold climate: measurement errors, power losses, overproduction, mechanical failures, electrical failures and safety hazards.
Measurement errors: during the assessment phase, the anemometers, wind vanes and temperature sensors can be affected by ice. In icing conditions, wind speed errors can be as high as 30% [6]. Another study identifies a maximum error of 40% for an ice-free anemometer and 60% for a standard anemometer during icing events [5]

Power losses: ice accretion changes the shape and roughness of the blade airfoil (consequently affecting their aerodynamic characteristics) and introduces measurement errors from turbine instruments (wrong wind speed or direction, which affects yaw and power controls). Small amounts of ice on the leading edge of airfoils significantly reduce aerodynamic properties of the blade and the resulting power production.

Overproduction: Higher air density related to low temperatures and airfoil modifications can lead to overproduction of the WT. Overproduction of up to 16% has been recorded [7].

Mechanical failures: ice accretion will increase the load on the blades and on the tower structure, causing high amplitude vibrations and resonance as well as a mass imbalance between blades. Operation at low temperatures affects oil viscosity and changes the dimensions and mechanical properties of different components of the WT. This results in possible overheating and higher fatigue charges on components; one of the most affected being gearboxes whose lifetime is considerably reduced [8].

Electrical failure: snow infiltration in nacelle and extreme temperature lead to condensation in the electronics.

III. PROPOSED ALGORITHM

To cater all the losses and to prevent blades, gear box, yaw control from over fatigue and getting damaged following algorithm are proposed and was tested in MATLAB®.

A 1.3 KW turbine with a startup speed of 3 m/s, Furling start up wind speed of 10 m/s, spring hinge based tilt up furling method, 800 RPM at rated power was used for testing the algorithm. Data for complete one year was obtained. It included velocity data from 3 different sensors, which were connected at a height of 80 m and temperature was obtained from sensor connected at 10m height. The data were logged every hour.

A. Determine Icing Conditions

To determine icing conditions following conditions was taken into account.

1. Remove any readings effected by icing which results in extremely inaccurate values biased towards zero.
2. Icing conditions are when $t_{avg} < t_{Ice}$ and $v_{avg} < v_{Ice}$.

Here t_{avg} represents average temperature, t_{Ice} is for temperature during icing, v_{avg} is velocity average from three air velocity sensors, and v_{Ice} is velocity of air during icing condition.

3. For comparison, $t_{Ice} = 2^o$ and $v_{Ice} = 1$m/s were fixed with values
4. To determine icing condition following conditions was set:

idxTIce = tempS < tIce
idxVIce = velAvg < vIce

B. Power curve plotting

For plotting power curve following method was adopted

powervbins = prated*(v_{bins}.^2 - v_{in}^2)/(v_r^2 - v_{in}^2);
powervbins ($v_{bins} <= v_{in}$) = 0;
powervbins ($v_{bins} > v_{out}$) = 0;
powervbins($v_{bins} >= v_r$ & $v_{bins} <= v_{out}$) = p_{rated};

C. Capacity Factor

Capacity factor is ratio of the actual output of a turbine over a period of time and its potential output if it had operated at full capacity the entire time. Typical capacity factor ranges from 20–50% depending on location and wind turbine. From data sheet of turbine and from data obtained from sensors capacity factor was calculated.

IV. RESULTS

The following results were obtained after running the algorithm.

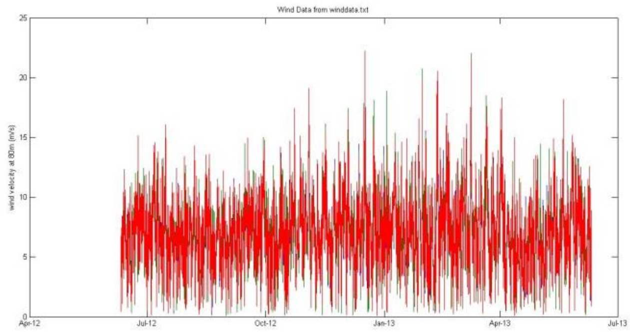

Figure 1. Showing wind data for one complete year

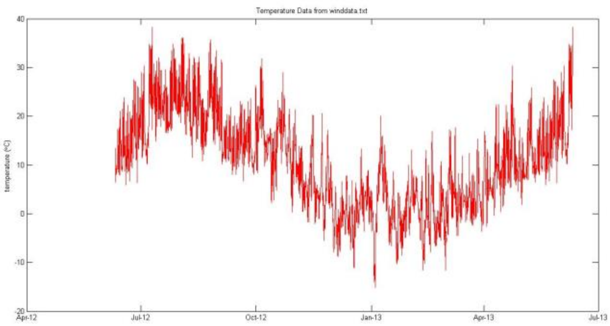

Figure 2. Showing temperature data log one year

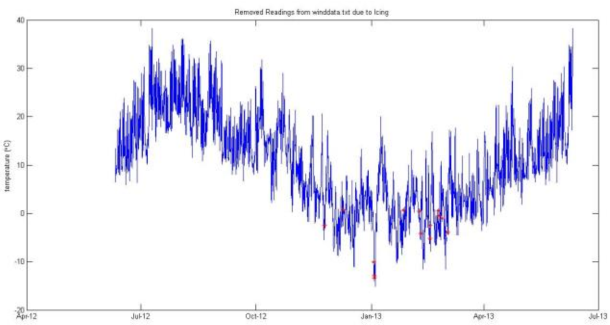

Figure 3. Temperature log without icing conditions

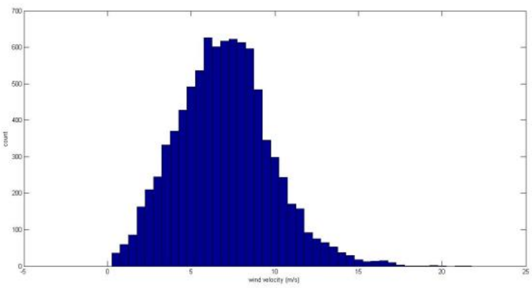

Figure 4. Graph for Wind Velocity vs count.

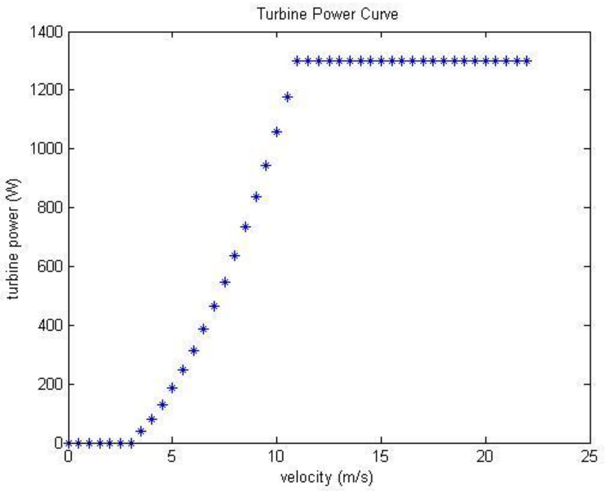

Figure 5. Turbine Power vs Velocity. Power Curve

Table 1
Turbine operational data

Rated Wind Speed	11 m/s (39 km/h)
Start-up Wind Speed	3 m/s (11 km/h)
Furling Start-up Wind Speed	10 m/s (36 km/h)
Furling Method	Spring/hinge-based tilt-up
RPM at Rated Power	800 RPM
Survival RPM	1,400 RPM
Survival Wind Speed	45 m/s (162 km/h)

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