Exploring the Limits of Early Predictive Maintenance Applying Anomaly Detection Technique

Mindaugas JANKAUSKAS, Artūras SERACKIS, Van Khang HYUNH, Toomas VAIMANN

E-mail: {m.jankauskas | arturas.serackis}@vilniustech.lt,

Department of Electronic Systems, Vilnius Gediminas Technical University (VILNIUS TECH),

Department of Engineering Sciences University of Agder Grimstad, Norway,

Department of Electrical Power, Engineering and Mechatronics, Tallinn University of Technology, Tallinn, Estonia

Introduction

In this investigation, we propose to use a recurrent neural network to model the time series of the healthy device parameters in order to detect anomalies by comparing predicted values with actually measured ones. An experimental investigation was performed on SCADA estimates received from different wind turbines with failures. A recurrent neural network was used to predict the oil temperature of the gearbox. The comparison of the predicted oil temperature values and actual measured ones showed that anomaly in the gearbox oil temperature could be detected up to 37 days in advance before the failure of the device-critical component. Performed investigation compares different models that can be used for temperature time-series modeling and the influence of selected input features to the performance of temperature anomaly detection.

Aims and Goals

The aim of the presented investigation is to explore the time gap between anomaly appearance in continuously measured parameters of the device and a failure related to the end of the remaining resource of the device-critical component.

Main objectives:

- Propose a set of features for the prediction of wind turbine gearbox temperature while operating in a normal state.
- Compare several alternative regression models used for gearbox temperature prediction.
- Propose an algorithm for early detection of temperature anomaly, followed by wind turbine failure, and estimate how many days in advance the failure could be predicted from the anomaly.

Methods

The data for the experimental research is taken from the Wind Turbine Failure Detection Challenge 2019 [1].

Table 1: Failure list based on [1]

Component	T01		T06		T07		T09		T11	
	Train	Test	Train	Test	Train	Test	Train	Test	Train	Test
Gearbox	1	0	0	1	0	0	1	1	0	0
Generator	0	0	5	0	0	1	0	0	1	0
Generator Bearing	0	0	0	0	1	1	3	1	0	0
Transformer	0	1	0	0	2	0	0	0	0	0
Hydraulic Group	0	0	1	1	0	2	0	1	1	2

A technique, proposed in this paper uses a set of ambient (wind speed and temperature) and generator RPM signals to predict gearbox bearing on high-speed shaft temperature in a normal state when there were no failures in wind turbines Table 1. These features were sampled in 3, 6, and 24-hour ranges and gearbox bearing temperature was predicted with three different regression models: Long Short-Term Memory (LSTM), Gated Recurrent Unit (GRU), Bidirectional Long Short-Term Memory (bi-LSTM). Structures with one recurrent layer (128 cells) and two recurrent layers (128 + 100 cells) were tested.

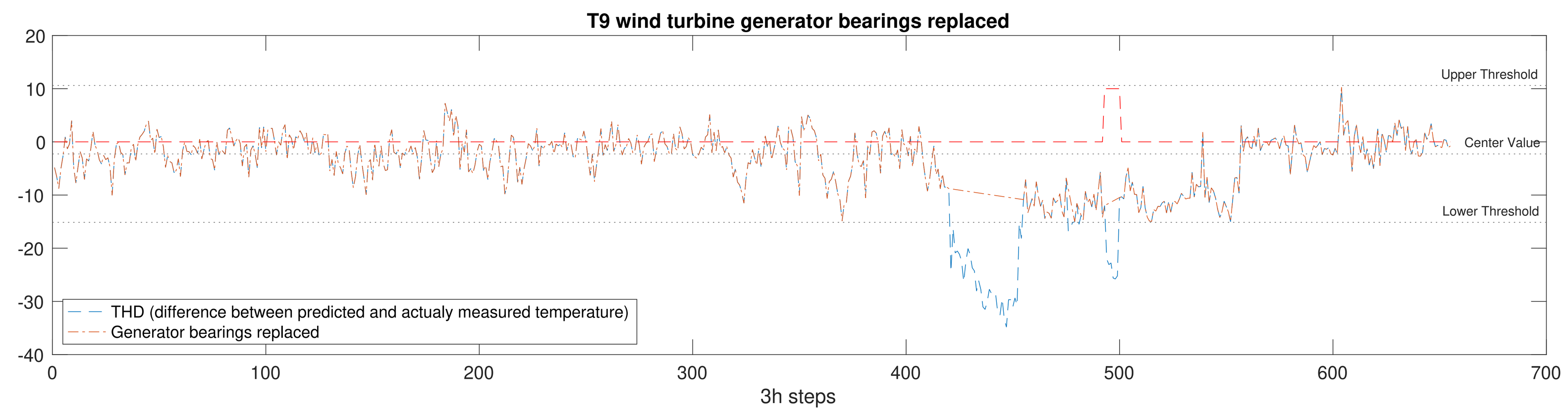

Figure 1: Illustration of selected decision threshold for temperature anomaly detection

Train and test were applied multiple times with different scenarios when train data was selected from one turbine and tested with data from other turbines. In addition, multiple turbine data was combined and tested with the remaining data. Regression models were trained and tested 144 times to select the model with the best RMSE score.

Results

The best temperature prediction results were achieved with a regression model having two layers of bi-LSTM cells.

Model	*RMSE*	*Std*	*Min*	*Max*
LSTM	1,91	1,49	0,0012	11,58
bi-LSTM	1,79	1,34	0,0033	10,27
GRU	1,85	1,33	0,0058	10,42
LSTM + LSTM	1,69	1,09	0,0027	7,037
bi-LSTM + bi-LSTM	**1,61**	1,10	0,0021	7,17

Models were trained to predict gearbox bearing on high-speed shaft temperature to compare with actual temperature and find anomalies. Two automatic THD selection techniques compared: based on 3 standard deviations from mean value and based on moving median. The effect to early failure prediction is given in Table 2. The selection of the decision threshold is illustrated in Figure 1.

Table 2: Estimation of how many days in advance the failure could be predicted from the anomalies

Component failure	Model with two LSTM layers THD estimation method		Model with two bi-LSTM layers THD estimation method	
	Mean+3*STD	Moving Median	Mean+3*STD	Moving Median
Gearbox	14	22	22	32
Generator	15	24	26	37
Generator Bearing	13	24	22	36
Transformer	23	22	24	35
Hydraulic Group	12	22	20	33

Conclusions

- Model with two layers of bi-LSTM cells showed better prediction results than other regression models.
- The better prediction was received with input features estimated from shorter time range (3 hours).
- Using THD selection according to moving median the temperature anomaly related with turbine component failure can be predicted 60% earlier.

References

[1] Energias De Portugal. Wind turbine failure detection. Online, 2019. Accessed: 2022-06-01.

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