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“Fuzzy Logic Applied to SCADA Systems”

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Fuzzy Logic Applied to SCADA Systems

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Abstract:

This article focuses on the monitoring of a wind farm in real time based on big data collected by Supervisory Control and Data Acquisition (SCADA) system. The decision-making of the type of maintenance to be applied can be insured by SCADA system. This system generates alarms based on the collected data. False alarms cause false interventions by the maintenance team resulting in loss of production and costs. The reduction of these false alarms makes it possible to contribute better to the management of the maintenance of the wind farm. In this paper, we propose a new approach for the identification of alarms by Fuzzy Logic based on the data collected by the SCADA system. The alarms generated in this case can be divided into two categories: orange alarms corresponding to faults requiring the intervention of preventive maintenance and red alarms corresponding to critical states that can cause system failures.

Keywords: Wind Farm, monitoring; SCADA; alarms; Fuzzy Logic Approach.

1. Introduction

The generation of electricity through wind energy systems is demanded by the industry in order to increase the competitiveness of the business. The maintenance of these systems becomes very complex because the stochasticity of the random loads can cause catastrophic failures **¡Error! No se encuentra el origen de la referencia..** The optimization of the maintenance planning is a crucial factor for the efficiency of the wind farms **¡Error! No se encuentra el origen de la referencia..** With this purpose, wind turbines (WT) can be monitored by SCADA or condition monitoring systems to detect failures **¡Error! No se encuentra el origen de la referencia.¡Error! No se encuentra el origen de la referencia.,** risks **¡Error! No se encuentra el origen de la referencia.** and to take necessary actions online. Several studies have proved the efficiency of this systems in the WTs **¡Error! No se encuentra el origen de la referencia.** and other types of industries **¡Error! No se encuentra el origen de la referencia.[10][9][15].**

False alarms generated by SCADA system are a important problem because they cause unnecessary stops, false interventions by the maintenance team, loss of production and, consequently, extra costs. Some studies aim to eliminate false alarms of WTs [4]. Chen *et al.* **¡Error! No se encuentra el origen de la referencia.** present a study on the treatment of SCADA using an artificial neural network 'ANN'. Qiu *et al* **¡Error! No se encuentra el origen de la referencia.** proposes two methods (sequential and probabilistic) for the analysis of alarms for two large onshore wind farms considering the defects of pitch and converter systems.

This paper proposes a new approach based on fuzzy logic for controlling wind farms considering the big data collected by SCADA system, and give a complementary response to strengthen the response of the SCADA. Figure 1 shows the general structure of a fuzzy system **¡Error! No se encuentra el origen de la referencia..**

Fig.1: Basic configuration of a fuzzy logic system.

In the fuzzification part, any numeric value of the input data is converted into a linguistic value between 0 and 1. The fuzzy system requires functions for each input data:

- Input (1): Variable (1). Subsets: low, average and maximum.
- Input (2): Variable (2). Subsets: low, average and maximum.
- Input (3): Variable (3). Subsets: low, average and maximum.
- Input (n): Variable (n). Subsets: low, average and maximum.

Fuzzy inference is a method that interprets the values in the input vector and, based on fuzzy rules, assigns values to the output vector **¡Error! No se encuentra el origen de la referencia..** With this purpose, it is necessary to establish the rules that will perform the defuzzification process

to provide the output. The Fuzzy rules (IF antecedent THEN consequent) in expert system are usually is following **¡Error! No se encuentra el origen de la referencia.:**

IF Var (1) is A11 and/or Var (2) is A21 ... THEN y is B1
else
IF Var (1) is A12 and/or Var (2) is A22 ... THEN y is B2
else
IF Var (1) is A1n and/or Var (2) is A2n ... THEN y is Bn

where *Var (1)*, *Var (2)*,... *Var(n)* are the fuzzy input (antecedent) variables, *y* is a single output (consequent) variable, and *A11 . . . A1n* are the fuzzy sets **¡Error! No se encuentra el origen de la referencia.** Generally, there are *n* input variables consisting of 3 fuzzy linguistic variables. Therefore, a total of 3^n rules will provide all possible combinations of the input variables.

Defuzzification is the process of producing a quantifiable result given fuzzy sets and corresponding membership degrees. There are many types of defuzzification methods, usually maximum membership and centroid techniques are used **¡Error! No se encuentra el origen de la referencia.,¡Error! No se encuentra el origen de la referencia.**

2. Methodology proposed

In this paper, a novel methodology is presented to make an original treatment of the SCADA dataset. The flowchart of the methodology proposed is shown by Figure 2.

Fig.2: Alarm identification flowchart.

In the diagram adopted for the identification of alarms, it is integrated the real data collected by SCADA system with the fuzzy system. With this purpose, the SCADA data will be preprocessed before of being inputted in the fuzzy system. This preprocess starts with the evaluation of the simple moving average (SMA) of the SCADA signals. Then, the difference between the signals and the SMA is calculated. These differences will be used as input vectors for the fuzzy system.

Once the new variables have been obtained, the next step is to establish some control laws for them. The new variables will be analyzed statistically to obtain two thresholds. These thresholds will separate the graph into three different regions. Figure 3 shows the definition of the thresholds and the regions (good, acceptable, unacceptable) considered.

Fig.3: Classification for member functions.

This classification allows for determining the member functions of the inputs of the fuzzy system and generate the fuzzy system. The control of each physical parameter collected by SCADA can be represented by the difference between the values of all the peaks and the mean value. The fuzzy inference system is based on different rules to generate the occurrence probabilities of the alarms in the output **¡Error! No se encuentra el origen de la referencia..**

The output of the fuzzy logic will correspond to three different scenarios:

- *No alarm*: The parameters analyzed have adequate values and the condition of the WT is correct. The output of the fuzzy logic is less than 0.5.
- *Orange alarms*: indicator of probable defects that do not cause problems for maintenance planning and can be programmed with daily or weekly preventive maintenance tasks. This alarm will be considered when the output of fuzzy system is between 0.5 and 0.75.
- *Red alarms*: critical states (maximum values for more than one physical variable), which requires diagnosis and urgent intervention to return the status parameters to acceptable levels. This alarm will be considered when the output of fuzzy system is more than 0.75.

3. Real Case Study

The data considered for this real case study is obtained from the European Project entitled OPTIMUS **¡Error! No se encuentra el origen de la referencia..** The database used in this paper come from a SCADA system that provides different measures every 10 minutes in the period from 01/01/2015 to 28/03/2015. The system measure 37 physical variables, but in this paper only 4 parameters have been considered to simplify the example. These parameters correspond to the speed of main shaft (*Vel*), vibration at the main shaft (*Vibr*), oil temperature (*Toil*) and bearing temperature (*Tbear*). Figure 4 shows these parameters.

Fig.4: Evolution of real data in time.

Figure 5 shows the preprocessing of the variable Tbear before of being inputted in the fuzzy system. The blue line corresponds to the “Temperature of bearing (Tbear)”. The red line evaluates the moving average (MA) calculated for a period of 2 hours. The black line represents the absolute value of the difference blue and the red line. This new variable will be named “Difference of Tbear” and noted (DTbear).

Fig.5: Preprocessing of SCADA signals.

The same procedure will be applied to the rest of variables. The new variables will be obtained by the following equations:

$$Dvel = |Vel - SMA(Vel)|$$

$$DVibr = |Vibr - SMA(Vibr)|$$

$$DToil = |Toil - SMA(Toil)|$$

$$DTbear = |Tbear - SMA(Tbear)|$$

Consequently, Figure 4 will be transformed to Figure 6, considering the new variables.

Fig.6: Evolution of real data in time.

For establishing the different thresholds pointed in Figure 3, a maximum value have been assigned to each input considering several norms and standards **¡Error! No se encuentra el origen de la referencia..¡Error! No se encuentra el origen de la referencia..¡Error! No se encuentra el origen de la referencia.** and **¡Error! No se encuentra el origen de la referencia..** These values correspond to:

- Max (Rotor velocity) = 20.2 rpm,
- Max(Vibration)= 115 μm , Max (Temperature of oil) = 95 $^{\circ}\text{C}$,
- Max (Temperature of bearing) = 110 $^{\circ}\text{C}$.

Thus, some of the rules defined in this example are :

- IF DVel is good and DVibr is good and DToil is good and DBear is good THEN the output is green.
- IF DVel is good and DVibr is acceptable and DToil is unacceptable and DBear is Good THEN the output is red.
- IF DVel is unacceptable and DVibr is good and DToil is unacceptable and DBear is unacceptable THEN the output is red.
- If DVel or DVibr or DToil or DBear is unacceptable then the output is red

More rules of the Fuzzy system are presented graphically in the Figure 7:

Fig.7: Rule based Fuzzy Inference System for generation of probabilistic alarms.

The red line of each variable shows the value of the variable. The displacements to the left or the right of these lines generates a new position of the output, and therefore, a new probability of alarm. Once, the fuzzy system is defined, it is possible to represent surfaces that explain the behavior of the system under different conditions. For example, Figure 8 represents the probability of alarm depending on DTbear and DVibr.

It is noted that the probability varies proportionally with the temperature of the bearings and the vibration. For values of DTbear and DVibr respectively less than certain value, the probability has very minimal values, in opposite, the probability of alarm increase exponentially when these values are exceeded.

Fig.8: Surface view of alarms probability with respect to DTbear and DVibr.

The system built has been proved by performing a simulation with the SCADA data. The results of the simulations are shown in Figure 9. The system provides a certain probability of alarm regarding to the inputs.

Fig.9: Probability of alarms generation.

A total of 10768 inputs have been analyzed through the created fuzzy system. The outcomes are:

- 10407 normal measures. This represent the 96.7% of the total data
- 361 orange alarms. This represent a 3.3% of the total data.
- No red alarms. In the period studied there is not any value exceeding the limits of critical alarm.

This method allows to transform the data collected by the SCADA system into probability of alarms. It can be a useful information for complementing the decision making. The methodology can aid to reduce false alarms because when a critical alarm arises from the SCADA system, the response of the fuzzy system can reinforce that alarm.

4. Conclusions

In this paper, a new methodology based on fuzzy logic is proposed in order to analyze the SCADA data and provide an alternative decision support. The main purpose is to process the signals collected by the SCADA system from a different perspective. These signals are converted into new variables to be inputted in the fuzzy system. A fuzzy system has been created using several standards and considering the signals of the SCADA system from a statistical point of view. The creation of the fuzzy systems implies the definition of a set of fuzzy rules. In this case, the variables considered correspond to the distance of the value measured by the SCADA to the simple moving average. The more distance to the average, the more probability of being an abnormal measure, and therefore, the more probability to generate an alarm.

Three different outcomes of the fuzzy system have been considered. Firstly, the values are in range of normal behavior and no actions are required. Secondly, orange alarms where the probability of alarm reaches exceeds a defined threshold but it is not a critical point. Finally, red alarm when the probability is unacceptable and the system need an urgent action.

The results of this methodology can become a statistical support for the generation of alarms. The methodology can be also used as a complementary information for evaluate the priority of each alarm.

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References

- [1] Muñoz, C.Q.G.; Márquez, F.P.G.; Tomás, J.M.S. Ice detection using thermal infrared radiometry on wind turbine blades. *Measurement* 2016, 93, 157-163.
- [2] A. Pliego, F.P. Garcia Márquez, J.M. Pinar, Optimal Maintenance Management of Offshore Wind Farms, *Energies*, 9(1), 46, 2016.
- [3] B. Chen, Y. Qiu, Y. Feng, P. Tavner and W. Song, "Wind turbine SCADA alarm pattern recognition," in Renewable Power Generation (RPG 2011), IET Conference on. IET, 2011, Edinburgh, UK Sept 6 – 8. pp. 1–6. .
- [4] de la Hermosa González, Raúl Ruiz, Fausto Pedro García Márquez, and Vichar Dimlaye. "Maintenance management of wind turbines structures via MFCs and wavelet transforms." *Renewable and Sustainable Energy Reviews* 48 (2015): 472-482.
- [5] Demonstration of Methods and Tools for the Optimisation of Operational Reliability of Large-Scale Industrial Wind Turbines, OPTIMUS Project. (OPTIMUS, Ref.: FP-7-Energy-2012-TREN-1: 322430).
- [6] Gómez Munoz, C.; dDe la Hermosa Gonzalez-Carrato, R.; Trapero Arenas, J.; Garcia Marquez, F. A novel approach to fault detection and diagnosis on wind turbines. *GLOBAL NEST JOURNAL* 2014, 16, 1029-1037.

- [7] Gómez Muñoz, C.Q.; García Márquez, F.P. A new fault location approach for acoustic emission techniques in wind turbines. *Energies* 2016, 9, 40
- [8] Gustavo Luiz C. M. de Abreu; José F. Ribeiro, "On-line control of a flexible beam using adaptive fuzzy controller and piezoelectric actuators", *Revista Controle & Automacao/Vol.14 no.4/Outubro, Novembro e Dezembro 2003*
- [9] Márquez, Fausto Pedro García, and Jesús Miguel Chacón Muñoz. "A pattern recognition and data analysis method for maintenance management." *International Journal of Systems Science* 43.6 (2012): 1014-1028.
- [10] Márquez, Fausto Pedro García, Diego J. Pedregal, and Clive Roberts. "New methods for the condition monitoring of level crossings." *International Journal of Systems Science* 46.5 (2015): 878-884.
- [11] Marugán, A.P.; Márquez, F.P.G. A novel approach to diagnostic and prognostic evaluations applied to railways: A real case study. *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit* 2015, 0954409715596183.
- [12] Marugán, A.P.; Márquez, F.P.G.; Lavirgen, J.L. In *Decision making via binary decision diagrams: A real case study*, Proceedings of the Eighth International Conference on Management Science and Engineering Management, 2014; Springer: pp 215-222.
- [13] MathWorks. (2007). Fuzzy logic toolbox <https://es.mathworks.com/products/fuzzy-logic.html>.
- [14] Muñoz, C.Q.G.; Márquez, F.P.G.; Tomás, J.M.S. Ice detection using thermal infrared radiometry on wind turbine blades. *Measurement* 2016, 93, 157-163.
- [15] Muñoz, JM Chacón, FP García Márquez, and M. Papaelias. "Railroad inspection based on ACFM employing a non-uniform B-spline approach." *Mechanical Systems and Signal Processing* 40.2 (2013): 605-617.
- [16] P. García Márquez, Pérez, J.M. Pinar, A. Pliego, and M. Papaelias, "Identification of critical components of wind turbines using FTA over the time." *Renewable Energy* 87 (2016): 869-883
- [17] Peng Zhang "Advanced Industrial Control Technology", First edition, Elsevier 2010.
- [18] Robert Errichello, Jane Muller. "Applications requirements for wind turbine Gearboxes", GEARTECH, Albany, California, September 1994.
- [19] SKF spherical roller bearings, Setting the standard for performance and reliability. Available at the link: http://www.skf.com/binary/143-148465/6100_EN.pdf
- [20] Tahar Benmessaoud, Kamal Mohammedi et and Yousef Smaili, "Influence of Maintenance on the Performance of Wind Farm", *PRZEGLĄD ELEKTROTECHNICZNY*, ISSN 0033-2097, R. 89 NR 3a/2013.
- [21] Vibration standard is available from the ANSI website at the following link: <http://webstore.ansi.org/>
- [22] Vikshant Khanna and Rupinder Kaur Cheema, "Fire Detection Mechanism using Fuzzy Logic", *International Journal of Computer Applications* (0975 – 8887), Volume 65– No.12, March 2013.
- [23] Wind power evolved aw1500 technical specifications (visited on 20/01/2017) http://www.acciona-wind-power.es/media/1390114/11052015-aw1500_inusa_abril-2.pdf
- [24] Yingning Qiu, Yanhui Feng, Peter Tavner, Paul Richardson, Gabor Erdos and Bindi Chen, "Wind turbine SCADA alarm analysis for improving reliability", *Wind Energy*. (2011) © 2011 John Wiley & Sons, Ltd. DOI: 10.1002/we.