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DETERMINATION OF THE VARIABLES FOR THE DIAGNOSIS IN THE WIND TURBINE OF "GIBARA 1"

Determinación de las variables para el diagnóstico en los aerogeneradores de "Gibara 1"

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Abstract:

The article deals with how the variables of diagnosis of the wind turbines of "Gibara 1" Wind Farm are determined, through a procedure based on a systemic and statistical analysis. The procedure proposed was established when three wind turbines from the "Gamesa" company, model G52-850 kW belonging to "Gibara 1" Wind Farm, in Gibara municipality, Holguín province were studied and analyzed. The fundamental tasks carried out were: to study the factors that influence in the wind turbines operation, to analyze the methods for determining variables of diagnosis, to collect statistical data regarding to the variables to be studied and the development of a procedure for determining variables of diagnosis. In the course of the investigation, it was possible to analyze the behavior of the variables searched in the wind farm studied and were determined the ones which allow the technical diagnosis of the equipment.

Keyswords: variables; diagnosis; wind turbines; procedure.

Resumen

En el artículo se aborda como se determinan las variables para el diagnóstico de los aerogeneradores del Parque Eólico Gibara 1, a través de un procedimiento sustentado en un análisis sistémico y estadístico. El procedimiento propuesto fue establecido al ser estudiados y analizados tres aerogeneradores de la firma Gamesa, modelo G52-850 kW pertenecientes al Parque Eólico "Gibara 1", del municipio Gibara, provincia Holguín. Las tareas fundamentales desarrolladas fueron: estudiar los factores que influyen en el funcionamiento de los aerogeneradores, analizar los métodos para la determinación de variables de diagnóstico, recopilar datos estadísticos referentes a las variables a estudiar y el desarrollo de un procedimiento para la determinación de las variables para el diagnóstico. En el transcurso de la investigación se logró, analizar el comportamiento de las variables registradas en el parque eólico de estudio y se determinan las que permiten el diagnóstico técnico del equipo.

Palabras Claves: variables; diagnóstico; aerogeneradores; procedimiento.

1. Introduction

The wind potential introduced in the Electrical Power System (EPS) has been increased during the last decades, causing the operators of the system must face difficult problem of adjusting this generation of electrical power, also called distributed generation (which has its own peculiarities, to make the system safe and reliable). Issues such as; the influence of wind farms on frequency and voltage regulation, wind fluctuations, voltage sags, etc., they are being studied within the framework of this new context [1]

The largest wind farm in Cuba is located in Gibara municipality in the north of Holguín Province. This wind farm consists of "Gibara 1" which delivers a capacity of 5.1 MW since February 2008 and "Gibara 2", in operation since October 2010, generating 4.5 MW, for a total of 9.6 MW.

The technology used in "Gibara 1" consists of six wind turbines "G52-850 kW" model, manufactured from "Gamesa Eólica" Spanish company. This equipment is a windward three-bladed rotor wind turbine, regulated by a pitch system and with a yaw system. The rotor is 52 m in diameter and it uses the Ingecon-W control system capable of adapting the wind turbine to operate in large ranges of speed [2].

One of the most important technological innovations in predictive maintenance is the monitoring of the wind turbine parameters, because it allows to receive continuously and automatically the work variables, through data acquisition systems, sensors installed in the wind turbine, and the machine's control sensors, to be evaluated in real time, using a system based on artificial intelligence [3]. This smart system is not installed in "Gibara 1" Wind Farm.

The problematic situation identified consists of several alarms recorded in this period, due to high temperatures in the gearbox and generator, mainly when wind speeds exceed 10 m/s; which brings about the shutdowns and unavailability of the wind farm, precisely when the favorable environmental conditions exist to increase generation. In each wind turbine 31 variables are recorded, which provide a lot of data, but little information. For this reason, the variables used to diagnose the technical condition of the wind turbine are not known.

The main objective of this research is to determine through the systemic analysis and statistical tools, the variables for the technical diagnosis in the wind turbines of "Gibara 1" Wind Farm. Whereas, as a research hypothesis is proposed; If a procedure is available, through a systemic analysis and using statistical tools that determine the relationships among the variables recorded by the SCADA and stratify them, This will allow to determine the variables for the real-time diagnosis of the "G52-850" wind turbines model of "Gibara 1" Wind Farm.

1.1 Research carried out through technical diagnosis in wind turbines

According to [4], the data stored in the supervisory control and data-acquisition (SCADA) system are used to supervise the operating parameters of the turbines and the wind farm in general, in order to monitor operating condition of the wind farm. In other words, some of these data are useful as a predictive maintenance tool. The challenge of this issues is to identify what data are useful for this purpose, and how to process it.

The study developed [5], states that several variables and parameters are identified during the work of the wind turbine. Some of them allow to evaluate the correct operation of the equipment, therefore, knowing variables is essential to study their regularities and identify failure patterns.

On other hand, [6], devises a method to detect automatically faults in geared pairs when the rotational speed is unknown and changable, without using a tachometer. This method uses synchronous damage detection based on Lock-in amplifiers and an algorithm to estimate the rotational speed automatically. The estimation of the rotation speed is based on the decomposition of the vibration signal into one-component signals and the analysis of the non-quadratic phase coupling. With the proposed method was possible to detect a faulty gear pair (with a broken gear tooth) in a gearbox of a 3 MW wind turbine. This method can be applied effectively under conditions of variation of the rotational speed (Δv) of up to 30%, even when the signal-to-noise ratio (SNR) is low.

The work developed by [7], some data from SCADA are used to control variables such as: bearing temperatures, vibrations, rotor currents and rotational speed, developing methods that extend to schemes of augmented observer banks and decision mechanisms. The proposed schemes allow the estimation of failures in systems with non-isolatable failures, using artificial intelligence techniques and statistics.

To validate the technique known as Current Signature Analysis, in the detection of failures of three induction generators doubly fed from a wind farm through SCADA data, is the objective of [8], to analyze the phase currents in the stator and the converter, detecting bearing problems and rotor imbalance.

In the investigation of [9], a diagnostic system is developed through SCADA data, using current signature analysis and vibrations in wind turbines for the detection of failures, detecting anomalies in bearings and gears of the gearbox and generator.

In case of authors like [10] support the research in a data algorithm for the online detection of failures in wind turbine components in different operating areas, using the analysis of the main components and the correlation among between wind and rotor speed, generator power, among others variables. Affirming that the largest number of failures reported by the control system take place when wind speeds are above 10 m/s.

A methodology based on the Wavelet packet transform to detect mechanical failures in a low-power wind turbine is used by [11], in order to know the behavior of the vibration signals that the wind turbine has with induced failures in blades and bearings, to compare them with the good technical condition. A statistical analysis was performed, obtaining Gaussian distribution functions to observe the discrimination capacity between failure conditions and normal operation. The methodology proposed allows to identify and classify the induced mechanical failures.

In the investigations provided by [12, 13], a study is carried out about the analysis of vibrations of distributed damage, and its difference with specific damages in terms of frequency response. They study four cases: bearing without failure, with damage located in the outer surface, with damage distributed in the outer and inner surface. Similarly, the gears of the gearbox are analyzed in two operating conditions (high and low).

According to the authors [14, 15], show in their research how the use of data-mining techniques in the daily information of the control systems of wind farms can be very useful to classify, define regularities and strata that allow evaluating the operation of the equipment . In the studies carried out, they apply several statistical methods and the field of multivariate analysis, making use of the statistical language "R" on the programming environment "RStudio", in addition, they use trend analysis as a diagnostic technique. They also propose an alternative multivariable control structure that allows to regulate efficiently the main variables of a wind turbine, seeking a smooth transition among operating regions, so they analyze variables such as; speed, wind turbulence, bearing temperature and generator power.

Through the fast Fourier transform (FFT), in [16], the faults are identified, and the discrete wavelet transform (TWD) applied to the modulus of the Park vector of the stator currents. Thus, the failure signatures were obtained by means of the frequency components with the FFT and through the calculation of the RMS value of the samples of the transformed signal in different frequency bands with the TWD.

The analysis developed by [17] shows anomalies detection approach that uses machine learning through statistics and neural networks to achieve monitoring state of wind turbines, using SCADA data. The variables analyzed are wind speed, temperatures in the oil and gearbox bearing. First, machine learning is used to estimate the temperature signals of the gearbox components, then, it analyzes the deviations among the estimated values and the measurements of the signals. Finally, the information from the alarms is integrated with previous analysis to determine the operating condition of the wind turbines. The approach proposed has been tested with data experience from a 2 MW wind turbine in Sweden. The result demonstrates that the approach can detect potential anomalies before failure occurs. It also certifies that it can alert to operators about possible operation conditions changes in the wind turbines, even when the logs do not report any alarms.

About the investigation [18] develops a model based on Artificial Neural Networks (ANN) for the analysis of temperature and vibration measurements of the gearbox by SCADA data, where it is compared the functioning model with similar approaches in the literature. Concluding that the time-scale vibration analysis of the SCADA data is not effective for fault diagnosis, even if it is driving by the artificial intelligence of the ANN, whereas the ANN model proposed for gearbox temperatures is useful for early fault diagnosis. The method tested on data sets from a wind farm in southern Italy and proved to be useful for diagnosing income faults in three of the nine wind turbines at the site.

On the other hand, the researchers [19], state that in practice it is very difficult to develop diagnostic algorithms capable of detecting many types of failures, to be applied to a wide range of employment patterns and configurations. But later, they assure that there are alternatives that allow to identify interesting relationships; among a large number of available signals, to be used as variables of diagnosis. In this case, it processes the signals from the Volvo truck during normal operation and failure, using data mining techniques and determines significant relationships.

About 4.0 technology [20, 21] , they state that allows real-time control of parameters, evaluating their changes and, through an intelligent system associated with a database, offering the most appropriate technical options to solve the obvious problem or the incipient fault.

This service is not available at "Gibara 1" Wind Farm; the SCADA system records an important group of variables (31), which can be accessed instantly. Operators have many data without processing and consequently do not have information about the technical conditions of the equipment. Many of the researches consulted associate the occurrence of faults with the wind speed, of course having the wind estimates reliably; This constitutes another difficulty in the present investigation, where there are no continuous historical records at the site, even the current system is capable of recording it in real time, but does not store it.

In the literature consulted, the variables that allow quickly and efficiently diagnose the technical condition in real time of the main elements of the wind turbine (gearbox and generator), under the operating conditions in Cuba, are unknown. However, benchmark research identifies possible diagnostic methods and techniques, employing vibrations, temperatures, generator current signals, and lubricating oil status from SCADA data.

2. Methodology

The wind farm object of the investigation belongs to Gibara municipality, Holguín province, Cuba; It has six wind turbines, model G52-850 kW from the company Gamesa, monitored by SCADA, which allows to show the variables recorded and stored by the installed sensors.Theoretical research methods such as analysis and synthesis were used; as well as the historical - logical to analyze trends and evolution.

The empirical methods used in data collection were participant observation, technical documentation reviews; as well as expert consulting during the bibliographic review; the logical-historical method of the technical diagnosis process was used, with emphasis on wind turbines. The systemic analysis of behavior in different elements that make wind turbine up was carried out, to identify the structure, composition and hierarchy of the variables.

The wind turbine technical manuals, files and work records were consulted. This investigation analyzes and process 31 variables taking from a database stored in the SCADA system, with 15,000 records, in the period of the years 2018 and 2019, corresponding to three generators of the wind farm. Besides, it was used statistical tools through the software "Statgrapihcs Centurion", to analyze the variables registered by the SCADA and to determine through multivariate analysis and correlation their dependencies, later, these results are integrated into the systemic analysis carried out to interpret the statistical results obtained.

3. Results and Discussion

The following diagram shows a procedure to determine the variables of diagnosis in the wind turbines of "Gibara 1" Wind Farm.

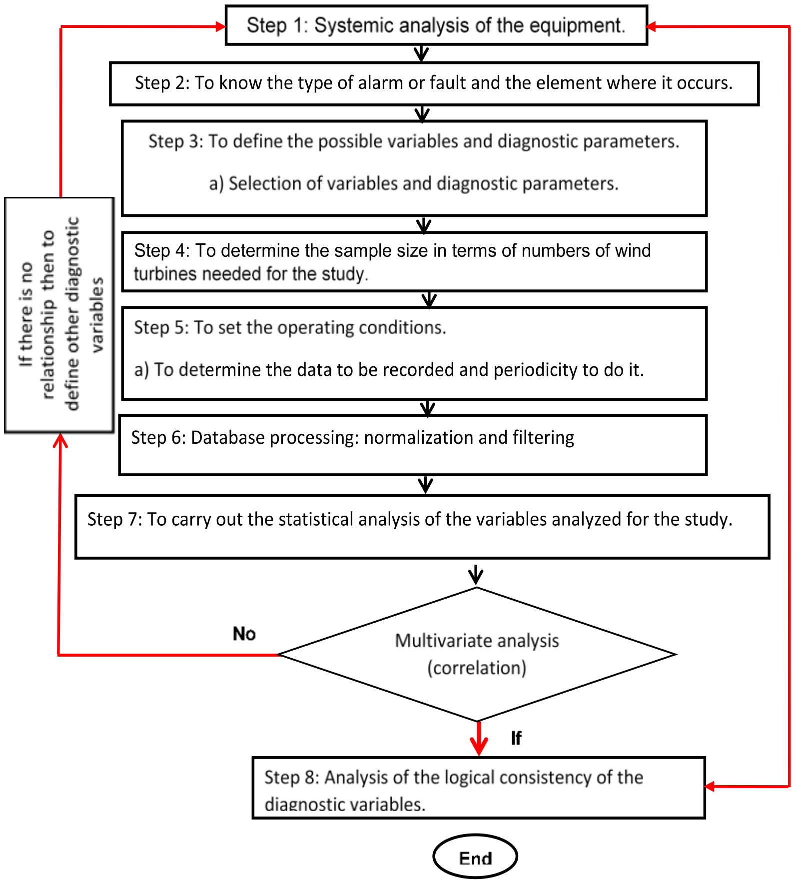

Figure 1. General diagram of the procedure to determine the variables of diagnosis in wind turbines.

Source: own elaboration.

The procedure is based on systemic and multivariate analysis; the development of its steps are addressed cyclically. In each step carried out and normalization of the databases, the following is fulfilled: The first six steps, from the characterization to the observation and recording in tables of the failures or alarms and the values of the variables, allow the evaluator to consolidate and readjust the systemic vision of the analyzed process.

In Step 7, the correlation between the different pairs of variables is calculated, if this correlation is very weak, then it is returned to Step 3 of the procedure to evaluate other variables. In the event that there is a good correlation between the pairs of variables coinciding with the occurrence of the failures or alarms, then they are evaluated in Step 8, through systemic analysis and consultation with specialists, to determine the logical consistency of the result in table 1 the variables registered by the SCADA are showed.

Table 1. Variables registered by the SCADA. Source: own elaboration.

Channel	Description	Channel	Description
01	Blade rotation angle	17	Hydraulic unit pressure
02	Servo valve output	18	Network voltage
03	Wind direction	19	Network current
04	Nacelle temperature	20	Network frequency
05	Gearbox bearing temperature	21	Generator voltage
06	Gearbox oil temperature	22	Generator current
07	Environment temperature	23	Generador frequency
08	Hydraulic unit oil temperature	24	Rotor current
09	Generator front bearing temperature	25	Stator power
10	Generator rear bearing temperature	26	Rotor power
11	Maximum generator winding temperature	27	Total power
12	Maximum transformer temperature	28	Reactive power
13	Control temperature (CCU card)	29	BUS voltage
14	Temperature of the electrical connections of the generator	30	Position of the nacelle
15	Upper radiator temperature	31	Wind speed
16	Lower radiator temperature		

To analyze the work of the wind turbine, the researchers (7, 10, 14, 15, 17 and 18) focus their attention on the variables that census the electrical system and the temperatures of the different components within the nacelle. They argue that the behavior of the variables depends on the wind speed, the stability of the network and of course, the technical condition of the cooling system, the bearings, the coils, the correct electrical grounding and fixing of the electrical connections. Any alteration of these operating conditions produces high temperatures.

The table 2 shows the variables selected for the analysis of the recorded data considering the references analyzed.

Table 2. Variables selected for analysis. Source: own elaboration.

Canal	Descripción
09	Generator front bearing temperature (GFBT)
10	Generator rear bearing temperature (GRBT).
11	Maximum generator winding temperature (MGWT)
07	Environment temperature (ET).
31	Wind Speed (WS).
06	Gearbox oil temperature (GOT).
05	Gearbox bearing temperature (GBT).
17	Hydraulic unit pressure (HUP).
08	Hydraulic unit oil temperature (HUOT).
04	Nacelle temperature (NT)

The processing of the databases uses the STATGRAPHICS Centurión-statistics. Sgp. P software, a normalization of the values of each variable analyzed was carried out, with the objective of knowing if readings were adjusted or not to a normal distribution;

subsequently, those data corresponding to readings with wind speeds below 4 m/s were filtered, in other words, when the wind turbine is not operational.

The remaining values are stratified into three operating regions, the first region for wind speeds between 4-7 m/s, the second region 7-10 m/s and the third 10-15 m/s, These ranges are assumed considering the distribution of failures for different wind speeds, the bibliography consulted and the criteria of specialists.

Finally, different results were obtained in each operation region, where the highest correlation coefficients obtained in the variables analyzed are found with wind speeds greater than 10 m/s, coinciding with most of the incidents recorded.

Below in table 3 a summary of the results is presented, which allowed to validate the close relationship existing (highlighted in bold) between the temperature variables recorded in the gearbox oil, in the bearings of the gearbox and the generator, as well as, in the winding, as regards the wind speeds and with the records of failures that occurred in the period analyzed, when the wind intensity exceeds 10 m/s.

Table 3. Correlations of positive and significant variables. Source: own elaboration.

	GFBT	GRBT	MGWT	GOT	HUOT	NT
GFBT		**0,9905**	**0,9407**	**0,8722**	-0,7148	-0,5813
		(15 000)	(15 000)	(15 000)	(15 000)	(15 000)
		0,0000	0,0000	0,0000	0,0000	0,0000
GRBT	**0,9905**		**0,9537**	**0,8801**	-0,3163	-0,4748
	(15 000)		(15 000)	(15 000)	(15 000)	(15 000)
	0,0000		0,0000	0,0000	0,0000	0,0000
MGWT	**0,9407**	**0,9537**		**0,9481**	-0,3451	-0.623
	(15 000)	(15 000)		(15 000)	(15 000)	(15 000)
	0,0000	0,0000		0,0000	0,0000	0.000
GOT	**0,8722**	**0,8801**	**0,9481**		-0,1141	-0,4277
	(15 000)	(15 000)	(15 000)		(15 000)	(15 000)
	0,0000	0,0000	0,0000		0,0793	0,0000
GBT	**0,8748**	**0,8840**	**0,9543**	**0,9988**	-0,1263	-0,4509
	(15 000)	(15 000)	(15 000)	(15 000)	(15 000)	(15 000)
	0,0000	0,0000	0,0000	0,0000	0,0691	0,0000
HUP	0,275	0,2221	0,121	0,1112	0,0990	-0.002
	(15 000)	(15 000)	(15 000)	(15 000)	(15 000)	(15 000)
	0,0003	0,0000	0,0048	0,0173	0,1548	0.0547
WS	**0,7229**	**0,7475**	**0,8818**	**0,9249**	-0,1232	-0,2744
	(15 000)	(15 000)	(15 000)	(15 000)	(15 000)	(15 000)
	0,0000	0,0000	0,0000	0,0000	0,0272	0,0001
NT	-0,5813	-0,4748	-0.623	-0,4277	**0,9200**	
	(15 000)	(15 000)	(15 000)	(15 000)	(15 000)	
	0,0000	0,0000	0.000	0,0000	0,0000	

Taking into account the recommendations made by experts and the bibliography consulted, a significant correlation coefficient 0.7. Table 3 shows that the recorded ambient temperature does not significantly influence the operation of the main elements; The wind speed does have a great relationship with the temperature values analyzed, this is based on the increase in the mechanical load throughout the system.

The Figure 2 shows a general diagram of the main elements of the G52-850 kW wind turbine at "Gibara 1" Wind Farm, where it can be show by lines and framed within a box the location of the sensors (PT 100) that report the temperature alarms in the analyzed variables.

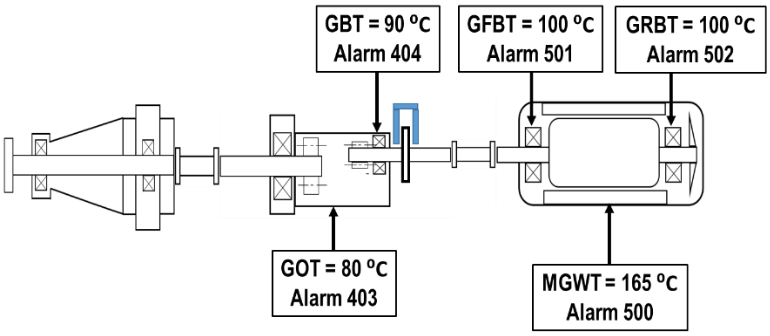

Figure 2. Location of the PT 100 sensors in the different elements of the gearbox and generator. Source: own elaboration.

Evaluating the correlations and knowing the hierarchies and functions of the components, it is determined that variables that must be assumed for the diagnosis are the values of gearbox oil temperature oil temperatures and gearbox bearing temperature; as well as on generator rear bearing temperature, generator front bearing temperature and on the generator winding.

The figures 3 and 4 show the behavior of the diagnostic variables registered by the SCADA, belonging to the generator and the gearbox respectively. Knowing the temperature values at which the alarm is activated, it is possible to evaluate the technical actions and the response of the system. In this case, it is recommended to check the fixation and alignment of the mechanical components, as well as the quantity and frequency of lubrication, inspections of the generator's electrical circuit, cleaning of the radiator, oil filters, and etcetera.

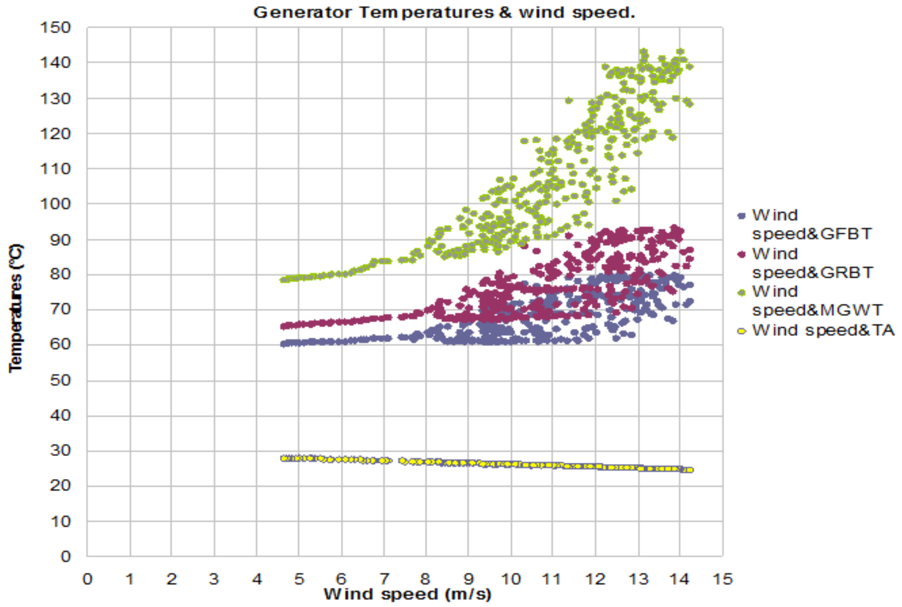

Figure 3. Behavior of the generator temperature variables with respect to the wind. Source: own elaboration.

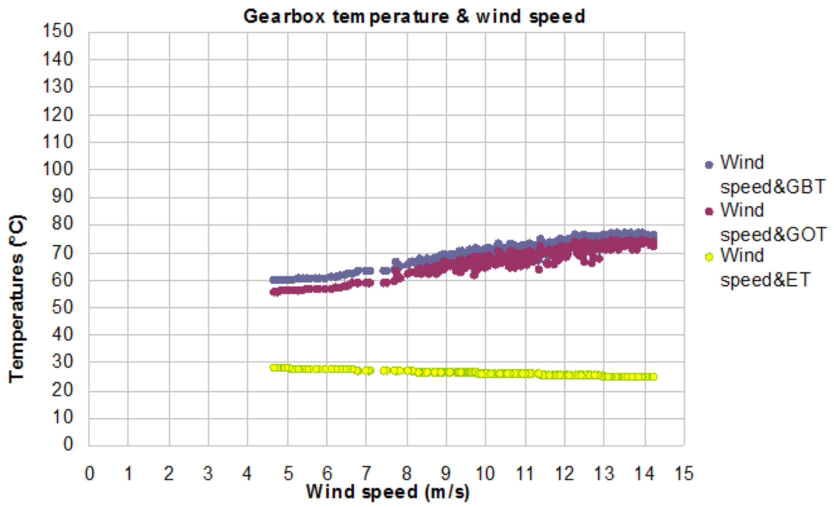

Figure 4. Behavior of the gearbox temperature variables with respect to the wind. Source: own elaboration.

4. Conclusions

1. A procedure is obtained through a model based on a systemic analysis and statistical techniques, that allows the variables to be stratified and to determine those that can be used for the diagnosis of the wind turbines of "Gibara 1" Wind Farm, such as:

• Gearbox oil temperature (GOT).

• Gearbox bearing temperature (GBT).

• Generator front bearing temperature (GFBT)

• Generator rear bearing temperature (GRBT).

• Maximum generator winding temperature (MGWT).

2. The environmental temperature has not relation to the temperatures registered by the SCADA in the gearbox and the generator.

3. Wind speeds have a great influence on the temperatures recorded by the SCADA in the gearbox and generator elements.

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