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Wind turbines design corrections for next Galicia climatic conditions

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Abstract. Galicia, placed in northwest of Spain, is a clear example of global wind energy development as a consequence of its climate conditions. Despite this fact, previous research works have indicated a climate change in the next years that must be considered at the time of wind turbine design, selection, and placement. In this work, information about weather conditions and power output from twenty four wind turbines was sampled in a typical year, and a statistic study was done. Based on this information, a model that relates weather to power conversion in this particular region and wind turbines model was obtained. This particular procedure lets us define the effect of climate change over wind power on Galician wind farms. Results showed a 10% power output fall during spring and summer seasons. Therefore, future studies about new technologies that work out well under those conditions, such as low wind turbines, must be done. At the same time, results can be employed for future wind turbines placement optimization. Finally, nowadays, there is no standard or procedure to consider this highly complex situation, and so the present work aims to be the initial guide.

1. Introduction

European weather starts from the Atlantic, and consequently, what happens over there determines the weather and climate of Europe to a large extent. To be more precise, Galicia is located in northwest of Spain where the climate is mild and mainly influenced by the Azores anticyclone, the Iceland depression, and the central Europe thermal anticyclone.

As a result of this climate, regions, such as Jylland in Denmark and Galicia, are notable as the leading global wind energy development and grid integration. It is known that wind-powered future would mean reducing risks related to fossil and nuclear fuels. Not only does wind power involve no geo-political risk, but also it reduces external energy dependence and the need for energy imports together with no fuel costs, no fuel price risk, no resource constraints, no CO_2, or any other harmful emissions or radioactive waste [1].

On the other hand, recent papers [2-5] have shown that climate change might alter this situation due to wind turbines' power conversion which depends mainly on moist air density and wind velocity. For example, nowadays, wind turbines farms are selected according to wind frequency [6] and direction, but if we consider the maximum power a wind turbine can convert from a free air stream, then we can draw the conclusion that moist air density can affect this issue, and then the climate change is sure to follow.

As a consequence, the effect of the climate change can involve an error on wind turbine selection and its behaviour once it is put in. These effects are really

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significant when we consider the fact that a contribution [7] of the wind energy to the European electricity consumption of about 22.6% (965 TWh) by 2030 is expected, and the average size of a wind turbine will be 2 MW onshore and 10 MW offshore. Then, only 90,000 turbines (75,000 onshore and 15,000 offshore) would be needed to fulfill the 300 GW target. Furthermore, being the technical lifetime for a turbine twenty years onshore and twenty-five years offshore, it is the right time to consider new development pathways, such as lower moist air density and low speed wind turbines.

Taking previous field reports as reference [8], in this paper, twenty-four wind turbines are analysed in a typical year to get a model that relates weather to power conversion. Once that model is achieved, the climate change is assessed in wind turbines in Galicia.

2. Materials and methods

In this paper, a farm with twenty-four wind turbines was tested during a typical year under different weather conditions. Once this was achieved, this model was employed to explain the climate change with wind turbines.

2.1. Climatic data

The climatic data were sampled in 50 weather stations located in the main interesting points in Galicia, as we can see in Table 1. Its climate is affected by the Atlantic Ocean winds, Siam 2008 [9].

In previous research works [10], it is shown that climate change is more than temperature, and other parameters, such as wave height, can be among the affective factors. In our case, wind power can be directly related to relative humidity and wind velocity. In consequence, these meteorological stations show variables, such as temperature, relative humidity, and wind speed, among others, with a sample frequency from about five to ten minutes. Furthermore, its temperature, relative humidity, and wind velocity margin of error are of 0.1°C, 0.2%, and 0.1 m/s, respectively.

Finally, these weather stations have been chosen for this study due to the fact that they avoid the buildings and other parameters that could interfere with the sample data, according to ASHRAE 2005 measuring conditions. In consequence, their height and placement are considered adequate for wind speed observation [11].

2.2. Climatic change predictions

Models of climatic change were obtained from references after a curve fit for each season, according to Eqs. (1) to (4). Each equation shows the average temperature rise in Galicia for the last thirty years regarding the average value of 13.63°C in 1987:

$$\Delta t_{\text{winter}} = 0.05.\tau, \tag{1}$$

$$\Delta t_{\text{spring}} = 0.07.\tau, \tag{2}$$

$$\Delta t_{\text{summer}} = 0.05.\tau, \tag{3}$$

$$\Delta t_{\text{Autumn}} = 0.03.\tau, \tag{4}$$

where Δt is the mean seasonal temperature increment (°C); and τ is the time (years).

Once these models are obtained, they can be used to predict the climate change in Galicia for the next twenty years. The year 2030 was chosen due to the high expectancy of the wind energy contribution from the wind turbines to the European electricity and also because wind turbines have an average technical lifetime of twenty years.

2.3. Effect of moist air density on wind power

As it was already mentioned, the aim of this research is to show the relationship between climatic conditions and the wind power conversion. In order to provide a reference for this power output, it will be compared to the power of the free-air stream, which flows through the same cross-sectional area A, without extracting the mechanical power. On the other hand, ASHRAE psychometric equations let us define moist air specific volume, as shown in Eq. (5) [12].

$$v = 0.29.\frac{T}{P}.(1 + 1.6078.W), \tag{5}$$

where W is the humidity ratio (kg/kg); T is the mean temperature (K); and P is the total pressure (Pa).

Finally, we must remember that the moist air density is the inverse of its specific volume, according to Eq. (6):

$$\rho = \frac{1}{v}, \tag{6}$$

where ρ is the moist air density (kg/m^3).

The software EES (Engineering Equation Solver) was employed to automate the process during the design process.

2.4. Curve fit

Once the real annual samples of the wind power conversion data were obtained from wind farms, they were related to the weather conditions during the same year by the statistical software SPSS 11.0. In particular, a 3D curve fit was designed to define an adequate model that would enable us to predict the future wind power production. The results are shown in Figure 1.

3. Results and discussion

As it was explained in advance, this paper relates real wind turbine power conversion to climate, weather, and future climate change that will have effect on the wind turbines design, their location, and their power conversion. Hourly climatic conditions in wind

Table 1. Weather stations coordinates and altitude.

Weather station	UTMX-29T	UTMY-29t	Altitude (m)
CIS Ferrol	560575	4815596	35
Corrubedo-A	497788	4711340	30
Fontecada-A	510673	4757523	365
Mabegondo-A	560035	4787795	98
Marco da Curra-A	589723	4799415	645
Melide-A	583063	4751027	475
Monte Xalo-A	548165	4787002	510
Muíños	502146	4764251	490
Muralla-A	518434	4732856	650
Olas-A	558736	4775147	401
Río do Sol	525478	4770587	340
Santiago-Físicas-A	535915	4747144	255
Sergude	544164	4741185	226
Campus Lugo-A	618765	4761198	420
Conchada	641837	4705345	600
Folgueira de Aigas	669976	4758503	910
Fragavella-A	625715	4812475	605
Guitiriz-A	598922	4786880	690
Marroxo-A	623291	4703593	630
Monte Panda	641017	4778172	605
O Xipro	660504	4782755	840
Os Ancarea-A	669920	4742923	1365
Pedro Murias A	654986	4822541	45
Sambreixo	598550	4777692	498
Santalla	645239	4737385	720
Serra Vacaloura	601970	4741768	795
Xunqueira	612845	4834430	15
Alto do Rodicio-A	616296	4683835	962
As Petarelas	670470	4703269	555
Baltar	606369	4643587	820
Castelo da Pena	636358	4642815	670
O invernadeiro-A	636971	4664276	1020
O Xurés	584682	4639012	1000
Pedreiriño	573955	4643896	720
Pieles	585455	4708064	680
Serra do Eixe	664341	4691308	1225
Verín-A	632770	4648322	555
Arcos da Condesa	531354	4173851	145
Carballedo	541735	4702509	350
Castro Vicaludo	511413	4649371	450
Castrove-A	524471	4701077	415
Corón-A	520514	4714577	7
Cuntis	533209	4721465	265
Fornelos de Montes-A	550571	4685361	759
Illas Cíes	508050	4674377	15
Lourizán-A	527746	4695497	60
Monte Aloia-A	526608	4658156	410
Mouriscade-A	570877	4718272	501
Pereira	555880	4720398	715
Queimadelos-A	547276	4675193	360

turbines farm were sampled with real wind power. The temperature, the relative humidity, the wind velocity, and the wind power conversion were sampled for each season of the last few years. These figures prove that climatic conditions are mild with a high mean relative humidity of 80% during the whole year. The temperature shows a clear variation between winter and summer seasons from 4°C in winter to 14°C in summer. Wind velocity ranges from 4 m/s to 12 m/s mainly in the winter season. These values are in

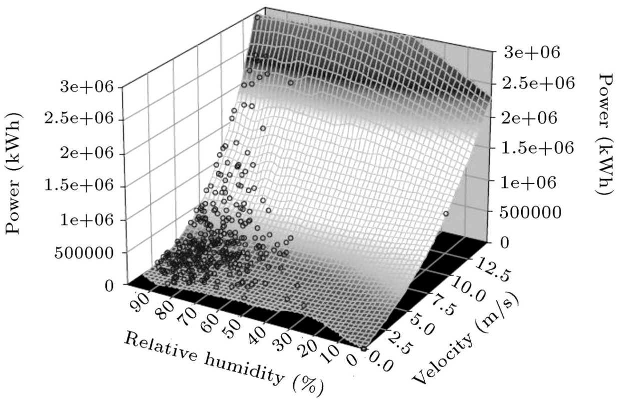

Figure 1. Curve fit among the wind power, the wind velocity, and the moist air density.

agreement with previous research works about the ocean wind energy resource and trends [13-14], and all these variables will simultaneously influence the wind power obtained.

After studying the climatic conditions and the wind power conversion in the past year, it is interesting to settle its relationship. To prove it, a 3D fit of real sample data was done to relate the power conversion and climatic conditions of temperature and relative humidity, expressed as moist air density, in a wind turbine farm. Results proved the adequate model as a function of moist air density and a cube of wind velocity for a correlation factor of 0.99, as seen in Figure 1 and Eq. (7):

$$P_{ow} = -249492.18 + 21722274.\rho + 1128.9655.V^3, \quad (7)$$

where P_{ow} is the wind power (kWh); ρ is the moist air density (kg/m^3); and V is the wind velocity (m/s).

The resulting model presents some constants that consider real factors, such as ambience and wind turbine characteristics. This model could be employed to predict that power conversion can respect climatic conditions. The average temperatures and the wind velocity for the last ten years are represented in Figures 2 and 3, and its corresponding power conversion is shown in Figure 4 for each season, according to the resulting model.

These figures prove that seasonal climatic conditions respect the wind power conversion. Figure 2 shows the annual mean temperature of the wind farm zone for each different season. Therefore, the mean temperature in the summer shows its higher value at about 16°C, and in winter, it is at 7°C. Autumn and spring seasons present intermediate values of 13 and 11°C, respectively.

On the other hand, mean wind farm seasonal velocity is shown in Figure 3. This figure shows a summer mean velocity of 3.5 m/s that is the lowest value compared to 5.5 m/s in the other seasons.

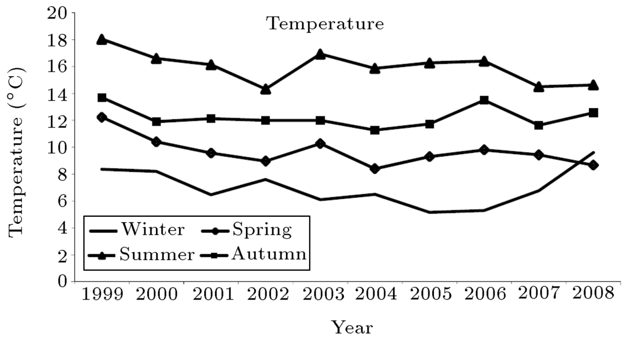

Figure 2. Seasonal mean temperature of the last ten years.

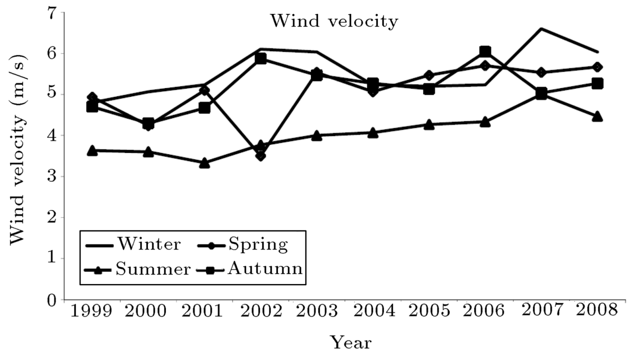

Figure 3. Seasonal mean wind velocity of the last ten years.

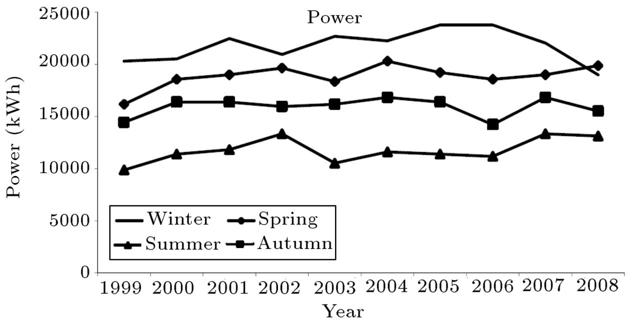

Figure 4. Seasonal mean power conversion of the last ten years.

This mean velocity is a consequence of the Azores anticyclone, as explained before.

In Figure 4, it can be seen that a mean value is similar to the nominal power obtained during spring and autumn seasons. This power rises to a value of 20 MWh during the winter. Finally, during the summer time, this wind power is experimented in a clear fall regarding the other seasons with a mean value of 10 MWh. These curves let us understand that although the mean wind velocity is nearly the same in spring as it is in autumn, it will be the mean temperature as the one that controls the wind power conversion. This effect will be present when we try to predict the climate effect on wind power conversion, because a temperature rise as a consequence of the

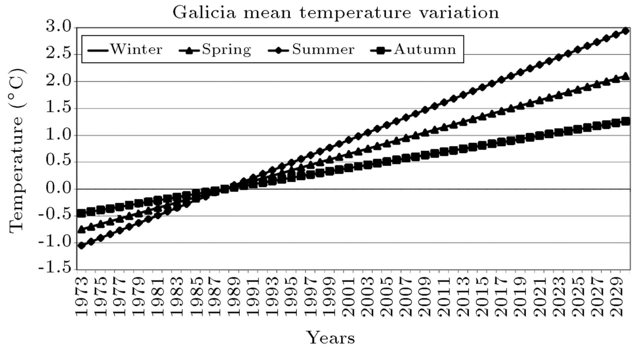

Figure 5. Mean Galicia temperature evolution during the last years.

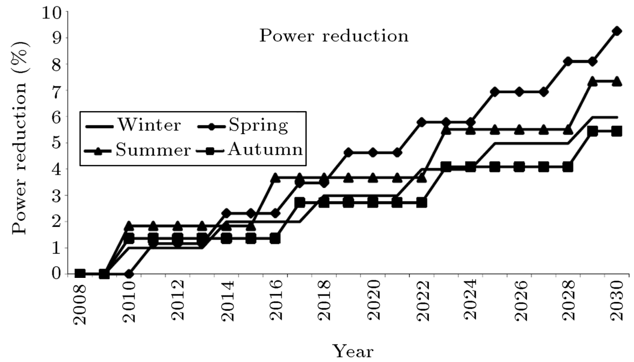

Figure 6. Power reduction percentage in the next few years.

climate change will modify wind power production in these years if the same wind turbines would still be working. Therefore, once the relationship between climate and wind power conversion is proved, it is interesting to know which climate will effect on wind turbines production. The references showed four linear adjustments in the average temperature rise during the last few years that let us predict the future mean temperature for each season, as seen in Figure 5 and in Eqs. (1) to (4). It is interesting to point out that the winter and summer seasons show the same annual temperature rise ratios, although the highest rise is shown in the spring time. This temperatures rise will involve a value of 3, 2.1, and 1.3°C in spring, winter, and autumn seasons by 2030, respectively, as seen in Figure 5. These values of temperature, mean relative humidity, and wind velocity are introduced in the resulting model, showing that the highest power reduction reaching a value of 9% by 2030 will happen in the springtime and that in the summer it will be about 7%. In winter and autumn winds, the power reduction will be about 6% of the current farm wind power, as we can see in Figure 6.

If we consider that there are not any wind turbines operating by 2030 due to the fact that the technical lifetime for a turbine is twenty years onshore and twenty-five years offshore, then it is the right time to consider new development pathways that could yield very great returns for technology. We should also consider the diversity of turbine types and materials used twenty years ago, which proves this point. The small wind energy sector is just one example of a leviathan starving to death for the lack of a long-term research [15-18]. A lower moist air density and a higher frequency of extreme wind velocities should be considered when it comes to research studies.

These low speed wind turbines must be analysed with different rotors, such as the Savonius rotors [19-22], and this should be done in depth in future papers.

4. Conclusions

In this paper, real wind farm power conversion was sampled during a typical year simultaneously with climatic conditions. As a consequence of these mean values, wind power conversion shows maximum mean value during the winter season and minimum mean during the summer as a result of its mean wind velocity. Furthermore, the A 3D model was obtained and tested under predicted temperature. Results showed that the highest power reduction reaching a value of 9% by 2030 would happen in the spring season, and that it will be about 7% in the summer. In winter and autumn, the wind power reduction will be about 6% of the current farm wind power.

Finally, we must remember that wind power can make a substantial contribution to the EU emission reduction targets under the Kyoto protocol. The wind could comply with the 30% of the Union's obligation by 2010 if there is enough emphasis on the technological R&D and market development. Therefore, if we consider that nowadays there are not any wind turbines operating by 2030 due to the fact that the technical lifetime for a turbine is twenty years onshore and twenty-five years offshore, then it is the right time to consider new development pathways that could yield very great returns for the technology like low speed wind turbines.

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Biographies

José A. Orosa was graduated in Marine Engineer and Naval Architecture at the University of A Coruña. He is the prize winner of the Spanish Marine Engineer Studies. Nowadays, he is Director of the Department of Energy of the University of A Coruña. During last years, he participated in the International Energy Agency Annex 41 and collaborated with the INEGA and IDEMEC of the University of Porto.

Ángel M. Costa is graduated in Marine Engineer and received a Master degree in Maritime Engineering. His PhD showed the link between weather conditions and failures in wind farms based on new statist procedures. Presently, he is a Full Professor and Researcher of the Department of Energy of the University of A Coruña (Spain) about wind energy conversion and management. During the last years, he participated in national and international research works about wind energy conversion and management in collaboration with the International Energy Agency (IEA).

Gholamreza Roshan received the PhD degree in Physical Geography field of climatology from University of Tehran, Tehran, Iran, in 2011. He is currently an Assistant Professor in Golestan University, Gorgan, Iran. His research interests lie in the climate change, global warming, biometeorology, and climate modeling. He has published more than 60 peer-reviewed publications and conference papers in his field as well as some technical reports for various public and private agencies. Also, he has been selected as a top professor in 2013, 2014, and 2015 years by Golestan University.

Enrique Juan García-Bustelo received his BS and MS in Marine Engineer from the University of A Coruña and Master in Marine Engineering. After that, as Marine Engineer, he received a great professional experience in power stations and thermodynamically processes. Currently, he is Full Professor and Researcher at the Department of Energy of the University of A Coruña. His PhD showed a new procedure for energy conversion under low wind velocities. In last years, his research topic has been centred on moist air modelling and new applications.