Int. J. Environ. Res., 9(4):1277-1286, Autumn 2015
ISSN: 1735-6865

Noise Pollution Analysis of Wind Turbines in Rural Areas

Ruggiero, A.[1*], Quartieri, J.[1], Guarnaccia C.[1] and Hloch, S.[2]

[1]Department of Industrial Engineering, University of Salerno,Via Giovanni Paolo II 132, I-84084, Fisciano (SA), Italy
[2]Department of Manufacturing Technologies, Faculty of Manufacturing Technologies, TU of Košice with the seat in Prešov Bayerova 1, 080 01 Presov, Slovak Republic

Received 14 Oct. 2014; Revised 30 Jan. 2015; Accepted 2 Feb. 2015

ABSTRACT: This paper is mainly focused on noise pollution problems related to the use of wind turbines. The installed turbines are Vestas V52 and the farm map under study is a typical rural area in south Italy, in which a wind farm has been recently installed and made operative. Since the area is rural and the number of vehicles per hour is negligible, noise emitted by roads does not affect the prediction on turbines effect. The paper deals with a predictive software approach and the experimental analysis of frequency spectra and time history of the acoustical noise produced by wind turbines. In the software framework, several simulations have been performed, introducing different operating conditions and simulating more turbines in a symmetric array, giving a first description of the results that can be achieved in terms of noise mapping in more complex configurations of wind farms. The possibility to obtain important information about the operating conditions and maintenance status of the turbine from the frequency spectra and time history analysis is reported.

Key words: Noise control, Wind turbine, Noise propagation, Spectrum analysis, Time history

INTRODUCTION

It is well known that the wind power was used in agriculture through the ages: in the first millennium Persia, China, and Rome used blades on a vertical axis to mill grain; in the 1800s Americans invented the first self-directing, self-governing windmill for use in the Plains states, pumping water from wells for farmers and railroad stops to fill boilers; in the 1920s the farmers used the same machines hooked to generators to create electricity from wind. This largely ended by World War II with the Rural Electrification Act bringing power lines to rural areas. In the middle ages Europe developed horizontal axis machines to mill grain and pump water. In 2000 a whole new class of wind turbines – designed specifically to generate electricity, and based on lift rather than drag – allow farmers to make more money harvesting the wind above their land than from raising crops. This century is going to be characterized by the time of energy crisis. The lack of petrol, the still ongoing research on nuclear fission plants and the global warming are the main elements that lead to the development of green and renewable energies. In this framework, wind turbines are a relevant component of the complex scenario of the sustainable development. Wind turbines generate renewable energy and thus contribute to sustainable development. However, disturbance from wind turbines may be an obstacle for large-scale production (Rand and Clark, 1990, Wagner *et al.*, 1996, Wolsink *et al.*, 1993). Few studies have so far been directed to the prevalence of disturbance, and existing knowledge of annoyance due to wind turbines is mainly based on studies of smaller turbines of less than 500 kW (Ackermann and Söder, 2000, Pedersen *et al.*, 1994). Global wind power installed at the end of 2003 reached 39 GW according to American Wind Energy Association (2004), an increase of 26% in just one year. United States (7 GW) and Europe (29 GW) account for 90% of the cumulative capacity. In Sweden, more than 600 wind turbines are operating today with a total installed capacity of 0.4 GW, producing 600 GWh per year. They are placed in 84 of Sweden’s 290 municipalities both along the coasts and in rural inland areas, concerning a number of people. The goal set up by the Swedish government for 2015 is 10 TWh, leading to an increase of 1600% from today. Most of new turbines could be probably situated off shore, but as the cost for building on land is considerably lower, the development on land is expected to continue. Already, turbines are being erected near densely populated areas. Some interviews

---

*Corresponding author E-mail: ruggiero@unisa.it

conducted among 12 respondents living within 800 m of a wind turbine, and a register study of the nature of complaints to local health and environments authorities, indicated that the main disturbances from wind turbines were due to noise, shadows, reflections from rotor blades, and spoiled views (Pedersen, 2000). In particular, among these environmental polluting agents, acoustical noise must be considered. The turbines generate unwanted sound, both mechanical and aerodynamic. In the last years, with the advancement of technology, wind turbines became much quieter, but their noise is still an important source, to be considered in the site choice phase. In this framework, new technologies need to be developed in order to reduce the environmental impact of the wind turbines. Together with the technologies, a source and propagation modeling improvement could be helpful in order to understand the correct behavior of the noise produced by the wind turbine. Such as for means of transportation noise (see for instance Guarnaccia *et al.,* 2011b, Guarnaccia, 2010, Guarnaccia, 2013, Iannone *et al.,* 2013, Quartieri *et al.,* 2010, Quartieri *et al.,* 2008, Guarnaccia and Quartieri, 2012), it is common to merge field measurements campaign with prediction tools adoption. For instance, innovative models can be adopted to estimate the surpassing of a certain threshold of noise, based on bayesian or on Time Series Analysis approaches, such as has been done for road traffic noise (Guarnaccia *et al.,* 2014a, Guarnaccia *et al.,* 2014b, Guarnaccia *et al.,* 2014c) and airport noise (Guarnaccia *et al.,* 2015); in this case, the adoption of field measurement is very important to calibrate the model and to validate its result.

Of course, the measurements have to be carefully planned, according to ISO standards (for instance, for wind turbine noise, IEC 61400-11, 2002 and ISO 9613-1, 1993) and taking into account uncertainty in environmental noise measurements (Ruggiero *et al.* 2010). Experimental data may be used to check the robustness of the model and for its validation (Guarnaccia *et al.,* 2011a).

In Guarnaccia *et al.,* 2011c, 2011d, 2011e, the authors analyzed the properties of noise intensity function from a wind turbine, from an analytical point of view, focusing on its slope when considering different dependences.

In this paper, a predictive software application is presented, together with an experimental analysis on frequency spectra and time history of the noise produced by the blade rotation and the wind turbine mechanical operations.

MATERIALS & METHODS

In this section, the authors will present an application of numerical methods for noise prediction, in an operating wind farm located in a rural area of south Italy.

The software used for the simulation is CadnaA®, by DataKustik. The “Angle Scanning” and the inverse “ray-tracing” principles are at the basis of the software algorithm. The calculation grid is obtained dividing area under analysis in many small surfaces in which a receiver is placed at a variable height (in our case is 2 m). Each grid element releases many rays with a full angle coverage (omni directive) and these rays, eventually after many reflections, intercept the noise source. The path length of the single ray describes the attenuation of the sound wave coming from a certain noise emitter. In addition, specific receivers can be inserted in the map, with the possibility to export the results in a worksheet.

The installed turbines are Vestas V52. The farm map under study is shown in Fig. 1, in which the red circles represent the turbines position. It is a typical

Table 1. Source power as a function of wind speed

Turbine noise	**Wind speed [m/s]**						
	4	5	6	7	8	9	10
L_W	99,7	100,8	101,9	103,0	104,1	105,2	106,3

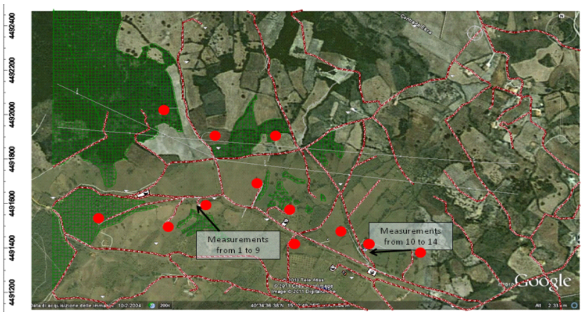

Fig. 1. Map of the area under study (Google map ©). Red circles represent the turbines

Table 2. Geometrical simulation parameters

Hub height	**65 m**
Evaluation grid height	2 m
Grid square element	3 m x 3 m

Table 3. Annual mean wind speed and corresponding source power

Turbine	**Wind speed [m/s]**	**L_W [dBA]**
1	7,5	103,55
2	7,2	103,22
3	7,1	103,11
4	6,9	102,89
5	7,1	103,11
6	6,8	102,78
7	6,7	102,67
8	7	103
9	6,8	102,78
10	6,9	102,89
11	7,1	103,11
12	7	103
13	6,7	102,67

rural area in south Italy, in which a wind farm has been recently installed and made operative. Since the area is rural and the number of vehicles per hour is negligible, noise emitted by roads does not affect the prediction on turbines effect. In order to perform the simulation, the source power is estimated as a function of wind speed, considering the certified measurement report in Bust and Hviid, 2000. Emission data are reported in Table 1.

RESULTS & DISCUSSION

In the first simulation, the annual mean wind speed data reported in Trelettra, 2003, are used to estimate the sound emissions of each turbine, resulting in a realistic average noise map of the environment.

The parameters of the simulation are reported in Table 2, except for the source power that is reported in Table 3 per each turbine. The resulting noise map is shown in Fig. 2.

Simulations results are useful to evaluate the emission of the sources and the values obtained at the receivers, in this case represented by the buildings in the area. Let us remind that the area under study is rural and is mainly devoted to agriculture. Thus, in order to estimate a potential danger on people working in the fields, a simulation of "high source power" condition is performed.

An increase of the source power of each turbine is simulated, mimicking a wind speed of 10-11 m/s. The resulting noise map of the area is reported in Fig. 3, with a zoom on the building area in Fig. 4.

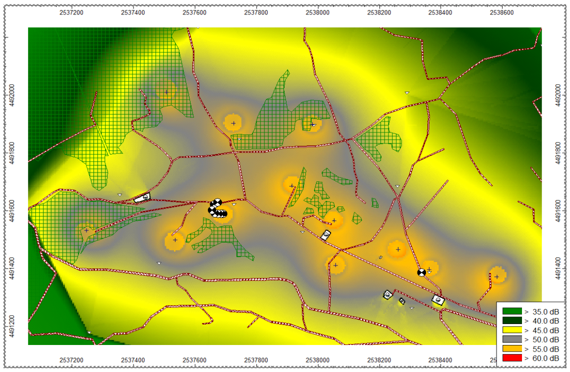

Fig. 2. Simulation of wind farm noise map. Annual mean wind speed for each turbine is used to set the source power

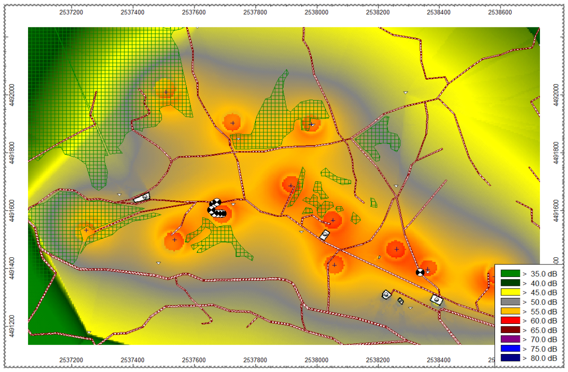

Fig. 3. High source power condition noise map.

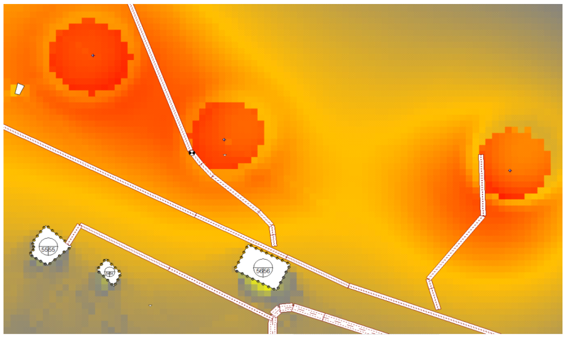

Fig. 4. Particular of noise map. Zoom on the buildings area.

Table 4. Main features of Vestas V52 turbine

Rotor diameter	**52**	**m**
Rated rotation speed	26	round/min
Blade number	3	
Tower height	74	m
Cut-in wind speed	4	m/s
Rated wind speed	16	m/s
Cut-out wind speed	25	m/s
Nominal power	850	kW

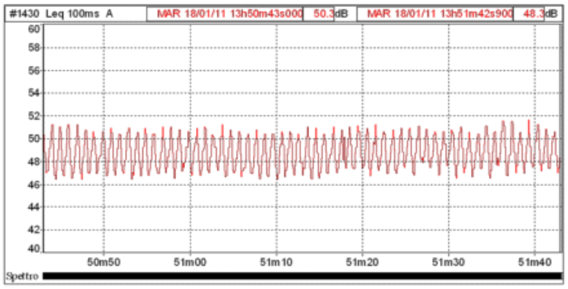

Fig. 5. Time history of wind turbine noise in one minute.

In the end, the results of the various simulations show that, in average wind speed conditions (see Fig. 2) the noise levels produced by turbines is under 60 dBA in all the area. Only when 10-11 m/s is set as wind speed, the zones under the turbine can be affected by levels around 60 dBA (red areas in Fig. 3 and 4). Anyway, these levels occur only in the very proximity of the turbine, where usually no human activity is performed.

Fig.s 2, 3 and 4 clearly show that the noise peaks are obtained in correspondence of the wind turbines, as expected from the analytical model presented in Guarnaccia *et al.*, 2011c. In addition, the orography of the terrain has a certain influence in the noise propagation, producing a particular pattern in each Fig.

In order to show some results regarding the experimental spectrum and time history analysis we recall the main features of the Vestas V52 turbine in Table 4. This is the turbine installed in the wind farm chosen for the field measurements campaign. 14 measurements have been performed, in different positions and operating conditions, in proximity of two separate turbines. Data analysis, performed in dBTrait © framework, allowed to extract a chosen time interval, in order to study the time history and frequency spectrum.

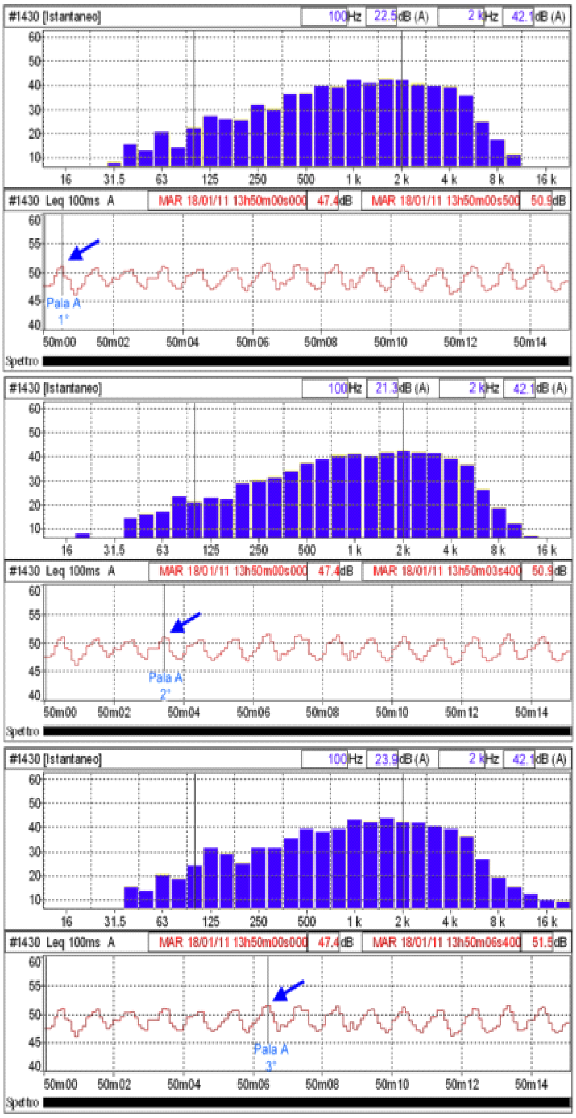

Fig. 6. Frequency spectra related to three subsequent transits of a single blade (A).

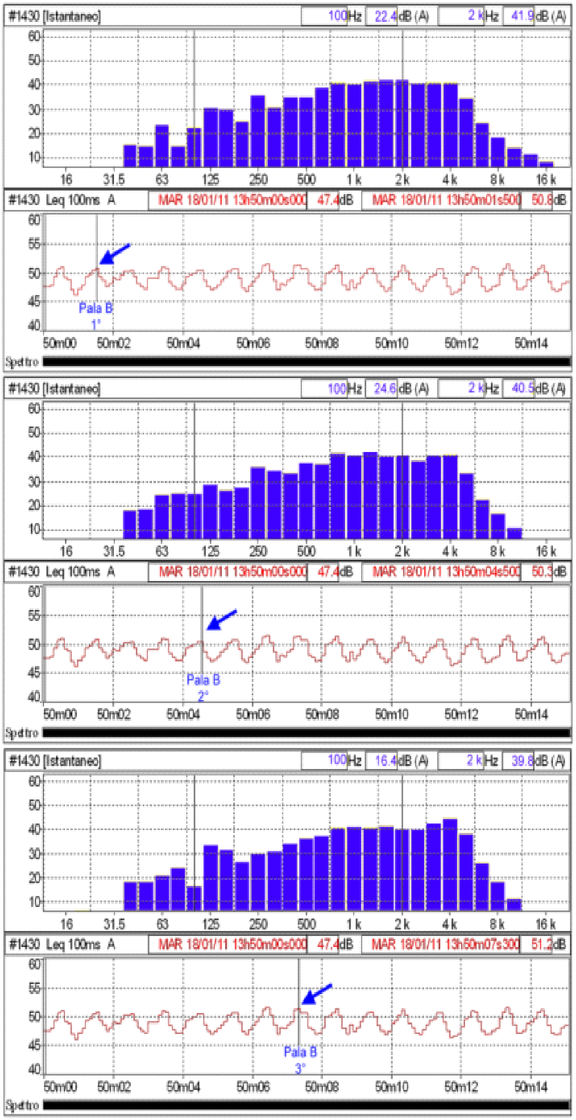

Fig. 7. Frequency spectra related to three subsequent transits of a single blade (B)

According to the time history shown in Fig. 5, related to one minute, a periodic behaviour of the pressure level signal is observed. Each peak is related to the transit of a blade in front of the sound level meter.

The number of peaks can be easily estimated and related to the rotation speed. In this example, 60 peaks are counted, that results, considering that the turbine is made of 3 blades, in a rotation speed of 20 rounds per minutes. Recalling the definition of tip speed ratio λ and considering R the radius of the blade, ω the rotation speed, v_{wind} the wind speed, f the frequency and n the number of rounds of a single blade, one can write:

$$\lambda = \frac{\omega R}{v_{wind}} = \frac{2\pi\ f\ R}{v_{wind}} = \frac{2\pi\ R}{v_{wind}}\frac{n}{60}$$

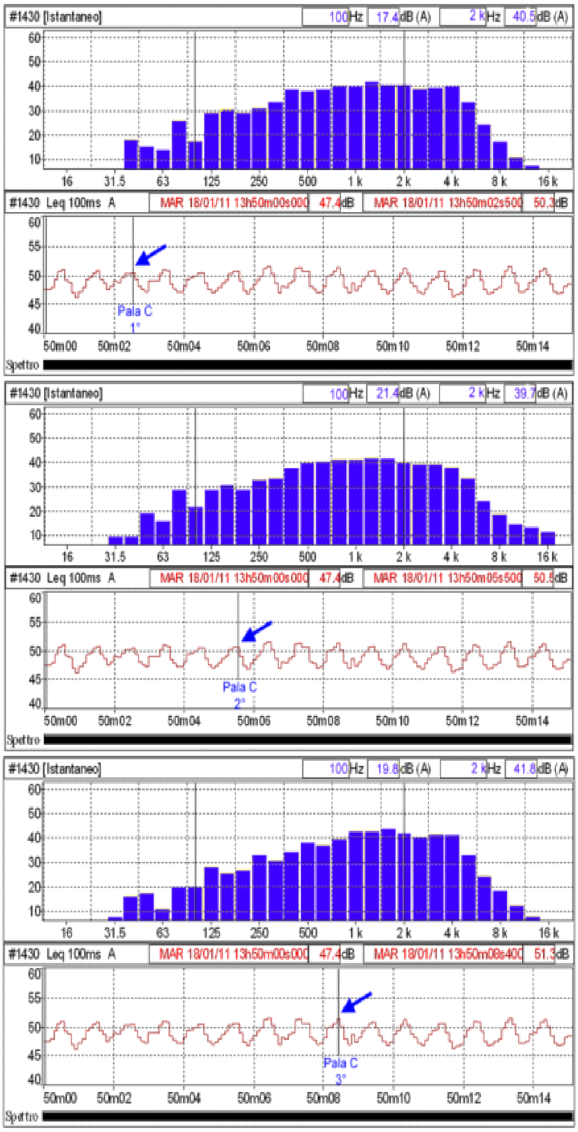

Fig. 8. Frequency spectra related to three subsequent transits of a single blade (C).

Thus, the wind speed may be estimated with the following formula:

$$v_{wind} = \frac{2R\pi\, n}{60\lambda}$$

Choosing for tip speed ratio a value of about 7, that is a suggested value for a three blades turbine, we obtain:

$$v_{wind} \cong 0{,}007\, D\, n$$

That is the wind speed (m/s) approximated estimation formula, as a function of the blade diameter (D, given in m) and the number of rounds of the blade (n, given in rounds/min). In the example reported in Fig. 5, the estimation of the wind speed gives a result of about 7 m/s , that is coherent with the observed

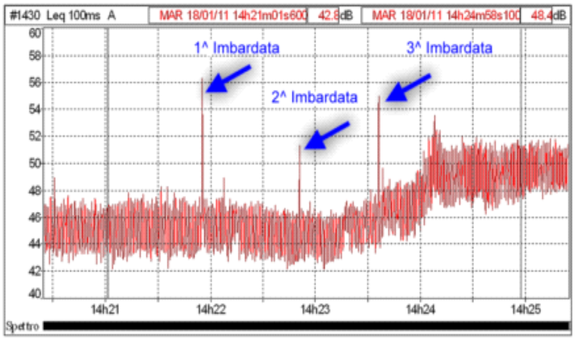

Fig. 9. Yaw events in measurement number 14.

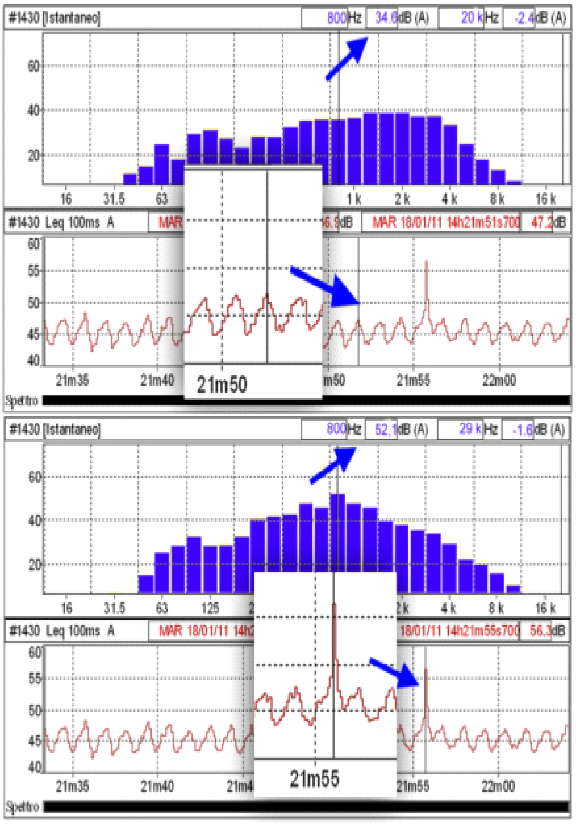

Fig. 10. Time history and spectrum before (up) and during the first yaw event occurrence (down).

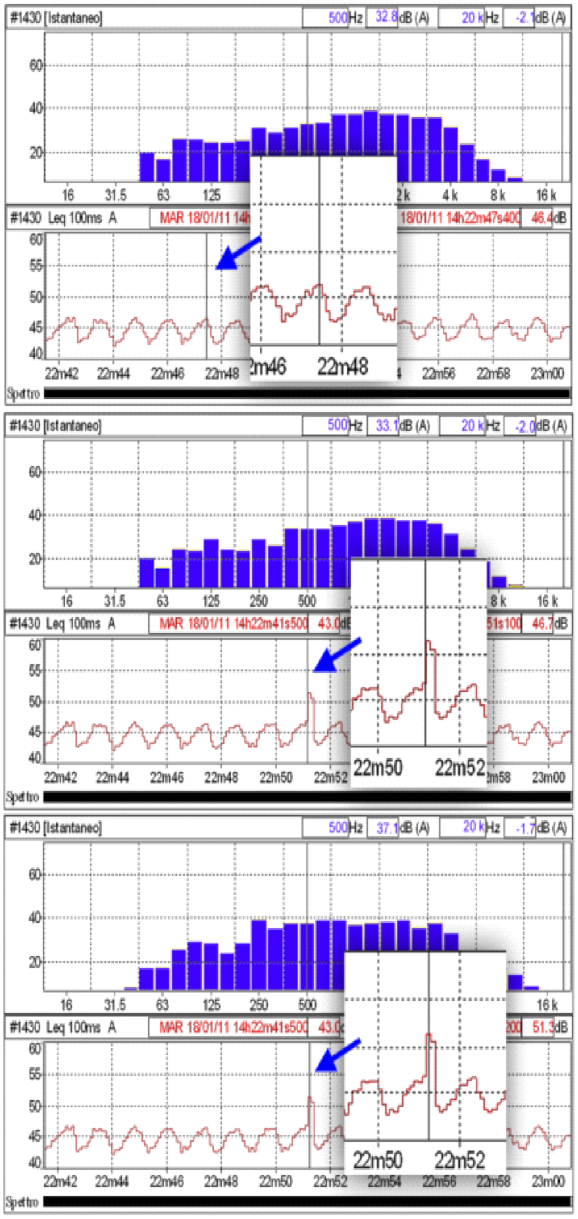

Fig. 11. Time history and spectrum before (up), during the transit of the blade (middle) and during the second yaw event occurrence (down).

wind speed. An interesting analysis can be performed on the spectrum of a blade transit. In the dBTrait framework, by placing the cursor on the peak of the time history, the instantaneous frequency spectrum content of the measured noise level can be displayed. In Fig. 6, the spectra of three subsequent transits of the same blade are reported (note that the turbine has three blades, thus the same blade transit will recur each three peaks). The same can be done for the other two blades, as reported in Fig.s 7 and 8.

In order to optimize the angle of attack of the blade, a yaw drive is present on the nacelle. The yaw operation, of course, represent a noisy event that can be detected looking at the time history and frequency spectrum of the pressure level emitted by a wind turbine. Considering measurement number 14, three yaw operations can be evidenced (Fig. 9). The first event results in a higher level of noise. Zooming on each event, the time history and spectrum show the reason of this difference.

The main difference is in the instant in which the yaw event occurs. In the first event, the yaw occurs quite exactly in correspondence of the blade transit in front of the sound level meter (peak in the time history). This results in a growth of the overall noise (about 56 dBA for the overall pressure level). The second yaw

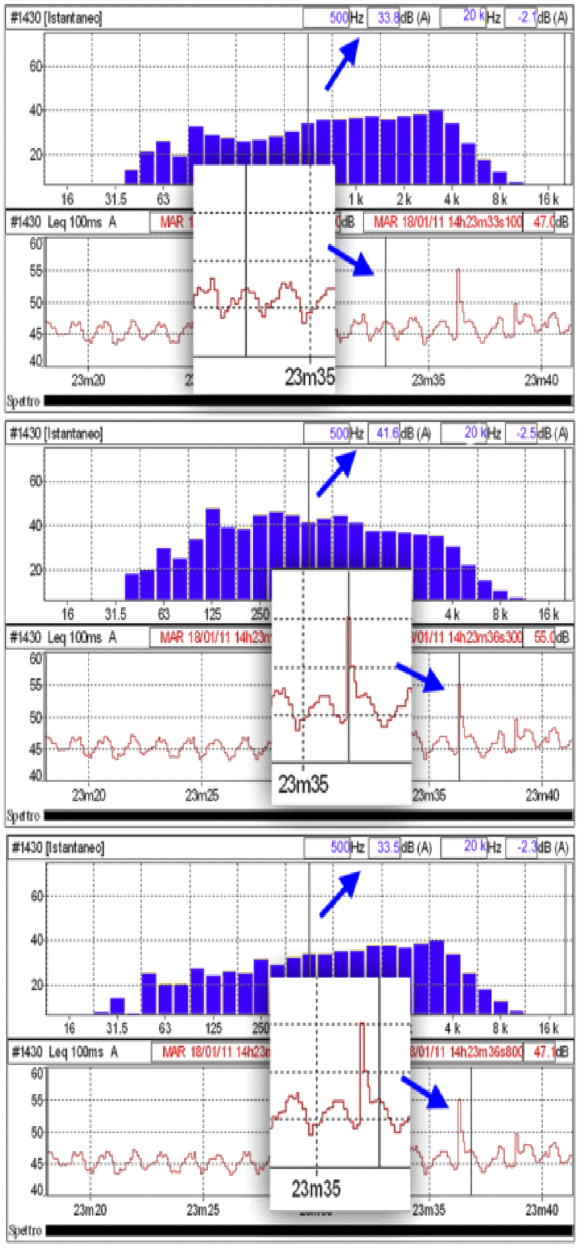

Fig. 12. Time history and spectrum before (up), during the third yaw event occurrence (middle) and during the transit of the blade (down).

event, instead, occurs just after the transit of the blade, resulting in about 51 dBA for the overall pressure level. Finally, the third yaw event occurs in a separate instant with respect to the blade transit. In this case, the overall pressure level is about 55 dBA in the yaw instant.

The proximity of this value to the first yaw event one, even though the third one is not enforced by the blade transit, can be explained considering a general growth of the noise level and, thus, considering a wind speed growth. According to subsection 3.1, an estimation of wind speed variation can be done looking at the number of peaks in two different ranges, each of them of 30 seconds (Fig. 13). Counting the number of peaks, dividing by three (number of blades), the number of transits of each blade is obtained. Thus, the wind speed can be estimated according to formula:

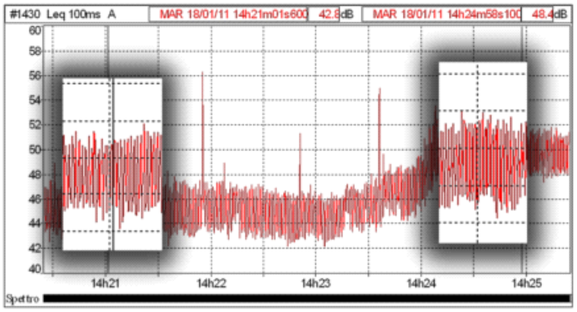

Fig. 13. Two range of data chosen to evaluate wind speed variation.

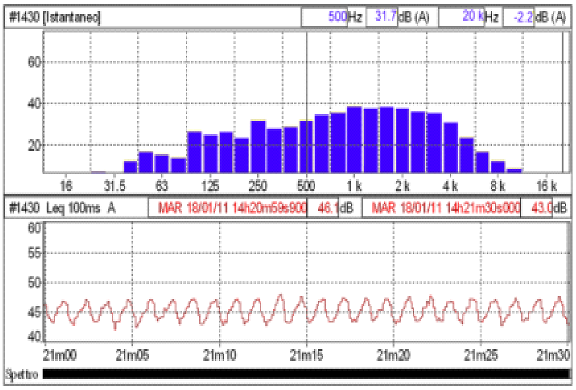

Fig. 14. First interval zoom.

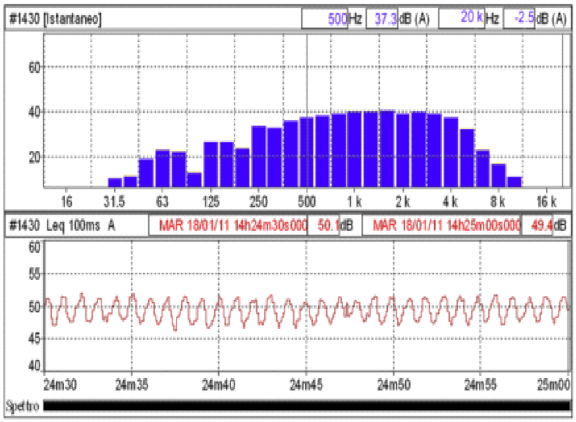

Fig. 15. Second interval zoom.

$$v_{wind} \cong 0{,}007\,D\,n$$

The results are about 6.9 m/s in the first interval and 8.2 m/s in the second range. This variation in the wind speed is consistent with what observed and with the growth in the measured sound level.

In general, literature report many studies about wind turbine annoyance, especially related to acoustical noise effect to people and to local environment. For instance, in Pedersen and Persson Waye., 2007, a survey approach has been pursued in order to evaluate the incidence of perception and annoyance due to wind turbine noise among people living in proximity of a wind farm. The psychological effect, in fact, is very important.

The papers that report about wind turbines noise predictive models are usually related to single turbine emissions and modelling. For instance, in Oerlemans *et al.*, 2007, a detailed analysis of the emissions of a three blades wind turbine is presented. The measurements are performed with a microphone array, able to measure the distribution of noise sources in the rotor plane and on the individual blades. Of course, such a precise analysis can be implemented in a general predictive model but the complexity will be strongly raised. In Oerlemans and Schepers, 2009, a semi-empirical prediction method for trailing edge noise is applied to calculate the noise from two modern large wind turbines. In this case, the prediction code needs as input the blade geometry and the turbine operating conditions. Again, even though the results show a good agreement between measured and predicted levels and spectra, this model is quite more complex than the one presented in previous sections.

Some special effects of wind turbine noise have been studied, such as in Makarewicz and Gołębiewski, 2013, where the swish and thump amplitude modulation effect in a wind turbine operation is discussed, since it enlarges the noise annoyance feeling.

In general, the authors can affirm that the implementation of a model in a predictive software framework, allows to perform predictions on a large scale and with several turbines operating at the same time, such as has been done in Evans and Cooper, 2012. The approach adopted in this paper is able to mix several aspects, both from the source point of view (identification of single special event, such as yaws, single blade spectrum, etc.) and from the environmental impact analysis (noise mapping with different source conditions). It can be deduced that this work integrates more than one approach, opening new ways to the turbine noise analysis and to the environmental impact assessment.

CONCLUSIONS

In this paper, a study on the impact of wind turbines in rural and agricultural areas is performed. In particular, the acoustical noise problem is analyzed by means of a predictive software approach and an experimental spectrum and time history analysis. A wind farm located in South Italy has been simulated by means of single sources placed per each turbine, with given geometrical and acoustical properties. Several simulations have been performed showing that the noise levels, in average wind speed conditions, are around 55 dBA in proximity of the turbines, and, of course, lower in the rest of the area. A high wind speed condition, about 10-11 m/s, has been simulated in terms of high source acoustical power of the turbines. The increase in the noise levels is evident, but it seems to be compatible with daily human agricultural activity. The analysis on the frequency spectrum and time history of the noise has been performed. In particular, after having estimated the wind speed relation with the rotor speed, the single blade frequency emission has been analyzed in different transits in front of the sound level meters. Eventual differences in the spectrum would have shown blade damages. Finally, the yaw process has been studied, evidencing how the noise emission can vary according to the occurrence instant of the yaw. A possible evolution of this work is the correlation with electrical power production, that seems to be an interesting field of research, in order to optimize the electricity and noise output. In addition, a further study that can be performed is the comparison between measured and predicted noise levels. This can be done with a multichannel sound level meters, by the contemporary measurement of wind speed (in order to set up the model) and noise level in several points.

ACKNOWLEDGEMENTS

The authors acknowledge the work of Eng. Sossio Mormile for the precious contribution to this analysis during his bachelor thesis.

REFERENCES

Ackermann, T. and Söder, L. (2000). Wind energy technology and current status: a review. Renewable and Sustainable Energy Review, 4 (4), 315–374.

Bust, O. and Hviid, N.J. (2000). Determination of Sound Power Level, Wind Turbine Vestas V52. Report n.2, Viborg.

Evans, T. and Cooper, J. (2012). Comparison of predicted and measured wind farm noise levels and implications for assessments of new wind farms. Acoustics Australia, 40 (1), 28-36.

Guarnaccia, C. (2010). Acoustical Noise Analysis in Road Intersections: a Case Study. Recent Advances In Acoustics & Music, (Paper presented at the 11th WSEAS International Conference on Acoustics and Music: Theory and Applications, Iasi, Romania, 13-15 June 2010, pp. 208-215).

Guarnaccia, C., Lenza, T.L.L., Mastorakis, N.E., and Quartieri, J. (2011a). A Comparison Between Traffic Noise Experimental Data and Predictive Models Results. International Journal of Mechanics, 5(3), 379-386.

Guarnaccia, C., Lenza, T.L.L., Mastorakis, N.E. and Quartieri, J. (2011b). Traffic noise predictive models comparison with experimental data. Recent Researches in Mechanics, (Paper presented at the 2nd International Conference on Theoretical and Applied Mechanics, Corfu Island, Greece, 15-17 July 2011, pp. 365-371).

Guarnaccia, C., Mastorakis, N.E. and Quartieri, J. (2011c). Wind Turbine Noise: Theoretical and Experimental Study, International Journal of Mechanics, 5 (3), 129-137.

Guarnaccia, C., Lenza, T.L.L. and Quartieri, J. (2011d). On the Propagation Model of Wind Farm Noise, (Paper presented at the 4th International Meeting on Wind Turbine Noise, Rome, Italy, 12-14 April 2011).

Guarnaccia, C., Mastorakis, N.E. and Quartieri, J. (2011e). A Mathematical Approach for Wind Turbine Noise Propagation, (Paper presented at the American Conference on Applied Mathematics, Puerto Morelos, Mexico, 29-31 January 2011, pp. 173-179).

Guarnaccia, C. and Quartieri, J. (2012). Analysis of road traffic noise propagation. International Journal of Mathematical Models and Methods in Applied Sciences, 6 (8), 926-933.

Guarnaccia, C. (2013). Advanced Tools for Traffic Noise Modelling and Prediction. WSEAS Transactions on Systems, 12 (2), 121-130.

Guarnaccia, C., Quartieri, J., Barrios, J. M. and Rodrigues, E. R. (2014a). Modelling Environmental Noise Exceedances Using non-Homogenous Poisson Processes. Journal of the Acoustical Society of America, 136, 1631-1639. http://dx.doi.org/10.1121/1.4895662.

Guarnaccia, C., Quartieri, J., Mastorakis, N.E. and Tepedino, C. (2014b). Development and Application of a Time Series Predictive Model to Acoustical Noise Levels. WSEAS Transactions on Systems, 13, 745-756.

Guarnaccia, C., Quartieri, J., Rodrigues, E.R. and Tepedino, C. (2014c). Acoustical Noise Analysis and Prediction by means of Multiple Seasonality Time Series Model. International Journal of Mathematical Models and Methods in Applied Sciences, 8, 384-393.

Guarnaccia, C., Quartieri, J. and Ruggiero, A. (2014d). Acoustical Noise Study of a Factory: Indoor and Outdoor Simulations Integration Procedure. International Journal of Mechanics, North Atlantic University Union, 298-306.

Guarnaccia, C., Quartieri, J., Ruggiero, A. and Lenza, T.L.L. (2014e) Industrial Settlements Acoustic Noise Impact Study by Predictive Software and Computational Approach. (Paper Presented at Latest Trends in Energy, Environment and Development Salerno, Italy 3-5th June 2014, WSEAS).

Guarnaccia, C., Quartieri, J., Tepedino, C. and Rodrigues E. R. (2015). An analysis of airport noise data using a non-homogeneous Poisson model with a change-point. Applied Acoustics, 91, 33-39. DOI:10.1016/j.apacoust.2014.12.002.

Hloch, S. and Ruggiero, A. (2013). Online Monitoring and Analysis ff Hydroabrasive Cutting by Vibration. Advances In Mechanical Engineering, 203, 1-10 Issn:1687-8132.

Iannone G., Guarnaccia, C. and Quartieri, J. (2013). Speed Distribution Influence in Road Traffic Noise Prediction. Environmental Engineering and Management Journal, 12(3), 493-501.

IEC 61400-11 (2002). Wind turbine generator systems - Part 11: Acoustic noise measurement techniques.

ISO 9613-1 (1993). Attenuation of sound during propagation outdoors - Part 1: Calculation of the absorption of sound by the atmosphere.

Makarewicz, R. and Gołębiewski, R. (2013). Amplitude modulation of wind turbine noise. Submitted to Acta Acustica united with Acustica, arXiv preprint arXiv: 1306.2752.

Oerlemans, S., Sijtsma, P. and Méndez López, B. (2007). Location and quantification of noise sources on a wind turbine. Journal of Sound and Vibration, 299, (4–5), 869–883.

Oerlemans, S. and Schepers, J. G. (2009). Prediction of wind turbine noise and validation against experiment. International Journal of Aeroacoustics, 8, (6), 555-584.

Pedersen, E. (2000). Storningsupplevelser fran vindkraft, forstudie (Experience of annoyance from wind turbines, a pilot study). Halmstad University, Sweden.

Pedersen, E. and Persson Waye, K. (2007). Wind turbine noise, annoyance and self-reported health and well-being in different living environments. Occupational and environmental medicine, 64, 480-486. doi:10.1136/oem.2006.031039.

Pedersen, T.H. and Nielsen, K.S. (1994). Genvirkning af støj fra vindmøller (Annoyance due to noise from wind turbines). Report 150 [In Danish]. Copenhagen, Denmark: DELTA Acoustic & Vibration.

Quartieri, J., Sirignano, L. and Guarnaccia, C. (2008). Equivalence between Linear and Curved Sources in Newtonian Fields: Acoustics Applications in New Aspects of Engineering Mechanics, Structures, Engineering Geology. (Paper presented at the International Conference on Engineering Mechanics, Structures, and Engineering Geology, Heraklion, Greece, 22-24 July 2008, pp. 393-395).

Quartieri, J., Iannone, G. and Guarnaccia, C. (2010). On the Improvement of Statistical Traffic Noise Prediction Tools. (Paper presented at the11th WSEAS International Conference on Acoustics and Music: Theory and Applications, Iasi, Romania, 13-15 June 2010, pp. 201-207).

Rand, M. and Clarke, A. (1990). The Environmental and Community Impacts of Wind Energy in the UK. Wind Engineering, 14 (5), 319-330.

Ruggiero, A., Senatore A., Lenza, T.L.L. and D'Agostino, P. (2010). On the determination of the uncertainty in environmental noise measurements (Paper presented at the

11th WSEAS International Conference on Acoustics & Music: theory and applications, Iaşi, Romania, 13-15 June 2010, pp. 225-230).

Ruggiero, A., Quartieri, J., Guarnaccia, C. and Hloch, S. (2013). Wind Energy in Agricolture: a Simple Predictive Noise Pollution Model. (Paper presented at the 5th International Scientific and Expert Conference of the International TEAM Society Presov 4-6/11/2013 Presov TEAM Society Pag.244-247).

Trelettra Srl (2003). Final Wind Park Planning Report. Report 01/2003.

Wagner, S., Bareiss, R. and Guidati, G. (1996). Wind turbine noise. Springer, Berlin.

Wolsink, M., Sprengers, M., Keuper, A., Pedersen, T. H. and Westra, C. A. (1993). Annoyance from wind turbine noise on sixteen sites in three countries. (Paper presented at the European community wind energy conference, 8-12 March 1993, Lübeck, Travemünde, 1993, pp. 27).