AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
DESIGN & PRODUCTION DEPARTMENT

Noise Impact Assessment of Wind Turbines

A Thesis submitted in partial fulfillment of the requirements of the

M.Sc. in Mechanical Engineering

By

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B.Sc., Mechanical Engineering, Design & Production Engineering Section
Ain Shams University, 2008

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STATEMENT

This thesis is submitted as a partial fulfillment of M.Sc. degree in Mechanical engineering, Faculty of Engineering, Ain Shams University.

The author carried out the work included in this thesis and no part of it has been submitted for a degree or qualification at any other scientific entity.

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Abstract

Renewable energy can be defined as energy comes from natural resources such as rain, sunlight, wind, waves and geothermal heat. Consumptions from renewable energy represent about 16% of the global energy consumption. From 2004 through 2009, renewable energy capacity grew at rates 10-60% annually. In 2009, growth of wind power technologies accelerated relative to the previous four years and more capacity of wind power was added during 2009 than any other renewable technology. Globally, the long-term potential of wind energy is believed to be five time total current global energy production or 40 times current electricity demand. This will require planning for installing more wind turbines over large areas especially of higher wind resources. In the areas of high wind speeds, it would be very effective to convert the wind energy into usable electricity using wind turbines. This can provide the needed electricity for small or large communities without exposing people to the harmful pollutants when using the other energy sources. A group of wind turbines can be installed as a windfarm to provide a large community with the entire electricity supply or can be installed as a single turbine for a small community. The high ground areas are most effective to install windfarms as the wind speed in these areas is higher than at lower ground and speed is more constant.

Impact of wind turbine noise on the surrounded areas is a major consideration in the planning phase of a windfarm installation. The purpose of this research is to assess the noise impact of the wind turbines, and determine the design constrains for the windfarms to adapt with the environmental regulations.

Noise Impact Assessment is very important procedure which assesses the negative or even the positive impact of any project before the construction phase in order to help the decision makers to consider these impacts before taking the decision of the project approval.

The Noise Impact Assessment considers three main areas: noise sources which deals with the characterization of the noise and predicts the generated sound

power, sound propagation which studies the effect of the environment on the propagation of noise and noise receivers which investigates the sound level that is received by the receivers and whether it is acceptable or not according to the regulations.

The research presents the noise mechanisms of wind turbines and the characteristics of each noise source, and it studies the different factors affecting noise propagation.

A survey on the different models of wind turbine noise prediction has been done to study the method of applying each model and the required input parameters.

A different noise propagation software and noise propagation methods have been investigated in order to be able to select the most suitable and effective way for the study.

The presented noise prediction models have been used to be applied on a wind turbine of 55kW rated power and 15.5m rotor diameter as a case study. A MATLAB code for each prediction model has been created and the results have been investigated to compare between the used models.

Zafarana windfarm has been selected for this research to study its noise propagation based on the different factors of noise propagation presented previously and the selected noise prediction model appropriate for this study. A noise impact assessment has been done for Zafarana with the definition of different factors required for the model including terrain elevations, meteorological data definitions, and sound sources definitions.

The last procedure in this research was a sound level measurement in Zafarana windfarm as a validation for the noise model and a comparison between the modeled results and the measured values has been investigated and concluded.

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Contents

Chapter 1: Introduction 1
1.1. Noise Mechanisms of Wind Turbines 1
1.1.1. Mechanical Noise 1
1.1.2. Aerodynamic Noise 3
1.2. Noise Prediction Models of Wind Turbines 6
1.2.1. Class I Models 8
1.2.2. Class II Models 11
1.3. Noise propagation Mechanisms 16
1.3.1. Air Absorption 17
1.3.2. Weather Effects 20
1.3.3. Ground Effect 21
1.3.4. Screening, Complex Terrain 22
1.3.5. Upwind/Downwind Effects 23
1.4. Noise propagation software 23
1.4.1. SoundPLAN 23
1.4.2. WindFarmer 24
1.4.3. WindPRO 25
1.4.4. SILANT 25
1.4.5. Conclusion 26
1.5. Noise propagation methods 26
1.5.1. BS 5228: Part 1:1997 [13] 27
1.5.2. ISO 9613-2 [14] 27
1.5.3. IEA 27
1.5.4. CONCAWE 28

1.5.5. Nord2000 28
1.5.6. NZS 6808:1998 28
1.6. Conclusion........ 28
Chapter 2: Numerical example........ 30
2.1. Class I models........ 30
2.1.1. Lowson model [3]........ 30
2.1.2. Hau model [6]........ 30
2.1.3. Hagg model [7, 8]........ 30
2.2. Class II models........ 33
2.2.1. Brooks, Pope, Marcolini (BPM) Model........ 34
2.2.2. Lowson's Model........ 39
2.2.3. Grosveld's Model........ 41
2.3. Conclusion........ 44
Chapter 3: Zafarana Windfarm........ 45
3.1. Phases of Zafarana windfarm implementation........ 46
3.1.1. Zafarana 1 windfarm (63 MW)........ 46
3.1.2. Zafarana 2 windfarm (77 MW)........ 47
3.1.3. Zafarana 3 windfarm (85 MW)........ 47
3.1.4. Zafarana 4 windfarm (120 MW)........ 47
3.1.5. Zafarana 5 windfarm (80 MW)........ 47
3.1.6. Zafarana 6 windfarm (120 MW)........ 48
3.2. Technical specifications of Zafarana wind turbines........ 50
3.3. Turbines location data........ 50
3.4. Zafarana weather conditions........ 53
3.4.1. Wind speed........ 53
3.4.2. Wind Direction........ 55

3.4.3. Turbulence Intensity 56
3.4.4. Temperature 57
3.4.5. Air pressure 58
3.4.6. Air density 58
3.4.7. Humidity 58
Chapter 4: Noise Impact Assessment of Zafarana windfarm 59
4.1. Digital ground model (DGM) 59
4.2. Wind turbines definition 66
4.2.1. Definition of wind turbines locations 66
4.2.2. Definition of wind turbines attributes 67
4.3. Hurghada main Road definition 69
4.4. Meteorological data definition 71
4.4.1. Roughness length: 71
4.4.2. Flow resistivity 72
4.4.3. Temperature 72
4.4.4. Air pressure 73
4.4.5. Humidity 73
4.4.6. Wind speeds 73
4.4.7. Wind directions 73
4.4.8. Some other parameters 73
4.5. Noise model for Zafarana windfarm 73
Chapter 5: Measurements in Zafarana site 76
Chapter 6: Summary & Conclusions 81

Chapter 1: Introduction

1.1. Noise Mechanisms of Wind Turbines

Noise from wind turbine can be generated from blades, generator and gearbox. The turbine noise can be classified to two potential types, mechanical noise and aerodynamic noise. The Mechanical noise is generated from the friction of the metal components moving against each other or from a corrupted part of the system. Aerodynamic noise is caused by the blade passing through air.

Sources of the aerodynamic noise can be listed as following:

- Low-frequency noise,

- Turbulent inflow noise,

- Airfoil self noise, which can be categorized into:

    - Turbulent boundary layer trailing edge noise,
    - Laminar boundary layer vortex shedding noise,
    - Tip vortex formation noise,
    - Trailing edge bluntness vortex shedding noise
    - Blade Surface Imperfections noise

1.1.1. Mechanical Noise

Mechanical noise is mainly generated from the friction of the moving metal components in the generator and the gearbox. Modern turbines have a reduced mechanical noise to half of the turbines of 1980s, this is because that the gearbox is carefully designed and the steel wheels of it have a flexible core and at the same time a hard surface to provide it the strength and longtime wear. Other techniques are used to reduce and avoid the mechanical noise of wind turbines, such as using damping materials and applying couplings so that the structure borne noise becomes minimum and using of oil cooler instead of using fan cooler to reduce noise emitted from the generator.

Table 1.1 shows an example for the values of sound power levels and the transmission paths from individual structure components [1]

Table 1-1. Sound power levels of mechanical noise of a 2MW Experimental wind turbine [1]

Element	Sound power level (dB(A))	Air-borne or structure-borne
Gearbox	97.2	Structure-borne
Gearbox	84.2	Air-borne
Generator	87.2	Air-borne
Hub(from gearbox)	89.2	Structure-borne
Blades(from gearbox)	91.2	Structure-borne
Tower(from gearbox)	71.2	Structure-borne
Auxiliaries	76.2	Air-borne

Sound pressure levels are measured at 115 meters from the experimental wind turbine with ignoring the air absorption effect and then somehow the sound power level are obtained.

It can be obvious from the table values that the gearbox has the dominant noise level. The importance of the gearbox is to transmit the rotating speed of the rotor blades to the generator with 50 times of its original value. This noise is caused due to either the dynamic loading on the gears or an error in the gear pair meshes transmission. This can be reduced by manufacturing a high quality gear pair and with the correct way of mounting the gears. Gears should be soft mounted on the shaft to prevent the shaft from deformation when the turbine is loaded. Also helical gears are quieter than spur gears. Mechanical noise of wind turbines is tonal due to the radiation from the meshing gears. Most of the modern turbines have a low significant noise from the mechanical components due to the consideration of better engineering designs to have quieter components. The main problem of the modern turbine is the aerodynamic noise, as this type of noise is not controllable in the engineering designs like the mechanical one. So many studies and researches have been done for the purpose of having quieter aerodynamic sources. This study is focused on the part of aerodynamic noise to obtain the most efficient way of dealing with it.

1.1.2. Aerodynamic Noise

Aerodynamic noise can be classified into three types of noise sources which are "low frequency noise", "turbulent inflow noise" and "airfoil self noise".

1.1.2.1 Low frequency noise

Low frequency noise is caused by the wind speed change passing through the blades with the tower presence. The most common designs of wind turbines nowadays are upwind designed which has a reduced effect from the tower comparing with the downwind type. The low frequency noise becomes not an important noise source when the A-weighting filer is applied to it. The blade passing frequency is the function determining the noise spectrum of the low frequency noise. The range of frequencies is between 1Hz to 20Hz depending of the blade passing frequency which is function in the blades number and the rotational speed.

BPF (Blade passing frequency) = rotation speed in seconds X blade numbers.

In the upwind turbines, the effect of the tower can be reduced by increasing the clearance between the tower and the rotor plan and hence this type of noise will not be dominant in the overall aerodynamics noise.

1.1.2.2 Turbulent inflow noise

Turbulent inflow noise is caused by the atmospheric turbulence and the interacting of the turbulent air with the turbine blades. The characteristics of this noise depend on the atmospheric boundary layer characteristics. The atmospheric boundary layer can be presented as a viscous flow over a rigid surface. The velocity at the surface layer is zero and it increases with the distance far of the surface until it reaches to the free stream velocity. The free stream velocity in the case of wind turbine can be defined as the mean wind velocity at the turbine hub. The actual wind velocity in the boundary layer equals to the mean velocity and the turbulence fluctuating velocities in the X, Y and Z directions.

1.1.2.3 Airfoil self noise

Noise from airfoil can be radiated even in the case of steady flow due to the instabilities occur in the boundary layer caused by the interaction of the air flow with the airfoil surface. The airfoil self noise has a broadband nature and it has different noise mechanisms of noise which are defined and described below.

a. Turbulent boundary layer trailing edge noise

The major source of airfoil self noise is the trailing edge noise. The transition from laminar flow to turbulent flow occurs at a certain chord position, which has a certain angle of attack, Reynolds number, surface structure, and inflow disturbances. This causes a fluctuating pressure on the pressure and suction sides of the airfoil trailing edge. This noise increases with low angles of attack. Noise also can occur at high angle of attack which is called separated flow noise when the boundary layer separation occurs. Eddies region at the suction side is larger than eddies of low angles of attack. This fluctuating is caused by the turbulent eddies convert into the wake. This type of noise shall be analyzed as suction side noise, pressure side noise and separation flow noise together.

The turbulent boundary layer trailing edge noise is a broadband noise and has a peak value at intermediate frequencies. The most effective parameter to determine the noise level is the boundary layer thickness. This means that the different airfoil shapes have different trailing edge noise spectrums. The boundary layer thickness is always a main parameter used for most of the noise prediction methods.

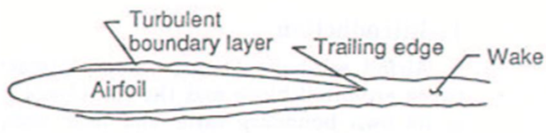

Figure 1-1. Turbulent boundary layer trailing edge noise [2]

b. Laminar boundary layer vortex shedding noise

The laminar boundary layer vortex shedding noise can occur at the low Reynolds numbers at range from 10^5 to 10^6. It is caused due to an interaction between the trailing edge and the laminar to turbulent transition flow. This type of noise is important in the case of small turbines where Reynolds numbers less than 10^6. The boundary layer displacement thickness is the main parameter to calculate the laminar boundary layer noise the same as in the trailing edge noise calculation.

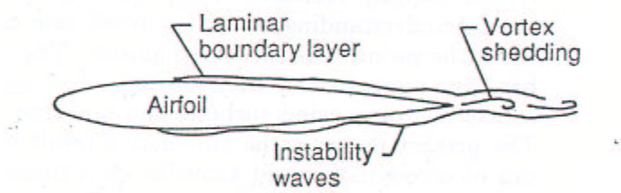

Figure 1-2. Laminar boundary layer vortex shedding noise [2]

c. Tip vortex formation noise

Tip vortex noise is caused due to the interaction between the trailing edge and the tip vortex. Tip vortex is generated due to three dimensional flow around the tip which leads to a rotational flow on the airfoil surface. This interaction between the trailing edge and the tip vortex has the same mode of the interaction between the trailing edge and the turbulent boundary layer. Tip noise depends on the airfoil blade tip geometry, so it can be significant noise source with the thick blade tip. That is why most of wind turbine designers have the approach to develop a well-designed tip shapes in order to reduce the noise effect of the blade tip. So in the modern wind turbine designs, tip noise is not considered as a major source. Tip noise also depends on the chord length and angle of attack.