Wind Turbine Noise

The mechanisms of noise generation and ways of mitigation

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Overview

Main sources of noise from wind turbines

- Aerodynamic Sources
- Mechanical Sources

Mitigation schemes

Principal Sources of Noise

Aerodynamic sources

Motion of air around the blades

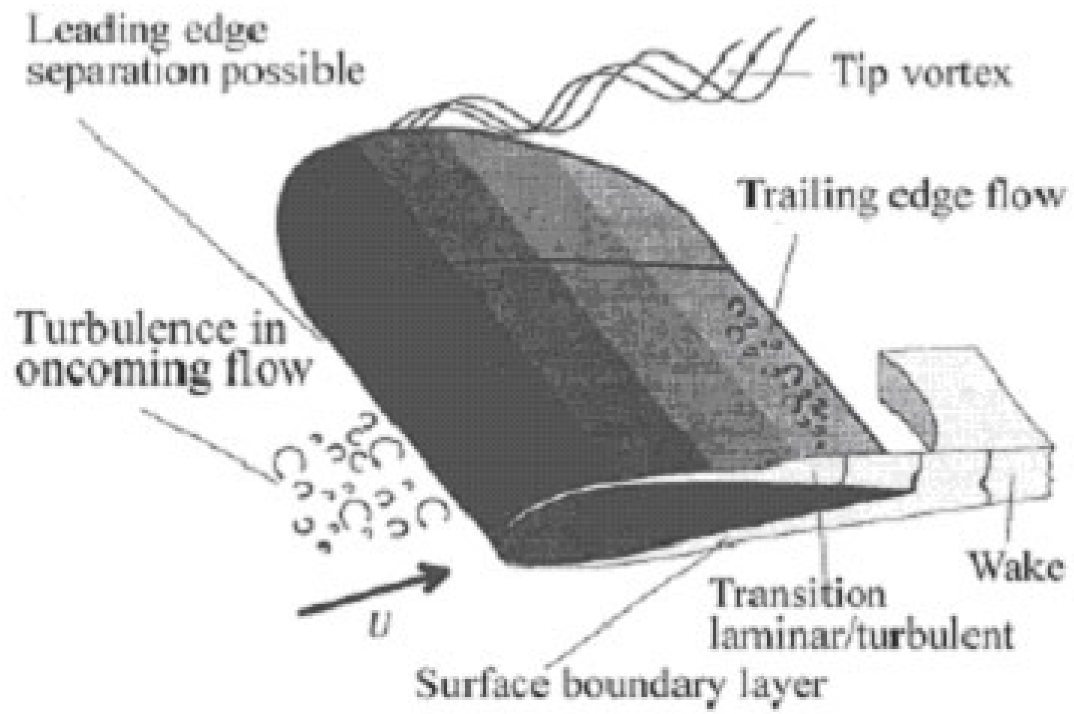
Various sources, complex mechanisms

Mechanical sources

Motion of mechanical & electrical components

Sources are more easily identified and controlled

Aerodynamic Sources

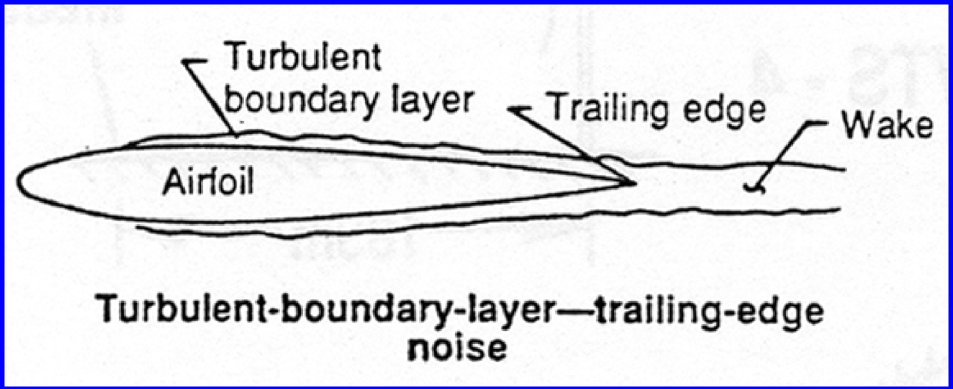


Source: 'Wind Turbine Noise' Warner,Bareiß & Guidati

Aerodynamic Sources

Trailing Edge Noise

Turbulent boundary layer interacts with trailing edge



Source 'Assessment & Prediction of Wind Turbine Noise' M.V. Lowson

Broadband and the main source of high frequency noise

Component of blade swish noise

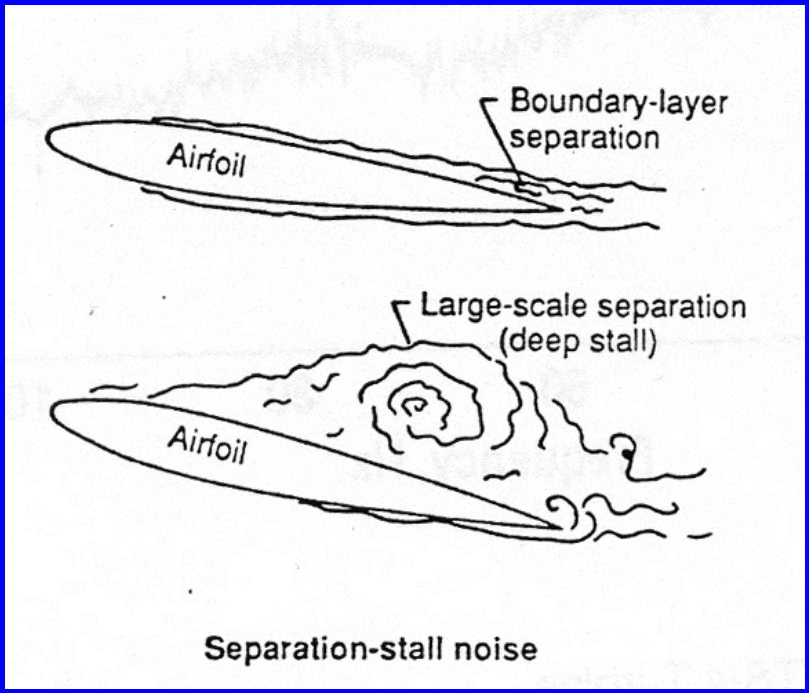
Minimised through design of the aerofoil section at trailing edge

Aerodynamic Sources

Separation-stall Noise

Separated boundary layer becomes turbulent and interacts with blade surface

Increases with angle of attack



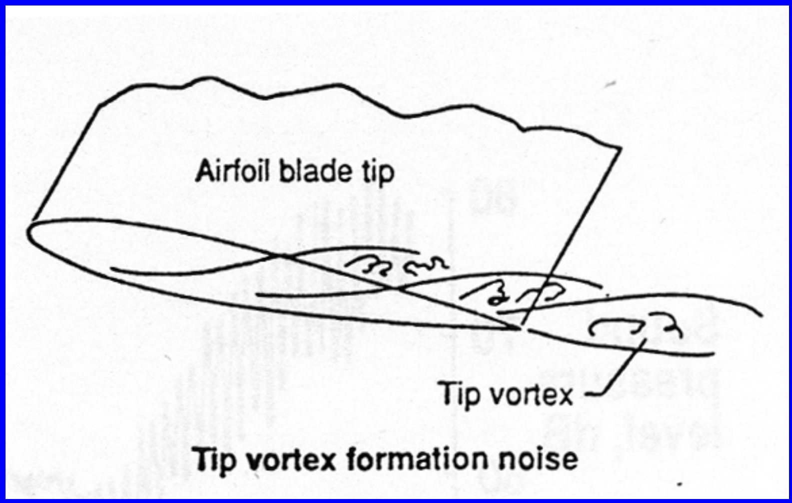
Source 'Assessment & Prediction of Wind Turbine Noise' M.V. Lowson

Minimised by blade pitch regulation

Aerodynamic Sources

Tip Vortex Formation

Separated vortex flow interacts with blade surface



Broadband ~ 2 to 3 kHz

Source 'Assessment & Prediction of Wind Turbine Noise' M.V. Lowson

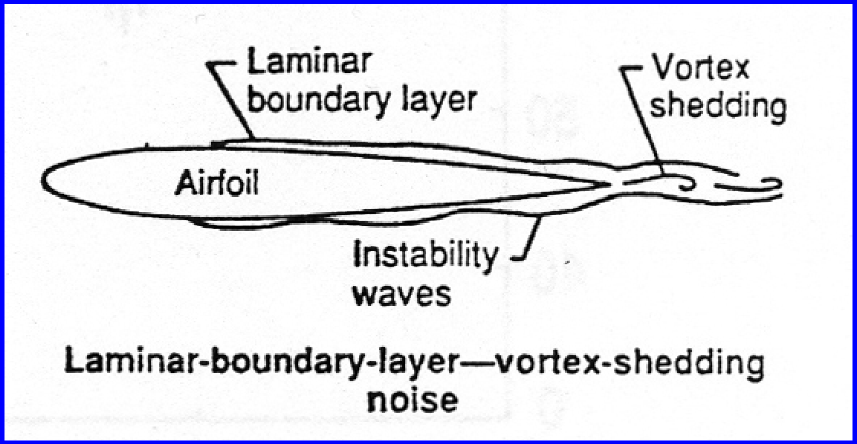
Component of blade swish

Minimised through design of the tip shape

Aerodynamic Sources

Laminar Boundary Layer Vortex Shedding

Instability in separated laminar flow from lower edge of blade



Source 'Assessment & Prediction of Wind Turbine Noise' M.V. Lowson

Tonal - typically around 3 kHz

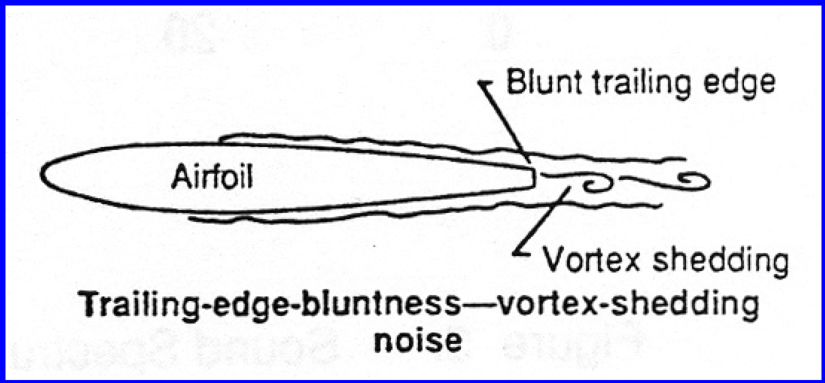
Minimised by preventing separation through design of the blade

Serrated leading edge of aerofoil found to be effective

Aerodynamic Sources

Trailing Edge Bluntness Vortex Shedding

Instability in wake due to thickness of trailing edge



Source 'Assessment & Prediction of Wind Turbine Noise' M.V. Lowson

Tonal ~ 2 kHz

Component of blade swish

Minimised by using a sharper blade profile

Aerodynamic Sources

In-Flow Turbulence

Blades respond to atmospheric turbulence caused by

- Nacelle yaw error
- Gradients of in-flow velocity due to high wind shear
- Wake effects from topographical features or turbines

Broadband but generally below 1 kHz

Minimised by optimal turbine positioning and separation

Aerodynamic Noise

Blade Swish

Source: Localisation and Quantification of Noise Sources on a Wind Turbine: Oerlemans & Lopez

Figure 1: Test set-up with G58 turbine and microphone array platform. The noise sources in the rotor plane (averaged over several rotations) are projected on the picture.

Aerodynamic Noise

Blade Swish

Rhythmic modulation of aerodynamic noise

Audible close to the turbines

Amplitude and frequency varies with blade passage as aspect of sources change relative to observer

Variation in source characteristics may be augmented by in-flow turbulence, yaw error and high wind shear

Increasingly less distinct as distances from the turbine increases

Significant factor of reported annoyance

Aerodynamic Noise

- Infrasonic Noise
- Low Frequency Noise

Aerodynamic Sources

Mitigation in general

Reduce tip speed

- Aerodynamic sources typically proportional to (tip speed)^5
- Increased rotor torque » increased turbine weight and cost

Blade pitch regulation

- Optimise angle of attack to prevent mechanisms developing

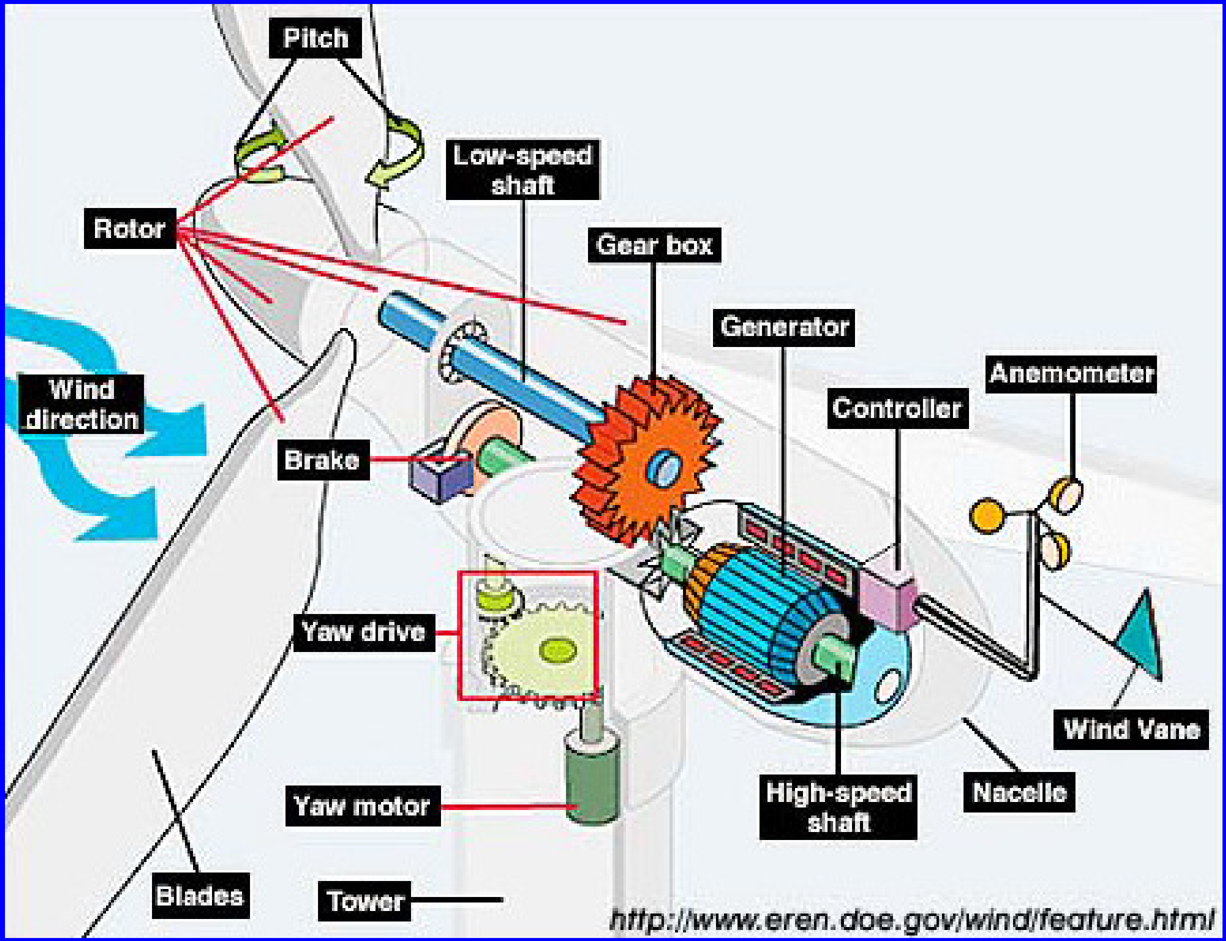
Improved blade design and condition

- Boundary layer trips prevent instabilities
- Clean surfaces, patch holes
- Noise modelling in development of blade design

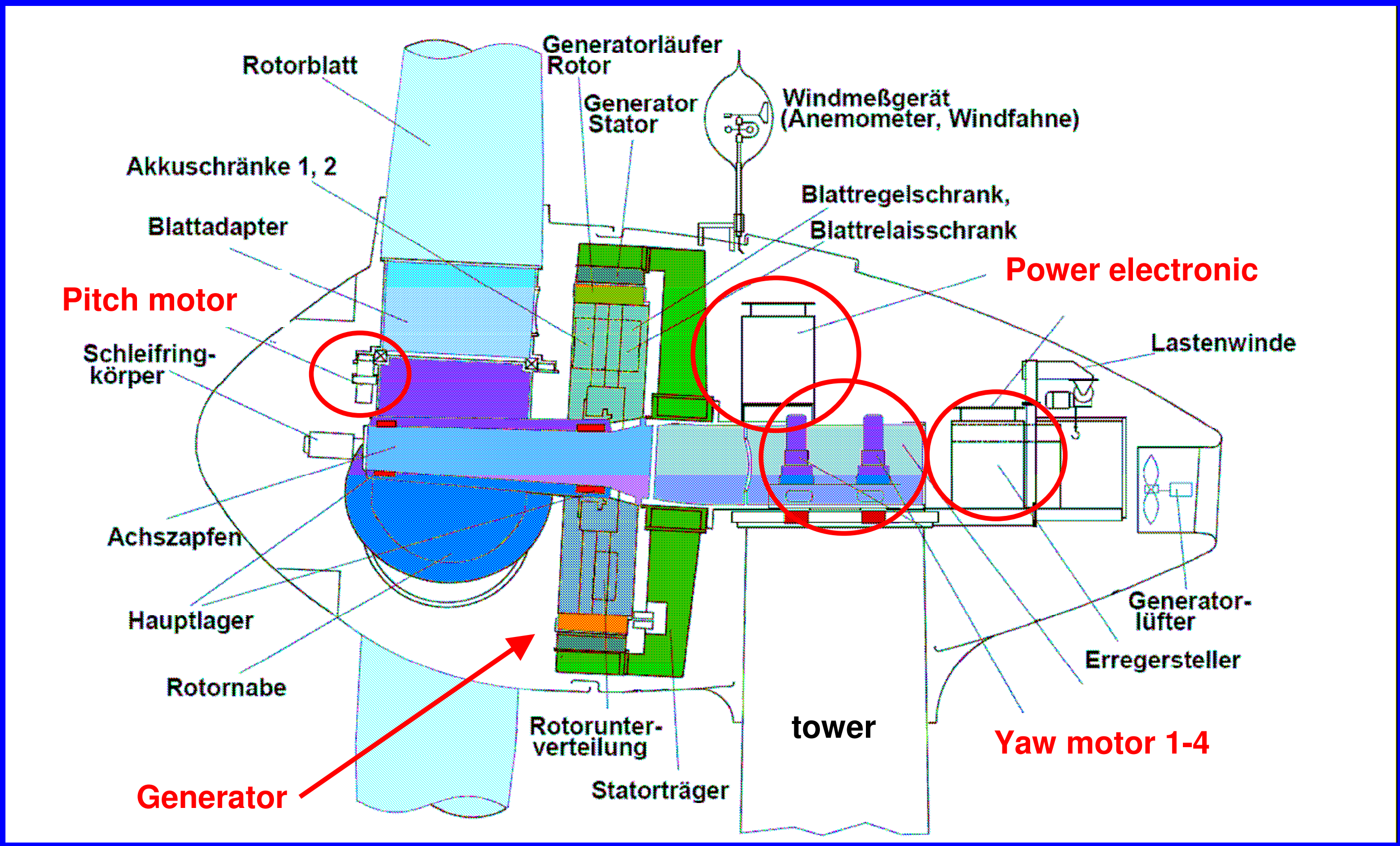
Mechanical Sources

- Gearbox
- Generator
- Yaw drive (motors)
- Cooling system (pumps)
- Power electronic

Mechanical Sources



Mechanical Sources



Mechanical Sources

Gearbox noise sources

Vibration of the drive train in gearbox and shafts transmitted into supporting structure

Noise radiated by nacelle housing, tower or blades

Mitigation

Treat sources: Quieter gearbox design, maintenance

Treat transmission paths: resilient couplings, mountings

Treat radiating surfaces: blade damping treatments etc

Direct drive: no gearbox - hub coupled directly to generator

Mechanical Source

Generator noise source

Vibration due to coil flexure of the generator windings

Yaw and pitch drive

Noise from the hydraulic compressors

Cooling system

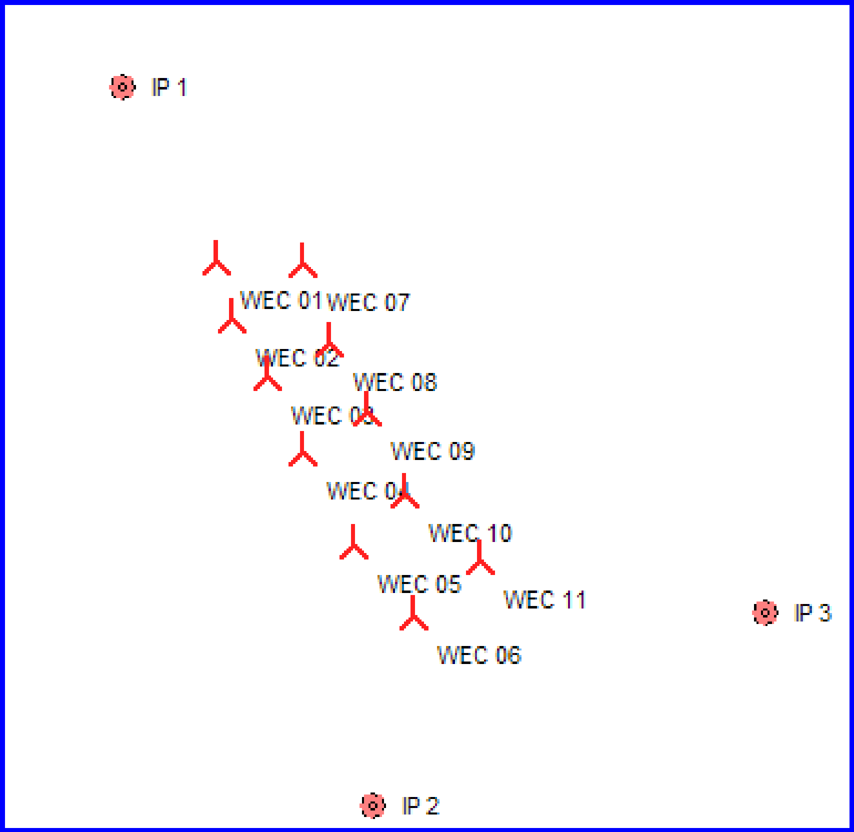
Noise from fans

Oil cooling may be quieter than elctric fans

Mitigation – Case Study

Noise limits not met
for several wind speeds

Mitigation necessary
- Fewer wind turbines
- Change layout
- Reduce sound emission of single turbines



Mitigation – Case Study

Use of noise reduced modes

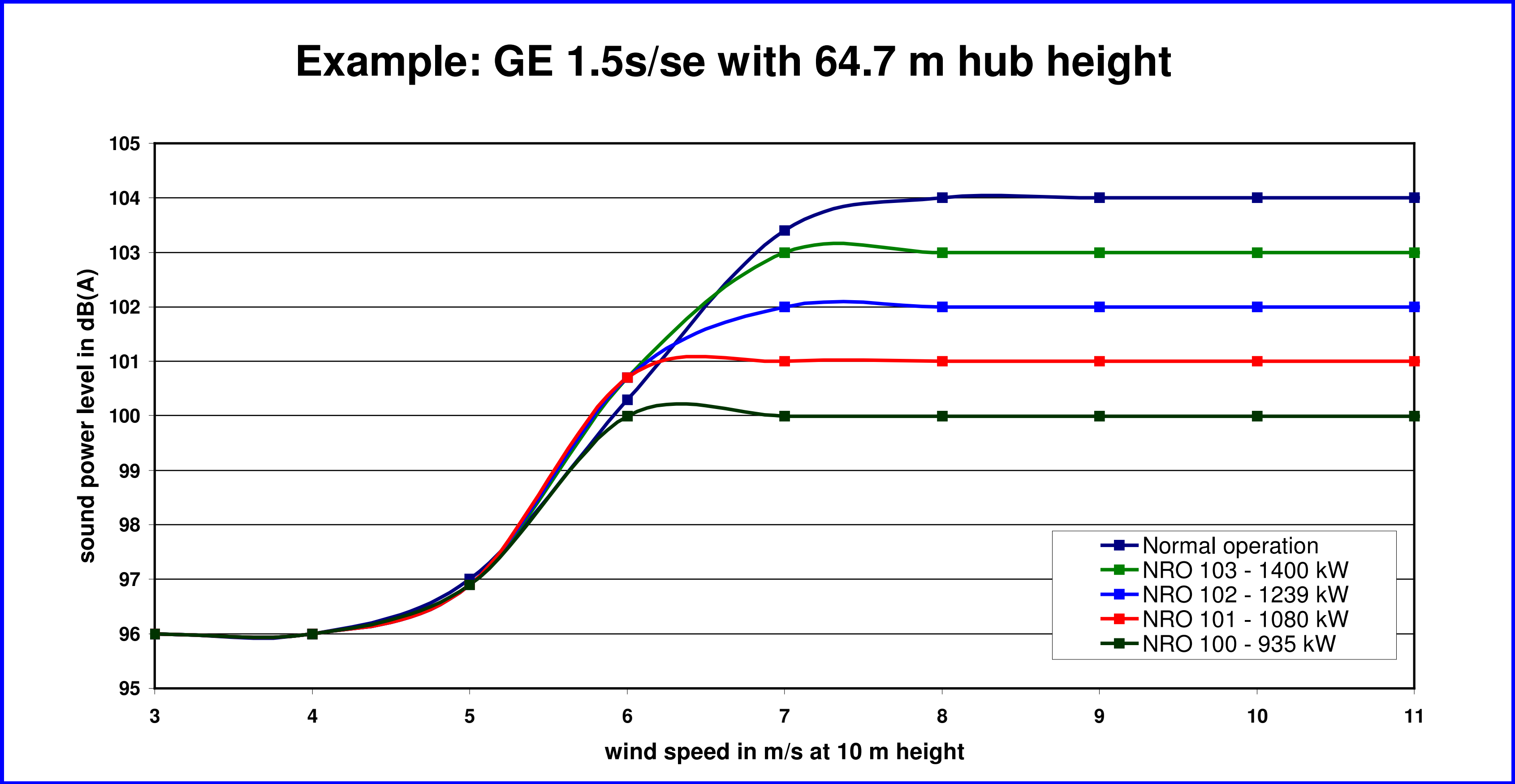
- "power capped" (reduce rotational speed, small generator)
- reduced sound power level for lower/middle wind speeds

Shut down of the wind turbine depending on

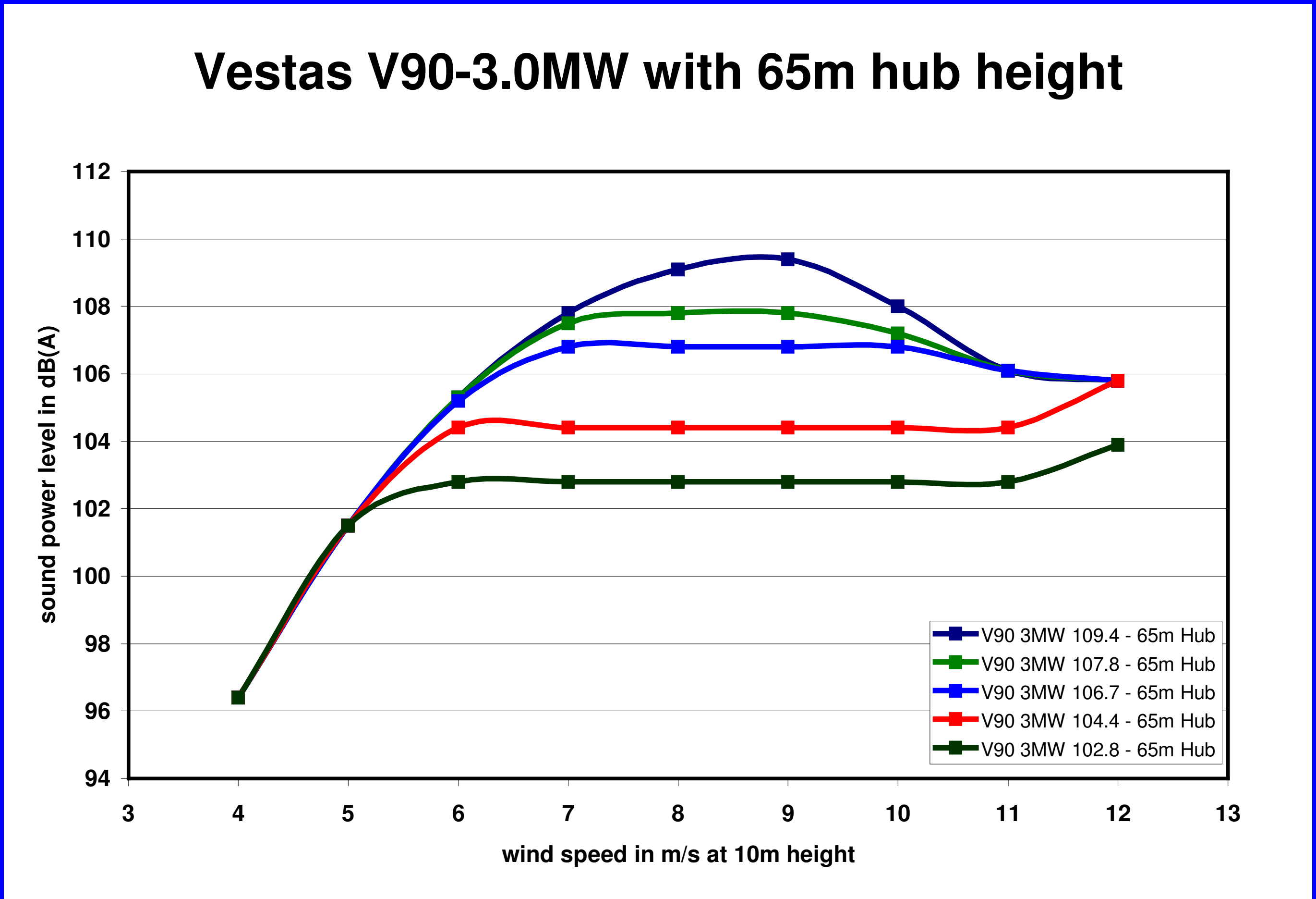
- Time of day
- Wind speed
- Wind direction

Switch to a second noise reduced mode when required

Mitigation – power cap



Mitigation – reduced "middle" SPL



Mitigation – Switch to NR Mode

Example for an ENERCON Shutdown/Switch Concept

wind turbine	3 m/s	4 m/s	5 m/s	6 m/s	7 m/s	8 m/s	9 m/s	10 m/s
WEC 01	stop/switch	stop/switch	stop/switch	stop/switch	stop/switch			
WEC 02	stop/switch	stop/switch	stop/switch	stop/switch				
WEC 03								
WEC 04			stop/switch	stop/switch				
WEC 05	stop/switch	stop/switch	stop/switch	stop/switch	stop/switch			
WEC 06	stop/switch	stop/switch	stop/switch	stop/switch				
WEC 07	stop/switch	stop/switch	stop/switch					
WEC 08								
WEC 09	stop/switch	stop/switch						
WEC 10	stop/switch	stop/switch						
WEC 11	stop/switch	stop/switch	stop/switch	stop/switch				

Energy yield losses depend on wind conditions for each WF site (were marginal according to calculation for this site)

Summary

Noise Emission caused by

- Aerodynamic effects (trailing edge, tip)
- Mechanical/electrical sources (gearbox, motors etc.)

Noise Reduction Strategies

- Blade design
- Choice of low-noise mechanical/electronical components)
- Project oriented solutions depending on wind turbine manufacturer