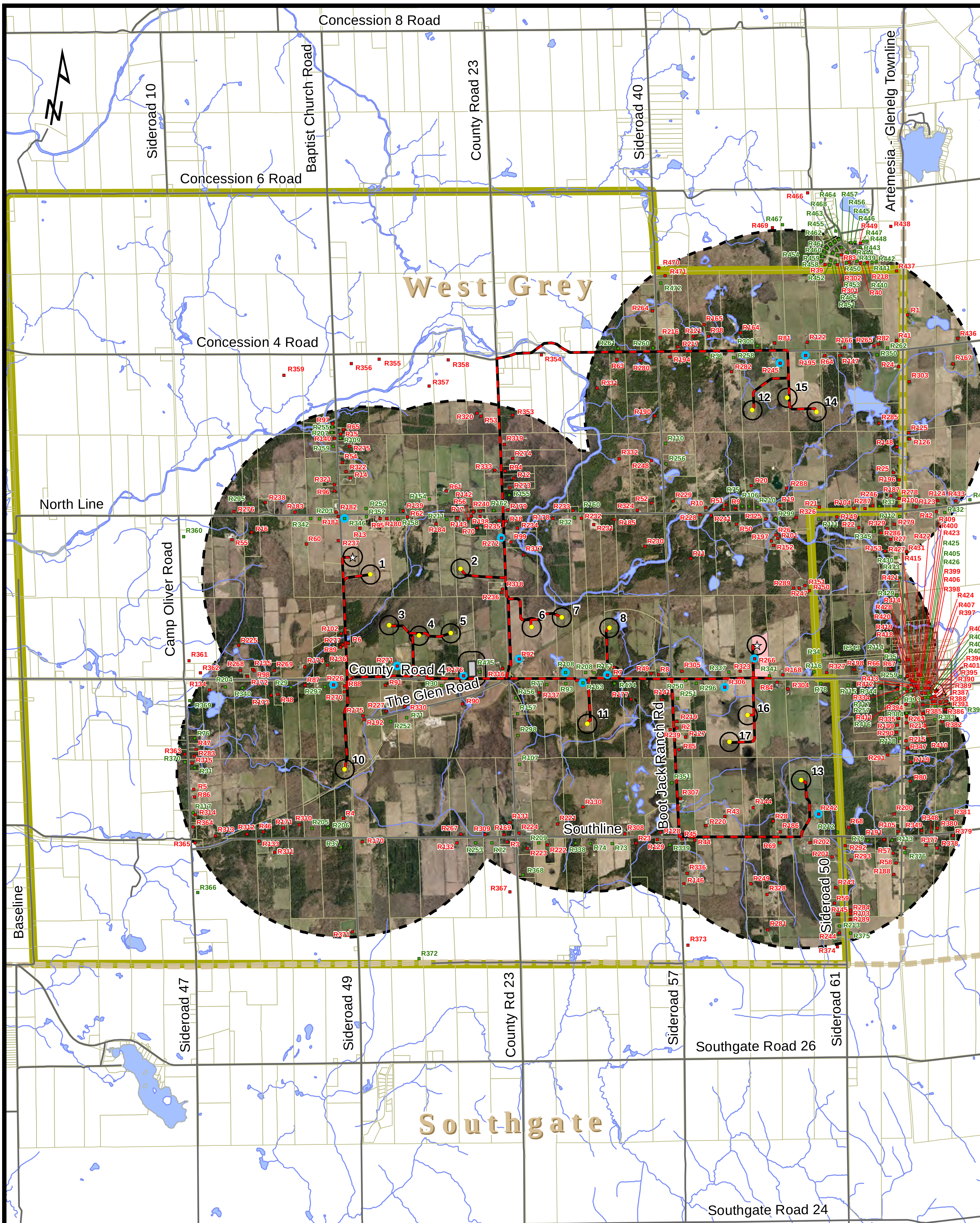
# Attachment A

# Project Layout Drawing




## Legend

- Receptor
- Vacant Lot Receptor
- Participating Receptor
- Proposed Wind Turbine (Sept 12, 2012)
- Proposed Met Tower
- Town / Village
- Roadway
- Collection Line
- 120 m Buffer Distance / Project Location
- 2 km Distance from Project Location
- Proposed Substation
- Laydown Area
- Parcel
- Municipal Lower Tier
- Project Boundary

NEXTera ENERGY RESOURCES

GENIVAR

Scale:

0 500 1,000 2,000 3,000 m

1:50,000

Project:

EAST DURHAM
WIND ENERGY CENTRE

Title:

# East Durham
# Site Plan

| Project No:. | Date: |
| --- | --- |
| MA-111-15446-MA | November 2013 |
| Revision No:. | Figure No:. |
| 1 | 2-1 |

# Attachment B

# Wind Turbine Specifications

GE Energy

**Parker D. Powell**
**Technical Leader**

March 28, 2013

Don Karwisch
NextEra Energy Resources
700 Universe Blvd
Juno Beach, FL 33408

RE: Tonality of 1.6-100, 1.39-100, & 1.34-100 Wind Turbine Generators

Mr. Karwisch:

On September 20, 2012, I responded to your request to help respond to the Ministry of Environment's request to "Provide a letter and report from manufacturer indicating that GE1.6-100, 1.62 MW is not tonal based on IEC 61400-11-ed.2.1: 2006. State the tonality of the turbines in the report."

IEC 61400-11 only requires a report of any tonality that exceeds 3dB, but appears not to define the term "tonal".

The 1.6-100, 1.39-100, and 1.34-100 turbines (with or without low-noise trailing edges) have an expected value for tonal audibility of $\Delta L_{a,k} < 2$ dB, irrespective of wind speed, hub height, and grid frequency based on the IEC 61400-11 standard and thuse does not require a report.

Nonetheless, please refer to the attached report on the 1.6-100, 1.39-100, and 1.34-100 with LNTE's, the models NextEra plans to install, for more detailed acoustic information. These are updates to the version provided with my September 20, 2012 letter. The following changes were made:

- Tabel 1 was replaced to include lower wind speeds and to update the low frequencies based on measurement data.
- The description for Audible Tonality was updated to conform with IEC 61400-11 standard. It now says, "The tonal audibility ($\Delta L_{a,k}$), when measured in accordance with the IEC 61400-11 standard, for the GE's 1.6-100 with LNTE is less than or equal to 2 dB.".

Best regards,

Parker D. Powell

Attachments: Technical Description of the 1.6-100 Wind Turbine with Low-Noise Trailing Edges (LNTE's) and Major Components Rev 3

Technical Description of the 1.39-100 Wind Turbine with Low-Noise Trailing Edges (LNTE's) and Major Components Rev 2

Technical Description of the 1.34-100 Wind Turbine with Low-Noise Trailing Edges (LNTE's) and Major Components Rev 2



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GE Power & Water

– Original Instructions –

Turbine A specs

# Technical Documentation Wind Turbine Generator Systems 1.6-100 with LNTE 50 Hz and 60 Hz

## Product Acoustic Specifications

Normal Operation according to IEC
Incl. Octave Band Spectra
Incl. 1/3rd Octave Band Spectra

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# Table of Contents

# 1 Introduction

This document summarizes the acoustic emission characteristics of the 1.6-100 with Low Noise Trailing Edge (LNTE) wind turbine for normal operation, including calculated apparent sound power levels $L_{WA,k}$, as well as uncertainty levels associated with the apparent sound power levels, tonal audibility, and calculated third octave band apparent sound power level.

All provided sound power levels are A-weighted.

GE continuously verifies specifications with measurements, including those performed by independent institutes. If a wind turbine noise performance test is carried out, it needs to be done in accordance with the regulations of the international standard IEC 61400-11, ed. 2.1: 2006 and Machine Noise Performance Test document.

## 2 Normal Operation Calculated Apparent Sound Power Level

The apparent sound power levels $L_{WA,k}$ are initially calculated as a function of the hub height wind speed $v_{HH}$. The corresponding wind speeds $v_{10m}$ at 10 m height above ground level have been evaluated assuming a logarithmic wind profile. In this case a surface roughness of $z_{0ref}$ = 0.05 m has been used, which is representative of average terrain conditions.

$$v_{10m} = v_{HH} \frac{\ln\left(\frac{10m}{z_{0ref}}\right)}{\ln\left(\frac{hub\ height}{z_{0ref}}\right)} \quad *$$

The calculated apparent sound power levels $L_{WA,k}$ and the associated octave-band spectra are given in Table 1 and Table 2 for two different hub heights. The values are provided as mean levels as a function of $v_{10m}$ for Normal Operation (NO) over cut-in to cut-out wind speed range. The uncertainties for octave sound power levels are generally higher than for total sound power levels. Guidance is given in IEC 61400-11, Annex D.

| 1.6-100 with LNTE – Normal Operation Octave Spectra | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Standard wind speed at 10 m [m/s]** | | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10-Cutout** |
| **Hub height wind speed at 80 m [m/s]** | | **4.2** | **5.6** | **7.0** | **8.4** | **9.7** | **11.1** | **12.5** | **14-Cutout** |
| **Frequency (Hz)** | **31.5** | 62.5 | 62.2 | 66.1 | 70.1 | 73.5 | 73.7 | 73.6 | 73.5 |
| | **63** | 72.1 | 71.9 | 75.9 | 80.3 | 84.0 | 84.1 | 84.1 | 84.0 |
| | **125** | 79.0 | 79.2 | 83.8 | 88.4 | 91.6 | 91.8 | 91.8 | 91.7 |
| | **250** | 84.0 | 84.6 | 89.4 | 94.7 | 95.4 | 95.3 | 95.4 | 95.5 |
| | **500** | 85.5 | 84.9 | 89.7 | 95.5 | 97.1 | 96.6 | 96.7 | 97.0 |
| | **1000** | 83.4 | 83.0 | 86.9 | 91.8 | 97.1 | 97.5 | 97.6 | 97.8 |
| | **2000** | 81.7 | 83.4 | 87.9 | 92.4 | 95.7 | 95.7 | 95.5 | 95.1 |
| | **4000** | 74.9 | 77.7 | 83.5 | 88.9 | 89.7 | 89.1 | 88.4 | 87.9 |
| | **8000** | 55.5 | 57.6 | 63.5 | 70.3 | 70.4 | 70.6 | 69.4 | 69.1 |
| | **16000** | 7.9 | 13.2 | 18.9 | 24.7 | 27.2 | 26.6 | 27.5 | 29.0 |
| **Total apparent sound power level $L_{WA,k}$ [dB]** | | **90.4** | **90.7** | **95.3** | **100.5** | **103.0** | **103.0** | **103.0** | **103.0** |

Table 1: Normal Operation Calculated Apparent Sound Power Level, 1.6-100 with LNTE with 80 m hub height as a function of 10 m wind speed ($z_{0ref}$ = 0.05 m), the octave band spectra are for information only

* Simplified from IEC 61400-11, ed. 2.1: 2006 equation 7

| 1.6-100 with LNTE – Normal Operation Octave Spectra | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Standard wind speed at 10 m [m/s] | | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10-Cutout |
| Hub height wind speed at 96 m [m/s] | | 4.3 | 5.7 | 7.1 | 8.6 | 10.0 | 11.4 | 12.8 | 14-Cutout |
| Frequency (Hz) | 31.5 | 62.4 | 62.4 | 66.6 | 70.6 | 73.7 | 73.7 | 73.6 | 73.5 |
| | 63 | 72.1 | 72.0 | 76.5 | 80.8 | 84.1 | 84.1 | 84.1 | 84.0 |
| | 125 | 79.0 | 79.5 | 84.4 | 89.0 | 91.6 | 91.8 | 91.8 | 91.7 |
| | 250 | 84.0 | 84.9 | 90.1 | 95.0 | 95.3 | 95.3 | 95.5 | 95.5 |
| | 500 | 85.4 | 85.0 | 90.3 | 96.0 | 96.8 | 96.6 | 96.8 | 97.0 |
| | 1000 | 83.4 | 83.1 | 87.5 | 92.4 | 97.2 | 97.4 | 97.7 | 97.8 |
| | 2000 | 81.8 | 83.7 | 88.5 | 92.9 | 95.8 | 95.7 | 95.4 | 95.1 |
| | 4000 | 75.1 | 78.2 | 84.2 | 89.3 | 89.7 | 88.8 | 88.4 | 87.9 |
| | 8000 | 55.7 | 57.9 | 64.4 | 70.7 | 71.1 | 69.8 | 69.3 | 69.1 |
| | 16000 | 8.4 | 13.6 | 19.5 | 25.2 | 27.3 | 26.4 | 27.8 | 29.0 |
| Total apparent sound power level $L_{WA.k}$ [dB] | | 90.4 | 90.9 | 96.0 | 101.0 | 103.0 | 103.0 | 103.0 | 103.0 |

Table 2: Normal Operation Calculated Apparent Sound Power Level, 1.6-100 with LNTE with 96 m hub height as a function of 10 m wind speed ($z_{0ref}$ = 0.05 m), the octave band spectra are for information only

At 10 m wind speeds lower than 5 m/s the sound power levels decreases, and may get so low that the wind turbine noise becomes indistinguishable from the background noise. For a conservative calculation the data at 5 m/s may be used.

For 10 m wind speeds above 10 m/s, the wind turbine has reached rated power and the blade pitch regulation acts in a way that tends to decrease the noise levels. For a conservative calculation the data at 10 m/s may be used.

The highest normal operation calculated apparent sound power level for the 1.6-100 with LNTE is $L_{WA,k}$ = 103.0 dB.

# 3 Uncertainty Levels

The apparent sound power levels given above are calculated mean levels. If a wind turbine noise performance test is carried out, it needs to be done in accordance with the regulations of the international standard IEC 61400-11, ed. 2.1: 2006. Uncertainty levels associated with measurements are described in IEC/TS 61400-14.

Per IEC/TS 61400-14, $L_{WAd}$ is the maximum apparent sound power level for 95 % confidence level resulting from n measurements performed according to IEC 61400-11 standard: $L_{Wad} = L_{WA} + K$, where $L_{WA}$ is the mean apparent sound power level from IEC 61400-11 testing reports and $K = 1.645\ \sigma_T$.

The testing standard deviation values $\sigma_T$, $\sigma_R$ and $\sigma_P$ for measured apparent sound power level are described by IEC/TS 61400-14, where $\sigma_T$ is the total standard deviation, $\sigma_P$ is the standard deviation for product variation and $\sigma_R$ is the standard deviation for test reproducibility.

Assuming $\sigma_R < 0.8$ dB and $\sigma_P < 0.8$ dB as typical values leads to a calculated $K < 2$ dB for 95 % confidence level.

# 4 Tonal Audibility

The tonal audibility ($\Delta L_{a,k}$), when measured in accordance with the IEC 61400-11 standard, for the GE's 1.6-100 with LNTE is less than or equal to 2 dB.

# 5 IEC 61400-11 and IEC/TS 61400-14 Terminology

- $\mathbf{L_{WA,K}}$ is wind turbine apparent sound power level (referenced to $10^{-12}$W) measured with A-weighting as function of reference wind speed $\mathbf{v_{10m}}$. Derived from multiple measurement reports per IEC 61400-11, it is considered as a mean value
- $\boldsymbol{\sigma_P}$ is the product variation i.e. the 1.6-100 with LNTE unit-to-unit product variation; typically < 0.8 dB
- $\boldsymbol{\sigma_R}$ is the overall measurement testing reproducibility as defined per IEC 61400-11; typically < 0.8 dB with adequate measurement conditions and sufficient amount of data samples
- $\boldsymbol{\sigma_T}$ is the total standard deviation combining both $\boldsymbol{\sigma_P}$ and $\boldsymbol{\sigma_R}$
- $\mathbf{K = 1.645\ \boldsymbol{\sigma_T}}$ is defined per IEC/TS 61400-14 for 95 % confidence level
- $\mathbf{R_0}$ is the ground measuring distance from the wind turbine tower axis per IEC 61400-11, which shall equal the hub height plus half the rotor diameter
- $\mathbf{\Delta L_{a,k}}$ is the tonal audibility according to IEC 61400-11, described as potentially audible narrow band sound

# 6 1/3rd Octave Band Spectra

The tables in Annex I are showing the 1/3rd octave band values for different hub heights in different wind speeds.

## Reference:


- IEC 61400-1. Wind turbines – part 1: Design requirements. ed. 2. 1999
- IEC 61400-11, wind turbine generator systems part 11: Acoustic noise measurement techniques, ed. 2.1, 2006-11
- IEC/TS 61400-14, Wind turbines – part 14: Declaration of apparent sound power level and tonality values, ed. 1, 2005-03
- MNPT – Machine Noise Performance Test, Technical documentation, GE 2011

## Appendix I - Calculated 1/3rd Octave Band Apparent Sound Power Level $L_{WA,k}$

| 1.6-100 with LNTE - Normal Operation 1/3rd Octave Band Spectra | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Standard wind speed at 10 m [m/s] | | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10-Cutout |
| Hub height wind speed at 80 m [m/s] | | 4.2 | 5.6 | 7.0 | 8.4 | 9.7 | 11.1 | 12.5 | 14-Cutout |
| Frequency (Hz) | 25 | 52.2 | 52.1 | 55.8 | 59.7 | 63.0 | 63.2 | 63.1 | 62.9 |
| | 32 | 56.6 | 56.4 | 60.2 | 64.2 | 67.5 | 67.7 | 67.7 | 67.5 |
| | 40 | 60.6 | 60.3 | 64.2 | 68.3 | 71.6 | 71.9 | 71.8 | 71.7 |
| | 50 | 63.7 | 63.5 | 67.4 | 71.6 | 75.0 | 75.2 | 75.2 | 75.0 |
| | 63 | 66.5 | 66.2 | 70.3 | 74.6 | 78.1 | 78.3 | 78.3 | 78.2 |
| | 80 | 69.7 | 69.5 | 73.6 | 78.0 | 81.8 | 82.0 | 81.9 | 81.8 |
| | 100 | 72.3 | 72.2 | 76.5 | 81.0 | 84.8 | 84.9 | 84.9 | 84.7 |
| | 125 | 74.1 | 74.2 | 78.7 | 83.3 | 86.6 | 86.9 | 86.9 | 86.8 |
| | 160 | 75.6 | 76.1 | 80.8 | 85.6 | 88.3 | 88.5 | 88.6 | 88.5 |
| | 200 | 77.5 | 78.1 | 83.0 | 87.9 | 89.7 | 89.9 | 90.0 | 90.0 |
| | 250 | 79.5 | 80.1 | 85.0 | 90.2 | 91.0 | 90.9 | 91.0 | 91.1 |
| | 315 | 80.3 | 80.7 | 85.6 | 91.0 | 91.1 | 90.8 | 90.8 | 91.0 |
| | 400 | 80.7 | 80.6 | 85.4 | 91.1 | 91.5 | 91.0 | 91.0 | 91.2 |
| | 500 | 81.0 | 80.4 | 85.1 | 91.0 | 92.4 | 91.9 | 91.9 | 92.2 |
| | 630 | 80.3 | 79.4 | 84.0 | 89.9 | 92.9 | 92.6 | 92.7 | 93.0 |
| | 800 | 79.0 | 78.0 | 82.3 | 87.8 | 92.6 | 92.6 | 92.7 | 93.0 |
| | 1000 | 78.4 | 77.9 | 81.7 | 86.4 | 92.3 | 92.7 | 92.8 | 93.0 |
| | 1250 | 78.5 | 78.7 | 82.4 | 86.6 | 92.1 | 92.8 | 92.9 | 93.0 |
| | 1600 | 77.9 | 78.7 | 82.8 | 87.0 | 91.4 | 91.9 | 91.9 | 91.6 |
| | 2000 | 77.0 | 78.8 | 83.3 | 87.8 | 91.1 | 91.0 | 90.6 | 90.2 |
| | 2500 | 75.7 | 78.5 | 83.4 | 88.1 | 90.4 | 89.7 | 89.1 | 88.6 |
| | 3150 | 73.2 | 76.1 | 81.8 | 86.9 | 88.1 | 87.2 | 86.7 | 86.1 |
| | 4000 | 69.1 | 71.7 | 77.7 | 83.5 | 83.6 | 83.5 | 82.5 | 82.2 |
| | 5000 | 63.7 | 65.4 | 72.0 | 78.0 | 78.0 | 78.2 | 76.7 | 76.7 |
| | 6300 | 55.3 | 57.3 | 63.3 | 70.0 | 70.1 | 70.2 | 69.1 | 68.7 |
| | 8000 | 42.6 | 45.5 | 51.0 | 57.4 | 58.6 | 58.8 | 57.9 | 57.4 |
| | 10000 | 27.1 | 31.3 | 36.5 | 42.5 | 44.6 | 44.4 | 44.4 | 44.4 |
| | 12500 | 7.9 | 13.2 | 18.9 | 24.6 | 27.2 | 26.6 | 27.4 | 29.0 |
| | 16000 | -19.0 | -13.2 | -6.1 | -0.3 | 1.9 | 1.8 | 4.0 | 6.3 |
| | 20000 | -47.8 | -42.5 | -34.1 | -26.9 | -25.9 | -24.6 | -21.8 | -19.1 |
| Total apparent sound power level $L_{WA,k}$ [dB] | | 90.4 | 90.7 | 95.3 | 100.5 | 103.0 | 103.0 | 103.0 | 103.0 |

Table 3: Calculated Apparent 1/3rd Octave Band Sound Power Level (A-weighted) 1.6-100 with LNTE with 80 m hub height as Function of Wind Speed $v_{10m}$

| 1.6-100 with LNTE - Normal Operation 1/3rd Octave Band Spectra | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Standard wind speed at 10 m [m/s] | | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10-Cutout |
| Hub height wind speed at 96 m [m/s] | | 4.3 | 5.7 | 7.1 | 8.6 | 10.0 | 11.4 | 12.8 | 14-Cutout |
| Frequency (Hz) | 25 | 52.1 | 52.2 | 56.4 | 60.2 | 63.2 | 63.2 | 63.1 | 62.9 |
| | 32 | 56.6 | 56.5 | 60.7 | 64.7 | 67.7 | 67.7 | 67.6 | 67.5 |
| | 40 | 60.6 | 60.5 | 64.7 | 68.8 | 71.8 | 71.9 | 71.8 | 71.7 |
| | 50 | 63.7 | 63.6 | 67.9 | 72.1 | 75.2 | 75.2 | 75.2 | 75.0 |
| | 63 | 66.5 | 66.4 | 70.8 | 75.1 | 78.3 | 78.3 | 78.3 | 78.2 |
| | 80 | 69.7 | 69.7 | 74.2 | 78.6 | 81.9 | 81.9 | 81.9 | 81.8 |
| | 100 | 72.3 | 72.4 | 77.0 | 81.5 | 84.9 | 84.9 | 84.9 | 84.7 |
| | 125 | 74.0 | 74.5 | 79.3 | 83.8 | 86.7 | 86.9 | 86.9 | 86.8 |
| | 160 | 75.6 | 76.4 | 81.4 | 86.1 | 88.3 | 88.5 | 88.6 | 88.5 |
| | 200 | 77.5 | 78.5 | 83.6 | 88.4 | 89.7 | 89.9 | 90.0 | 90.0 |
| | 250 | 79.5 | 80.4 | 85.6 | 90.6 | 90.9 | 90.9 | 91.1 | 91.1 |
| | 315 | 80.3 | 81.0 | 86.2 | 91.4 | 90.9 | 90.8 | 90.9 | 91.0 |
| | 400 | 80.7 | 80.8 | 86.1 | 91.5 | 91.2 | 90.9 | 91.1 | 91.2 |
| | 500 | 80.9 | 80.5 | 85.8 | 91.5 | 92.1 | 91.8 | 92.0 | 92.2 |
| | 630 | 80.3 | 79.4 | 84.7 | 90.5 | 92.7 | 92.6 | 92.8 | 93.0 |
| | 800 | 78.9 | 78.1 | 82.9 | 88.5 | 92.5 | 92.5 | 92.8 | 93.0 |
| | 1000 | 78.3 | 78.1 | 82.2 | 87.2 | 92.5 | 92.6 | 92.9 | 93.0 |
| | 1250 | 78.5 | 78.8 | 82.9 | 87.2 | 92.4 | 92.8 | 93.0 | 93.0 |
| | 1600 | 77.9 | 78.9 | 83.3 | 87.5 | 91.6 | 91.9 | 91.9 | 91.6 |
| | 2000 | 77.1 | 79.1 | 83.9 | 88.3 | 91.1 | 90.9 | 90.6 | 90.2 |
| | 2500 | 75.9 | 78.8 | 84.0 | 88.6 | 90.3 | 89.6 | 89.0 | 88.6 |
| | 3150 | 73.4 | 76.5 | 82.4 | 87.3 | 87.9 | 87.0 | 86.6 | 86.1 |
| | 4000 | 69.2 | 72.2 | 78.4 | 83.8 | 83.7 | 83.2 | 82.5 | 82.2 |
| | 5000 | 63.8 | 65.9 | 72.8 | 78.3 | 78.4 | 77.5 | 76.8 | 76.7 |
| | 6300 | 55.4 | 57.6 | 64.1 | 70.4 | 70.8 | 69.4 | 69.0 | 68.7 |
| | 8000 | 42.9 | 45.8 | 51.8 | 57.9 | 59.1 | 58.4 | 57.7 | 57.4 |
| | 10000 | 27.5 | 31.6 | 37.2 | 43.0 | 44.9 | 44.1 | 44.4 | 44.4 |
| | 12500 | 8.4 | 13.6 | 19.5 | 25.2 | 27.3 | 26.4 | 27.8 | 29.0 |
| | 16000 | -18.5 | -12.7 | -5.4 | 0.2 | 1.8 | 2.0 | 4.6 | 6.3 |
| | 20000 | -47.5 | -41.9 | -33.2 | -26.3 | -26.0 | -24.1 | -21.1 | -19.1 |
| Total apparent sound power level $L_{WA,k}$ [dB] | | 90.4 | 90.9 | 96.0 | 101.0 | 103.0 | 103.0 | 103.0 | 103.0 |

Table 4: Calculated Apparent 1/3rd Octave Band Sound Power Level (A-weighted), 1.6-100 with LNTE with 96 m hub height as Function of Wind Speed $v_{10m}$

Turbine B Specs

# Technical Description of the 1.39-100 Wind Turbine with Low-Noise Trailing Edges (LNTE's) and Major Components

The wind turbine is a three bladed, upwind, horizontal-axis wind turbine with a rotor diameter of 100 m. The turbine rotor and nacelle are mounted on top of a tubular tower giving a rotor hub height of 80m. The machine employs active yaw control (designed to steer the machine with respect to the wind direction), active blade pitch control (designed to regulate turbine rotor speed), and a generator/power electronic converter system.

The wind turbine features a distributed drive train design wherein the major drive train components including main shaft bearings, gearbox, generator, yaw drives, and control panel are attached to a bedplate (see Figure 1).

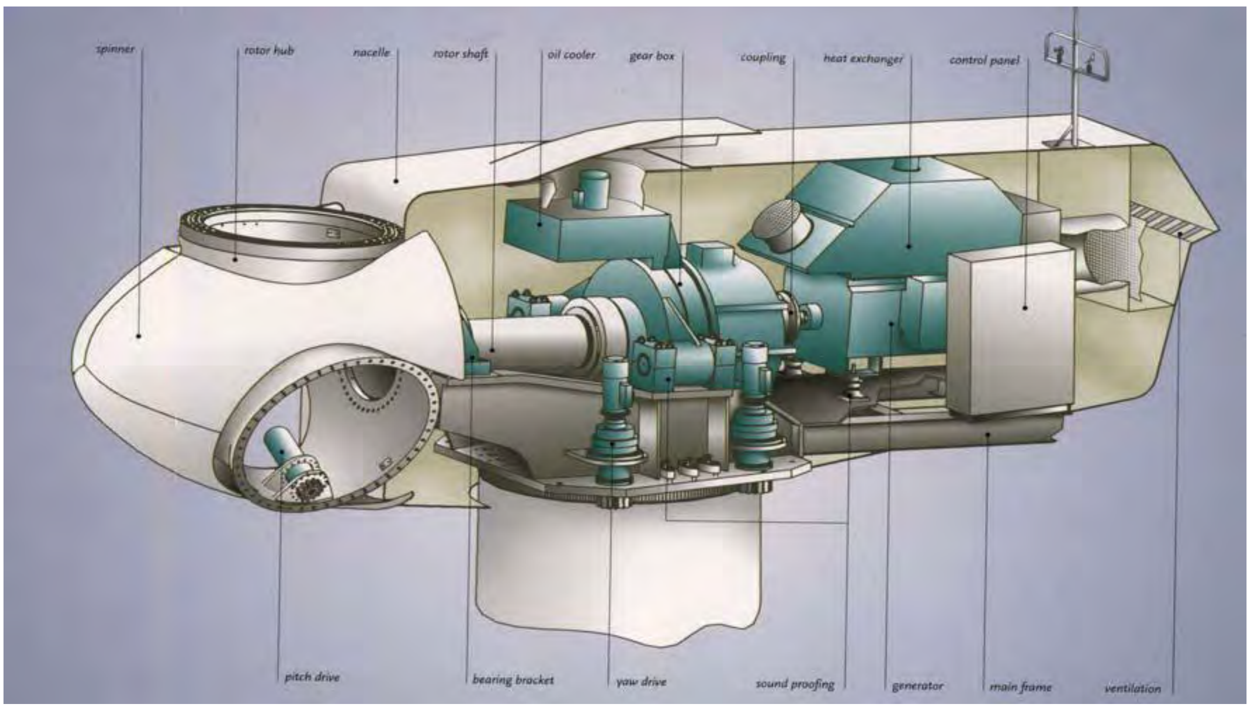



Figure 1: GE Energy 1.39-100 wind turbine nacelle layout

## Rotor

The rotor diameter is 100 m, resulting in a swept area of 7,854 m, and is designed to operate between 9.75 and 13.2 revolutions per minute (rpm). Rotor speed is regulated by a combination of blade pitch angle adjustment and generator/converter torque control. The rotor spins in a clock-wise direction under normal operating conditions when viewed from an upwind location.

Full blade pitch angle range is approximately 90°, with the 0°-position being with the airfoil chord line flat to the prevailing wind. The blades being pitched to a full feather pitch angle of approximately 90° accomplishes aerodynamic braking of the rotor; whereby the blades "spill" the wind thus limiting rotor speed.

## Blades

There are three rotor blades used on each wind turbine. The airfoils transition along the blade span with the thicker airfoils being located in-board towards the blade root (hub) and gradually tapering to thinner cross sections out towards the blade tip.

## Blade Pitch Control System

The rotor utilizes three (one for each blade) independent electric pitch motors and controllers to provide adjustment of the blade pitch angle during operation. Blade pitch angle is adjusted by an electric drive that is mounted inside the rotor hub and is coupled to a ring gear mounted to the inner race of the blade pitch bearing (see Figure 1).

GE's active-pitch controller enables the wind turbine rotor to regulate speed, when above rated wind speed, by allowing the blade to "spill" excess aerodynamic lift. Energy from wind gusts below rated wind speed is captured by allowing the rotor to speed up, transforming this gust energy into kinetic which may then be extracted from the rotor.

Three independent back-up units are provided to power each individual blade pitch system to feather the blades and shut down the machine in the event of a grid line outage or other fault. By having all three blades outfitted with independent pitch systems, redundancy of individual blade aerodynamic braking capability is provided.

## Hub

The hub is used to connect the three rotor blades to the turbine main shaft. The hub also houses the three electric blade pitch systems and is mounted directly to the main shaft. Access to the inside of the hub is provided through a hatch.

## Gearbox

The gearbox in the wind turbine is designed to transmit power between the low-rpm turbine rotor and high-rpm electric generator. The gearbox is a multi-stage planetary/helical gear design. The gearbox is mounted to the machine bedplate. The gearing is designed to transfer torsional power from the wind turbine rotor to the electric generator. A parking brake is mounted on the high-speed shaft of the gearbox.

## Bearings

The blade pitch bearing is designed to allow the blade to pitch about a span-wise pitch axis. The inner race of the blade pitch bearing is outfitted with a blade drive gear that enables the blade to be driven in pitch by an electric gear-driven motor/controller.

The main shaft bearing is a roller bearing mounted in a pillow-block housing arrangement. The bearings used inside the gearbox are of the cylindrical, spherical and tapered roller type. These bearings are designed to provide bearing and alignment of the internal gearing shafts and accommodate radial and axial loads.

## Brake System

The electrically actuated individual blade pitch systems act as the main braking system for the wind turbine. Braking under normal operating conditions is accomplished by feathering the blades out of the wind. Any single feathered rotor blade is designed to slow the rotor, and each rotor blade has its own back-up to provide power to the electric drive in the event of a grid line loss.

The turbine is also equipped with a mechanical brake located at the output (high-speed) shaft of the gearbox. This brake is only applied as an auxiliary brake to the main aerodynamic brake and to prevent rotation of the machinery as required by certain service activities.

## Generator

The generator is a doubly-fed induction type. The generator meets protection class requirements of the International Standard IP 54 (totally enclosed). The generator is mounted to the bedplate and the mounting is designed so as to reduce vibration and noise transfer to the bedplate.

## Flexible Coupling

Designed to protect the drive train from excessive torque loads, a flexible coupling is provided between the generator and gearbox output shaft this is equipped with a torque-limiting device sized to keep the maximum allowable torque below the maximum design limit of the drive train.

## Yaw System

A roller bearing attached between the nacelle and tower facilitates yaw motion. Planetary yaw drives (with brakes that engage when the drive is disabled) mesh with the outside gear of the yaw bearing and steer the machine to track the wind in yaw. The automatic yaw brakes engage in order to prevent the yaw drives from seeing peak loads from any turbulent wind.

The controller activates the yaw drives to align the nacelle to the average wind direction based on the wind vane sensor mounted on top of the nacelle.

A cable twist sensor provides a record of nacelle yaw position and cable twisting. After the sensor detects excessive rotation in one direction, the controller automatically brings the rotor to a complete stop, untwists the cable by counter yawing of the nacelle, and restarts the wind turbine.

## Tower

The wind turbine is mounted on top of a tubular tower. The tubular tower is manufactured in sections from steel plate. Access to the turbine is through a lockable steel door at the base of the tower. Service platforms are provided. Access to the nacelle is provided by a ladder and a fall arresting safety system is included. Interior lights are installed at critical points from the base of the tower to the tower top.

## Nacelle

The nacelle houses the main components of the wind turbine generator. Access from the tower into the nacelle is through the bottom of the nacelle. The nacelle is ventilated. It is illuminated with electric light. A hatch at the front end of the nacelle provides access to the blades and hub. The rotor can be secured in place with a rotor lock.

## Anemometer, Wind Vane and Lightning Rod

An anemometer, wind vane and lightning rod are mounted on top of the nacelle housing. Access to these sensors is accomplished through a hatch in the nacelle roof.

## Lightning Protection

The rotor blades are equipped with a lightning receptors mounted in the blade. The turbine is grounded and shielded to protect against lightning, however, lightning is an unpredictable force of nature, and it is possible that a lightning strike could damage various components notwithstanding the lightning protection deployed in the machine.

## Wind Turbine Control System

The wind turbine machine can be controlled automatically or manually from either an interface located inside the nacelle or from a control box at the bottom of the tower. Control signals can also be sent from a remote computer via a Supervisory Control and Data Acquisition System (SCADA), with local lockout capability provided at the turbine controller.

Service switches at the tower top prevent service personnel at the bottom of the tower from operating certain systems of the turbine while service personnel are in the nacelle. To override any machine operation, Emergency-stop buttons located in the tower base and in the nacelle can be activated to stop the turbine in the event of an emergency.

## Power Converter

The wind turbine uses a power converter system that consists of a converter on the rotor side, a DC intermediate circuit, and a power inverter on the grid side.

The converter system consists of a power module and the associated electrical equipment. Variable output frequency of the converter allows operation of the generator.

# Technical Data for the 1.39-100 with LNTE

## Rotor

| | |
|---|---|
| Diameter | 100 m |
| Number of blades | 3 |
| Swept area | 7,854 $m_2$ |
| Rotor speed range | 9.75 to 13.2 rpm |
| Rotational direction | Clockwise looking downwind |
| Maximum tip speed | 69.1 m/s |
| Orientation | Upwind |
| Speed regulation | Pitch control |
| Aerodynamic brakes | Full feathering |

## Pitch System

| | |
|---|---|
| Principle | Independent blade pitch control |
| Actuation | Individual electric drive |

## Yaw System

| | |
|---|---|
| Yaw rate | 0.5 degree/s |

# 1.39-100 with LNTE Calculated 1/1 and 1/3$^{rd}$ Octave Band Apparent Sound Power Level LWA,k

Table 1 provides reference values per IEC 61400-11, based on the total apparent sound power level (A-weighted) defined in the general product acoustic specification for this turbine type. The uncertainties for octave sound power levels are generally higher than for total sound power levels. Guidance is given in IEC 61400-11, Annex D.

| 1.39-100 LNTE with 80 m HH - Normal Operation 1/1 Octave Band Spectra | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Standard wind speed at 10 m [m/s] | | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10-Cutout |
| Hub height wind speed at 80 m [m/s] | | 4.2 | 5.6 | 7.0 | 8.4 | 9.7 | 11.1 | 12.5 | 14-Cutout |
| Frequency (Hz) | 31.5 | 62.4 | 62.2 | 66.1 | 70.2 | 70.8 | 70.9 | 70.8 | 70.6 |
| | 63 | 72.1 | 71.9 | 75.9 | 80.3 | 81.5 | 81.6 | 81.5 | 81.4 |
| | 125 | 79.0 | 79.2 | 83.8 | 88.5 | 89.4 | 89.5 | 89.5 | 89.4 |
| | 250 | 84.1 | 84.6 | 89.4 | 94.9 | 93.8 | 93.6 | 93.6 | 93.7 |
| | 500 | 85.5 | 84.9 | 89.7 | 95.6 | 95.4 | 95.2 | 95.3 | 95.6 |
| | 1000 | 83.4 | 83.0 | 86.9 | 91.8 | 94.9 | 95.4 | 95.5 | 95.6 |
| | 2000 | 81.7 | 83.4 | 87.9 | 92.5 | 93.4 | 93.1 | 92.7 | 92.1 |
| | 4000 | 74.8 | 77.7 | 83.5 | 89.1 | 87.2 | 87.3 | 86.1 | 85.3 |
| | 8000 | 55.4 | 57.6 | 63.5 | 70.5 | 68.3 | 68.6 | 66.3 | 66.5 |
| | 16000 | 7.9 | 13.2 | 18.9 | 24.7 | 24.2 | 23.2 | 24.4 | 27.1 |
| Total apparent sound power level $L_{WA,k}$ [dB] | | 90.4 | 90.7 | 95.3 | 100.7 | 101.0 | 101.0 | 101.0 | 101.0 |

Table 1: Octave Spectra for 1.39-100 with LNTE - Hub height wind speeds were calculated based on equation (7) from IEC standard 61400-11:2006 using a representative roughness length of 0.05 m.

**1.39-100 LNTE with 80 m HH - Normal Operation 1/3rd Octave Band Spectra**

| Standard wind speed at 10 m [m/s] | | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10-Cutout |
|---|---|---|---|---|---|---|---|---|---|
| Hub height wind speed at 80 m [m/s] | | 4.2 | 5.6 | 7.0 | 8.4 | 9.7 | 11.1 | 12.5 | 14-Cutout |
| Frequency (Hz) | 25 | 52.1 | 52.1 | 55.8 | 59.8 | 60.2 | 60.2 | 60.1 | 59.9 |
| | 32 | 56.6 | 56.4 | 60.2 | 64.3 | 64.8 | 64.8 | 64.8 | 64.6 |
| | 40 | 60.5 | 60.3 | 64.2 | 68.3 | 69.0 | 69.1 | 69.0 | 68.9 |
| | 50 | 63.7 | 63.5 | 67.4 | 71.7 | 72.4 | 72.5 | 72.5 | 72.3 |
| | 63 | 66.5 | 66.2 | 70.3 | 74.6 | 75.6 | 75.7 | 75.7 | 75.5 |
| | 80 | 69.7 | 69.5 | 73.6 | 78.1 | 79.4 | 79.4 | 79.4 | 79.3 |
| | 100 | 72.3 | 72.2 | 76.5 | 81.0 | 82.4 | 82.5 | 82.4 | 82.3 |
| | 125 | 74.0 | 74.2 | 78.7 | 83.4 | 84.5 | 84.6 | 84.6 | 84.4 |
| | 160 | 75.6 | 76.1 | 80.8 | 85.7 | 86.2 | 86.3 | 86.3 | 86.2 |
| | 200 | 77.5 | 78.1 | 83.0 | 88.1 | 87.8 | 87.8 | 87.9 | 87.8 |
| | 250 | 79.5 | 80.1 | 85.0 | 90.4 | 89.4 | 89.2 | 89.2 | 89.3 |
| | 315 | 80.4 | 80.7 | 85.6 | 91.2 | 89.6 | 89.2 | 89.3 | 89.4 |
| | 400 | 80.8 | 80.6 | 85.4 | 91.3 | 89.9 | 89.6 | 89.6 | 89.9 |
| | 500 | 81.0 | 80.4 | 85.1 | 91.2 | 90.7 | 90.5 | 90.6 | 90.9 |
| | 630 | 80.3 | 79.4 | 84.0 | 90.0 | 91.1 | 91.1 | 91.2 | 91.5 |
| | 800 | 78.9 | 78.0 | 82.3 | 87.9 | 90.6 | 90.9 | 91.0 | 91.2 |
| | 1000 | 78.4 | 77.9 | 81.7 | 86.5 | 90.1 | 90.7 | 90.8 | 90.9 |
| | 1250 | 78.5 | 78.7 | 82.4 | 86.7 | 89.8 | 90.5 | 90.5 | 90.2 |
| | 1600 | 77.9 | 78.7 | 82.8 | 87.1 | 89.1 | 89.3 | 89.1 | 88.5 |
| | 2000 | 77.0 | 78.8 | 83.3 | 87.9 | 88.7 | 88.3 | 87.6 | 87.1 |
| | 2500 | 75.7 | 78.5 | 83.4 | 88.3 | 87.9 | 87.3 | 86.7 | 85.8 |
| | 3150 | 73.1 | 76.1 | 81.8 | 87.0 | 85.4 | 85.3 | 84.5 | 83.5 |
| | 4000 | 69.0 | 71.7 | 77.7 | 83.7 | 81.2 | 81.8 | 80.0 | 79.6 |
| | 5000 | 63.6 | 65.4 | 72.0 | 78.2 | 75.8 | 76.3 | 74.1 | 74.2 |
| | 6300 | 55.2 | 57.3 | 63.3 | 70.3 | 68.0 | 68.3 | 66.0 | 66.2 |
| | 8000 | 42.6 | 45.5 | 51.0 | 57.6 | 56.6 | 56.2 | 54.5 | 55.1 |
| | 10000 | 27.1 | 31.3 | 36.5 | 42.6 | 42.3 | 41.4 | 41.0 | 42.7 |
| | 12500 | 7.9 | 13.2 | 18.9 | 24.7 | 24.2 | 23.2 | 24.3 | 27.1 |
| | 16000 | -18.9 | -13.2 | -6.1 | -0.2 | -1.9 | -1.5 | 1.0 | 4.1 |
| | 20000 | -47.8 | -42.5 | -34.1 | -26.7 | -30.3 | -28.1 | -25.1 | -21.9 |
| Total apparent sound power level $L_{WA,k}$ [dB] | | 90.4 | 90.7 | 95.3 | 100.7 | 101.0 | 101.0 | 101.0 | 101.0 |

Table 2: 1/3rd Octave Spectra for 1.39-100 with LNTE - Hub height wind speeds were calculated based on equation (7) from IEC standard 61400-11:2006 using a representative roughness length of 0.05 m.

## Tonal Audibility

The tonal audibility ($\Delta L_{a,k}$), when measured in accordance with the IEC 61400-11 standard, for the GE's 1.6-100 with LNTE is less than or equal to 2 dB.

## Uncertainty Levels

The apparent sound power levels given above are calculated mean levels. If a wind turbine noise performance test is carried out, it needs to be done in accordance with the regulations of the international standard IEC 61400-11, ed. 2.1: 2006. Uncertainty levels associated with measurements are described in IEC/TS 61400-14.

Per IEC/TS 61400-14, $L_{WAd}$ is the maximum apparent sound power level resulting from ***n*** measurements performed according to IEC 61400-11 standard for 95 % confidence level: $L_{WAd} = \overline{L_{WA}}$ + K, where $\overline{L_{WA}}$ is the mean apparent sound power level from ***n*** IEC 61400-11 testing reports and **K = 1.645 · $\sigma_T$**.

The testing standard deviation values $\sigma_T$, $\sigma_R$ and $\sigma_P$ for measured apparent sound power level are described by IEC/TS 61400-14 where $\sigma_T$ is the total standard deviation, $\sigma_P$ is the standard deviation for product variation and $\sigma_R$ is the standard deviation for test reproducibility.

Assuming $\sigma_R$ < 0.8 dB and $\sigma_P$ < 0.8 dB typical values, leads to calculated **K < 2 dB** for 95 % confidence level.

## IEC 61400-11 and IEC/TS 61400-14 Terminology

- **$L_{WA,k}$** is wind turbine apparent sound power level (referenced to $1^{-12}$ W) measured with A-weighting as function of reference wind speed $v_{10m}$. Derived from multiple measurement reports per IEC 61400-11, it is considered as a mean value.
- **$\sigma_P$** is the product variation i.e. the 1.39-100 with LNTE unit-to-unit product variation; typically < 0.8 dB
- **$\sigma_R$** is the overall measurement testing reproducibility as defined per IEC 61400-11; typically < 0.8 dB with adequate measurement conditions and sufficient amount of data samples
- **$\sigma_T$** is the total standard deviation combining both $\sigma_P$ and $\sigma_R$
- **K = 1.645** · $\sigma_T$ is defined by IEC/TS 61400-14 for 95 % confidence level
- **$R_o$** is the ground measuring distance from the wind turbine tower vertical axis per IEC 61400-11
- **$\Delta L_{a,k}$** is the tonal audibility according to IEC 61400-11, described as potentially audible narrow band sound

# Technical Description of the 1.34-100 Wind Turbine with Low-Noise Trailing Edges (LNTE's) and Major Components

The wind turbine is a three bladed, upwind, horizontal-axis wind turbine with a rotor diameter of 100 m. The turbine rotor and nacelle are mounted on top of a tubular tower giving a rotor hub height of 80m. The machine employs active yaw control (designed to steer the machine with respect to the wind direction), active blade pitch control (designed to regulate turbine rotor speed), and a generator/power electronic converter system.

The wind turbine features a distributed drive train design wherein the major drive train components including main shaft bearings, gearbox, generator, yaw drives, and control panel are attached to a bedplate (see Figure 1).

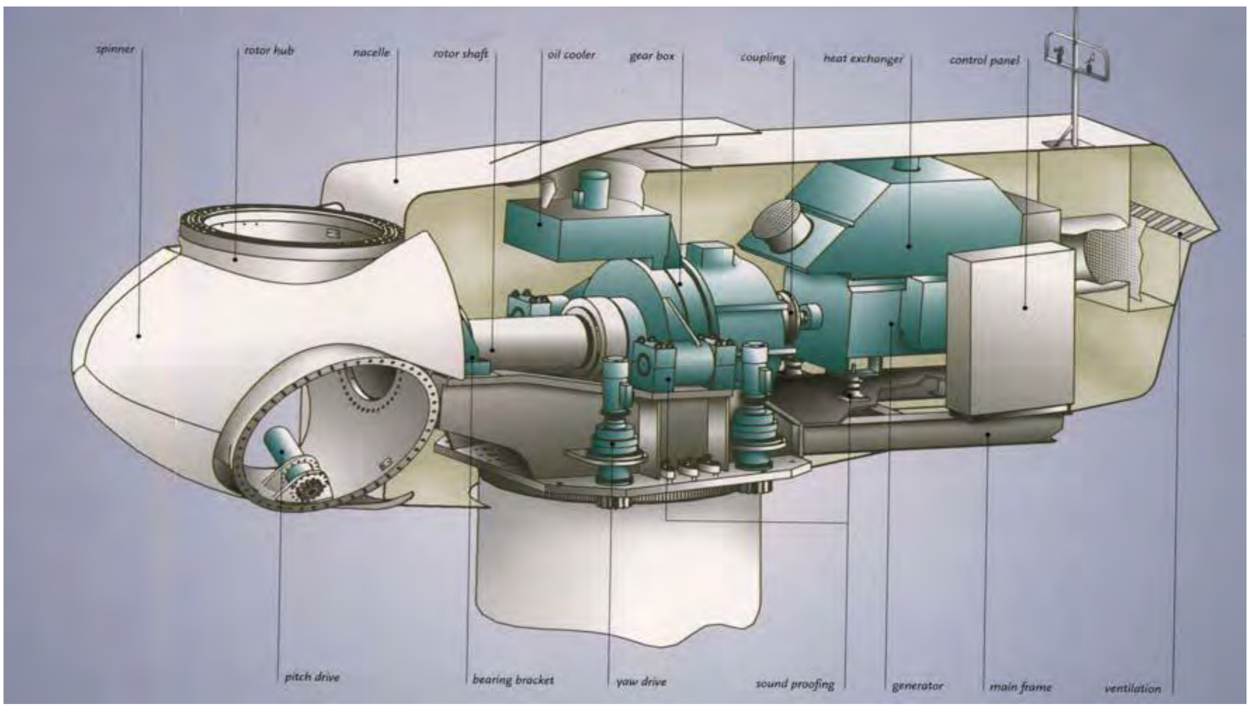


Figure 1: GE Energy 1.34-100 wind turbine nacelle layout

## Rotor

The rotor diameter is 100 m, resulting in a swept area of 7,854 m, and is designed to operate between 9.75 and 12.8 revolutions per minute (rpm). Rotor speed is regulated by a combination of blade pitch angle adjustment and generator/converter torque control. The rotor spins in a clock-wise direction under normal operating conditions when viewed from an upwind location.

Full blade pitch angle range is approximately 90°, with the 0°-position being with the airfoil chord line flat to the prevailing wind. The blades being pitched to a full feather pitch angle of approximately 90° accomplishes aerodynamic braking of the rotor; whereby the blades "spill" the wind thus limiting rotor speed.

## Blades

There are three rotor blades used on each wind turbine. The airfoils transition along the blade span with the thicker airfoils being located in-board towards the blade root (hub) and gradually tapering to thinner cross sections out towards the blade tip.

## Blade Pitch Control System

The rotor utilizes three (one for each blade) independent electric pitch motors and controllers to provide adjustment of the blade pitch angle during operation. Blade pitch angle is adjusted by an electric drive that is mounted inside the rotor hub and is coupled to a ring gear mounted to the inner race of the blade pitch bearing (see Figure 1).

GE's active-pitch controller enables the wind turbine rotor to regulate speed, when above rated wind speed, by allowing the blade to "spill" excess aerodynamic lift. Energy from wind gusts below rated wind speed is captured by allowing the rotor to speed up, transforming this gust energy into kinetic which may then be extracted from the rotor.

Three independent back-up units are provided to power each individual blade pitch system to feather the blades and shut down the machine in the event of a grid line outage or other fault. By having all three blades outfitted with independent pitch systems, redundancy of individual blade aerodynamic braking capability is provided.

## Hub

The hub is used to connect the three rotor blades to the turbine main shaft. The hub also houses the three electric blade pitch systems and is mounted directly to the main shaft. Access to the inside of the hub is provided through a hatch.

## Gearbox

The gearbox in the wind turbine is designed to transmit power between the low-rpm turbine rotor and high-rpm electric generator. The gearbox is a multi-stage planetary/helical gear design. The gearbox is mounted to the machine bedplate. The gearing is designed to transfer torsional power from the wind turbine rotor to the electric generator. A parking brake is mounted on the high-speed shaft of the gearbox.

## Bearings

The blade pitch bearing is designed to allow the blade to pitch about a span-wise pitch axis. The inner race of the blade pitch bearing is outfitted with a blade drive gear that enables the blade to be driven in pitch by an electric gear-driven motor/controller.

The main shaft bearing is a roller bearing mounted in a pillow-block housing arrangement. The bearings used inside the gearbox are of the cylindrical, spherical and tapered roller type. These bearings are designed to provide bearing and alignment of the internal gearing shafts and accommodate radial and axial loads.

## Brake System

The electrically actuated individual blade pitch systems act as the main braking system for the wind turbine. Braking under normal operating conditions is accomplished by feathering the blades out of the wind. Any single feathered rotor blade is designed to slow the rotor, and each rotor blade has its own back-up to provide power to the electric drive in the event of a grid line loss.

The turbine is also equipped with a mechanical brake located at the output (high-speed) shaft of the gearbox. This brake is only applied as an auxiliary brake to the main aerodynamic brake and to prevent rotation of the machinery as required by certain service activities.

## Generator

The generator is a doubly-fed induction type. The generator meets protection class requirements of the International Standard IP 54 (totally enclosed). The generator is mounted to the bedplate and the mounting is designed so as to reduce vibration and noise transfer to the bedplate.

## Flexible Coupling

Designed to protect the drive train from excessive torque loads, a flexible coupling is provided between the generator and gearbox output shaft this is equipped with a torque-limiting device sized to keep the maximum allowable torque below the maximum design limit of the drive train.

## Yaw System

A roller bearing attached between the nacelle and tower facilitates yaw motion. Planetary yaw drives (with brakes that engage when the drive is disabled) mesh with the outside gear of the yaw bearing and steer the machine to track the wind in yaw. The automatic yaw brakes engage in order to prevent the yaw drives from seeing peak loads from any turbulent wind.

The controller activates the yaw drives to align the nacelle to the average wind direction based on the wind vane sensor mounted on top of the nacelle.

A cable twist sensor provides a record of nacelle yaw position and cable twisting. After the sensor detects excessive rotation in one direction, the controller automatically brings the rotor to a complete stop, untwists the cable by counter yawing of the nacelle, and restarts the wind turbine.

## Tower

The wind turbine is mounted on top of a tubular tower. The tubular tower is manufactured in sections from steel plate. Access to the turbine is through a lockable steel door at the base of the tower. Service platforms are provided. Access to the nacelle is provided by a ladder and a fall arresting safety system is included. Interior lights are installed at critical points from the base of the tower to the tower top.

## Nacelle

The nacelle houses the main components of the wind turbine generator. Access from the tower into the nacelle is through the bottom of the nacelle. The nacelle is ventilated. It is illuminated with electric light. A hatch at the front end of the nacelle provides access to the blades and hub. The rotor can be secured in place with a rotor lock.

## Anemometer, Wind Vane and Lightning Rod

An anemometer, wind vane and lightning rod are mounted on top of the nacelle housing. Access to these sensors is accomplished through a hatch in the nacelle roof.

## Lightning Protection

The rotor blades are equipped with a lightning receptors mounted in the blade. The turbine is grounded and shielded to protect against lightning, however, lightning is an unpredictable force of nature, and it is possible that a lightning strike could damage various components notwithstanding the lightning protection deployed in the machine.

## Wind Turbine Control System

The wind turbine machine can be controlled automatically or manually from either an interface located inside the nacelle or from a control box at the bottom of the tower. Control signals can also be sent from a remote computer via a Supervisory Control and Data Acquisition System (SCADA), with local lockout capability provided at the turbine controller.

Service switches at the tower top prevent service personnel at the bottom of the tower from operating certain systems of the turbine while service personnel are in the nacelle. To override any machine operation, Emergency-stop buttons located in the tower base and in the nacelle can be activated to stop the turbine in the event of an emergency.

## Power Converter

The wind turbine uses a power converter system that consists of a converter on the rotor side, a DC intermediate circuit, and a power inverter on the grid side.

The converter system consists of a power module and the associated electrical equipment. Variable output frequency of the converter allows operation of the generator.

# Technical Data for the 1.34-100 with LNTE

## Rotor

| | |
|---|---|
| Diameter | 100 m |
| Number of blades | 3 |
| Swept area | 7,854 $m_2$ |
| Rotor speed range | 9.75 to 12.8 rpm |
| Rotational direction | Clockwise looking downwind |
| Maximum tip speed | 67.0 m/s |
| Orientation | Upwind |
| Speed regulation | Pitch control |
| Aerodynamic brakes | Full feathering |

## Pitch System

| | |
|---|---|
| Principle | Independent blade pitch control |
| Actuation | Individual electric drive |

## Yaw System

| | |
|---|---|
| Yaw rate | 0.5 degree/s |

# 1.34-100 with LNTE Calculated 1/1 and $1/3^{rd}$ Octave Band Apparent Sound Power Level LWA,k

Table 1 provides reference values per IEC 61400-11, based on the total apparent sound power level (A-weighted) defined in the general product acoustic specification for this turbine type. The uncertainties for octave sound power levels are generally higher than for total sound power levels. Guidance is given in IEC 61400-11, Annex D.

| 1.34-100 LNTE with 80 m HH - Normal Operation 1/1 Octave Band Spectra | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Standard wind speed at 10 m [m/s] | | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10-Cutout |
| Hub height wind speed at 80 m [m/s] | | 4.2 | 5.6 | 7.0 | 8.4 | 9.7 | 11.1 | 12.5 | 14-Cutout |
| Frequency (Hz) | 31.5 | 62.4 | 62.2 | 66.1 | 69.5 | 70.0 | 70.0 | 70.0 | 69.8 |
| | 63 | 72.1 | 71.9 | 75.9 | 79.7 | 80.5 | 80.6 | 80.6 | 80.5 |
| | 125 | 79.0 | 79.2 | 83.8 | 87.9 | 88.4 | 88.5 | 88.5 | 88.4 |
| | 250 | 84.1 | 84.6 | 89.4 | 94.1 | 93.0 | 92.6 | 92.7 | 92.7 |
| | 500 | 85.5 | 84.9 | 89.7 | 94.6 | 94.5 | 94.3 | 94.4 | 94.7 |
| | 1000 | 83.4 | 83.0 | 86.9 | 90.8 | 93.6 | 94.4 | 94.5 | 94.5 |
| | 2000 | 81.7 | 83.4 | 87.9 | 91.7 | 92.2 | 91.9 | 91.4 | 90.8 |
| | 4000 | 74.8 | 77.7 | 83.5 | 88.2 | 86.4 | 86.3 | 84.9 | 84.0 |
| | 8000 | 55.4 | 57.6 | 63.5 | 69.4 | 68.2 | 67.4 | 65.1 | 65.2 |
| | 16000 | 7.9 | 13.2 | 18.9 | 23.9 | 22.9 | 21.9 | 23.3 | 26.3 |
| Total apparent sound power level $L_{WA,k}$ [dB] | | 90.4 | 90.7 | 95.3 | 99.8 | 100.0 | 100.0 | 100.0 | 100.0 |

Table 1: Octave Spectra for 1.34-100 with LNTE - Hub height wind speeds were calculated based on equation (7) from IEC standard 61400-11:2006 using a representative roughness length of 0.05 m.

| 1.34-100 LNTE with 80 m HH - Normal Operation 1/3rd Octave Band Spectra | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Standard wind speed at 10 m [m/s] | | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10-Cutout |
| Hub height wind speed at 80 m [m/s] | | 4.2 | 5.6 | 7.0 | 8.4 | 9.7 | 11.1 | 12.5 | 14-Cutout |
| Frequency (Hz) | 25 | 52.1 | 52.1 | 55.8 | 59.2 | 59.4 | 59.4 | 59.3 | 59.1 |
| | 32 | 56.6 | 56.4 | 60.2 | 63.6 | 64.0 | 64.0 | 63.9 | 63.8 |
| | 40 | 60.5 | 60.3 | 64.2 | 67.7 | 68.1 | 68.2 | 68.2 | 68.0 |
| | 50 | 63.7 | 63.5 | 67.4 | 71.0 | 71.5 | 71.6 | 71.6 | 71.5 |
| | 63 | 66.5 | 66.2 | 70.3 | 74.0 | 74.7 | 74.8 | 74.8 | 74.7 |
| | 80 | 69.7 | 69.5 | 73.6 | 77.4 | 78.4 | 78.5 | 78.5 | 78.3 |
| | 100 | 72.3 | 72.2 | 76.5 | 80.4 | 81.4 | 81.5 | 81.5 | 81.3 |
| | 125 | 74.0 | 74.2 | 78.7 | 82.7 | 83.5 | 83.6 | 83.6 | 83.4 |
| | 160 | 75.6 | 76.1 | 80.8 | 85.0 | 85.3 | 85.3 | 85.3 | 85.2 |
| | 200 | 77.5 | 78.1 | 83.0 | 87.4 | 87.0 | 86.8 | 86.9 | 86.9 |
| | 250 | 79.5 | 80.1 | 85.0 | 89.6 | 88.6 | 88.2 | 88.3 | 88.3 |
| | 315 | 80.4 | 80.7 | 85.6 | 90.4 | 88.9 | 88.3 | 88.4 | 88.5 |
| | 400 | 80.8 | 80.6 | 85.4 | 90.4 | 89.2 | 88.7 | 88.8 | 89.0 |
| | 500 | 81.0 | 80.4 | 85.1 | 90.1 | 89.9 | 89.6 | 89.7 | 90.1 |
| | 630 | 80.3 | 79.4 | 84.0 | 88.8 | 90.0 | 90.2 | 90.3 | 90.6 |
| | 800 | 78.9 | 78.0 | 82.3 | 86.6 | 89.3 | 89.9 | 90.0 | 90.3 |
| | 1000 | 78.4 | 77.9 | 81.7 | 85.5 | 88.6 | 89.6 | 89.7 | 89.8 |
| | 1250 | 78.5 | 78.7 | 82.4 | 85.8 | 88.5 | 89.3 | 89.3 | 89.0 |
| | 1600 | 77.9 | 78.7 | 82.8 | 86.3 | 87.9 | 88.1 | 87.8 | 87.2 |
| | 2000 | 77.0 | 78.8 | 83.3 | 87.1 | 87.5 | 87.1 | 86.4 | 85.8 |
| | 2500 | 75.7 | 78.5 | 83.4 | 87.4 | 86.8 | 86.1 | 85.5 | 84.6 |
| | 3150 | 73.1 | 76.1 | 81.8 | 86.2 | 84.5 | 84.3 | 83.3 | 82.2 |
| | 4000 | 69.0 | 71.7 | 77.7 | 82.8 | 80.6 | 80.8 | 78.8 | 78.3 |
| | 5000 | 63.6 | 65.4 | 72.0 | 77.2 | 75.6 | 75.3 | 72.9 | 72.8 |
| | 6300 | 55.2 | 57.3 | 63.3 | 69.2 | 67.9 | 67.2 | 64.8 | 64.8 |
| | 8000 | 42.6 | 45.5 | 51.0 | 56.6 | 56.1 | 55.0 | 53.3 | 54.1 |
| | 10000 | 27.1 | 31.3 | 36.5 | 41.7 | 41.3 | 40.1 | 39.8 | 41.9 |
| | 12500 | 7.9 | 13.2 | 18.9 | 23.9 | 22.8 | 21.9 | 23.2 | 26.3 |
| | 16000 | -18.9 | -13.2 | -6.1 | -1.1 | -3.4 | -2.8 | -0.2 | 3.0 |
| | 20000 | -47.8 | -42.5 | -34.1 | -27.7 | -31.5 | -29.5 | -26.4 | -23.1 |
| Total apparent sound power level $L_{WA,k}$ [dB] | | 90.4 | 90.7 | 95.3 | 99.8 | 100.0 | 100.0 | 100.0 | 100.0 |

Table 2: 1/3rd Octave Spectra for 1.34-100 with LNTE - Hub height wind speeds were calculated based on equation (7) from IEC standard 61400-11:2006 using a representative roughness length of 0.05 m.

## Tonal Audibility

The tonal audibility ($\Delta L_{a,k}$), when measured in accordance with the IEC 61400-11 standard, for the GE's 1.6-100 with LNTE is less than or equal to 2 dB.

## Uncertainty Levels

The apparent sound power levels given above are calculated mean levels. If a wind turbine noise performance test is carried out, it needs to be done in accordance with the regulations of the international standard IEC 61400-11, ed. 2.1: 2006. Uncertainty levels associated with measurements are described in IEC/TS 61400-14.

Per IEC/TS 61400-14, $L_{WAd}$ is the maximum apparent sound power level resulting from ***n*** measurements performed according to IEC 61400-11 standard for 95 % confidence level: $L_{WAd} = \overline{L_{WA}} + K$, where $\overline{L_{WA}}$ is the mean apparent sound power level from ***n*** IEC 61400-11 testing reports and **$K = 1.645 \cdot \sigma_T$**.

The testing standard deviation values **$\sigma_T$, $\sigma_R$** and **$\sigma_P$** for measured apparent sound power level are described by IEC/TS 61400-14 where **$\sigma_T$** is the total standard deviation, **$\sigma_P$** is the standard deviation for product variation and **$\sigma_R$** is the standard deviation for test reproducibility.

Assuming **$\sigma_R$** $< 0.8$ dB and **$\sigma_P$** $< 0.8$ dB typical values, leads to calculated **$K < 2$ dB** for 95 % confidence level.

## IEC 61400-11 and IEC/TS 61400-14 Terminology

- **$L_{WA,k}$** is wind turbine apparent sound power level (referenced to $1^{-12}$ W) measured with A-weighting as function of reference wind speed $v_{10m}$. Derived from multiple measurement reports per IEC 61400-11, it is considered as a mean value.
- **$\sigma_P$** is the product variation i.e. the 1.34-100 with LNTE unit-to-unit product variation; typically < 0.8 dB
- **$\sigma_R$** is the overall measurement testing reproducibility as defined per IEC 61400-11; typically < 0.8 dB with adequate measurement conditions and sufficient amount of data samples
- **$\sigma_T$** is the total standard deviation combining both **$\sigma_P$** and **$\sigma_R$**
- **$K = 1.645$** $\cdot$ **$\sigma_T$** is defined by IEC/TS 61400-14 for 95 % confidence level
- **$R_o$** is the ground measuring distance from the wind turbine tower vertical axis per IEC 61400-11
- **$\Delta L_{a,k}$** is the tonal audibility according to IEC 61400-11, described as potentially audible narrow band sound

# Attachment C

# Sub-station Transformer Sound Calculations

**Table 1: East Durham Wind  Transformer Substation Sound Levels**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Transformer Substation rating (dBA)** | | | 73 | As per Northern Transformer specs | | | | | | | **Description** |
| Area around Transformer ($m^2$) | | | 99.03 | (transformer top and four sides) | | | | | | | |
| Sound Power Level, dBA | 73+10logS | | 93.0 | | | | | | | | Ref. 1, Eq. 17 |
| **Octave Band Centre Frequency ( Hz )** | | | | | | | | | | | |
| **Sound Description** | **31.5** | **63** | **125** | **250** | **500** | **1000** | **2000** | **4000** | **8000** | **Sum** | |
| Base, dB | 93.0 | 93.0 | 93.0 | 93.0 | 93.0 | 93.0 | 93.0 | 93.0 | 93.0 | | |
| Octave Band Correction | -3 | 3 | 5 | 0 | 0 | -6 | -11 | -16 | -23 | | Ref. 1, Table 1 octave band corrections |
| Corrected Subs. Transformer PWL, dB | 90.0 | 96.0 | 98.0 | 93.0 | 93.0 | 87.0 | 82.0 | 77.0 | 70.0 | **101.7** | (93 dB + octave correction) |
| dB to dBA | -39.4 | -26.2 | -16.1 | -8.6 | -3.2 | 0.0 | 1.2 | 1.0 | -1.1 | | |
| PWL (dBA) | 50.6 | 69.8 | 81.9 | 84.4 | 89.8 | 87.0 | 83.2 | 78.0 | 68.9 | **93.3** | |
| Correct to 93.0 dBA | -0.3 | -0.3 | -0.3 | -0.3 | -0.3 | -0.3 | -0.3 | -0.3 | -0.3 | | |
| Corrected PWL (dBA) | 50.3 | 69.5 | 81.6 | 84.1 | 89.5 | 86.7 | 82.9 | 77.7 | 68.6 | **93.0** | |
| Tonal Penalty (dBA) | 5 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | | as per NPC-104 |
| Transformer Total PWL (dBA) | 55.3 | 74.5 | 86.6 | 89.1 | 94.5 | 91.7 | 87.9 | 82.7 | 73.6 | **98.0** | including Tonal Penalty |

Reference 1: Sound Power Level Prediction for Industrial Machinery by Bruce and Mortiz

## Area Calculation for Northern Transformer for East Durham Wind Energy

Top Area = (Area of rectangle A'B'E'F') – Area of (triangle A'AH + triangle B'BC + triangle DE'E + triangle FF'G)

= {(0.3+3.6+0.3) metres) x (2+3.11+2) metres} – {2 x (2 metres x 0.3 metres)}

= {(4.2 metres) x (7.11 metres)} – 1.2 metres

= 29.86 square metres – 1.2 square metres = **28.66 square metres**

Top Perimeter = 2 x 3.6 metres + 2 x 3.11 metres + 4 x SQRT($2^2$+$0.3^2$) metres

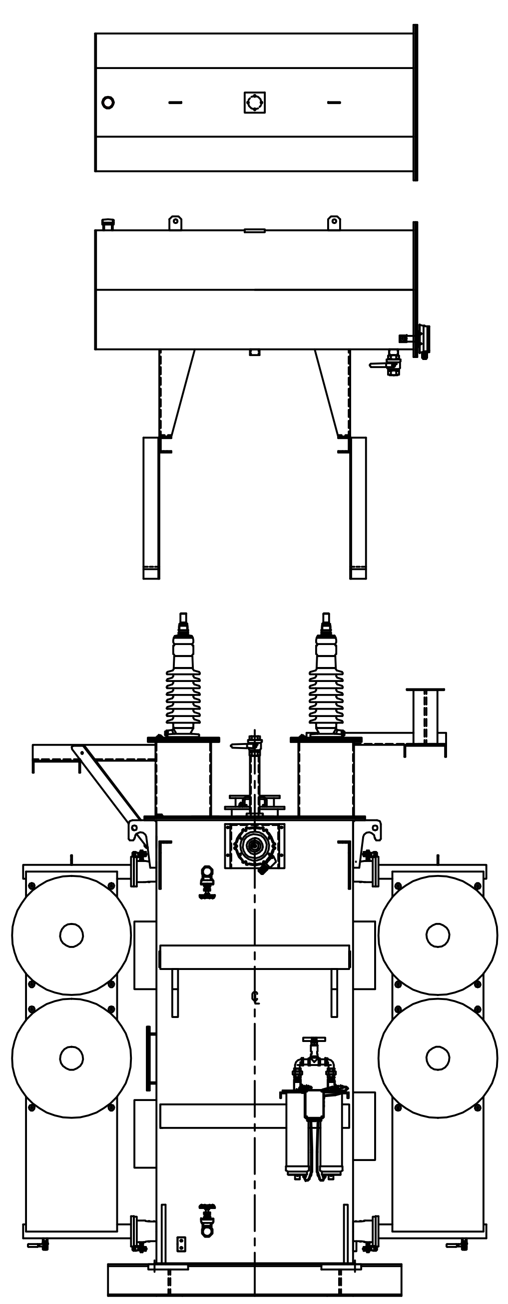
= 7.2 metres + 6.22 metres + 8.1 metres = 21.52 metres

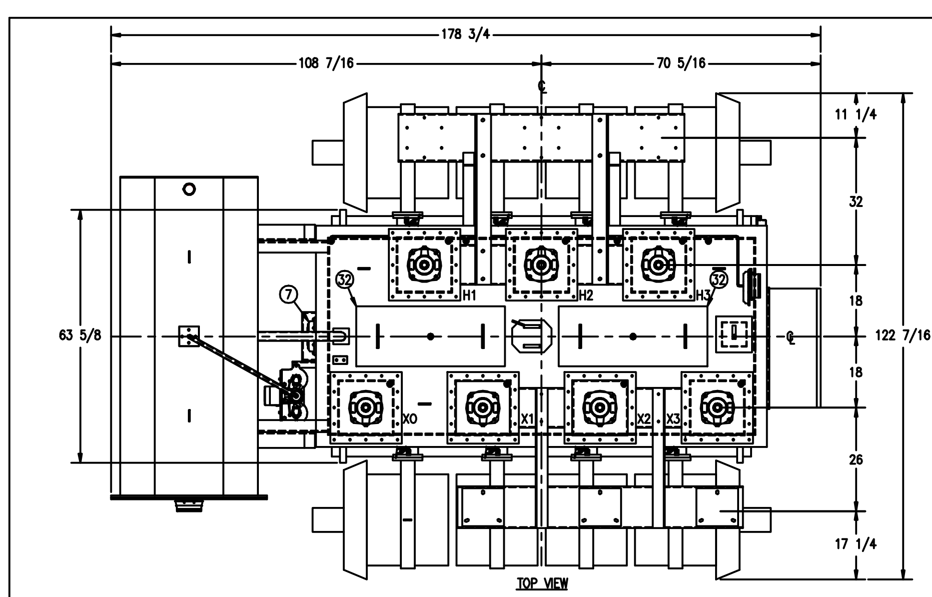
Side Areas = Top Perimeter x (height + 0.2 metre)

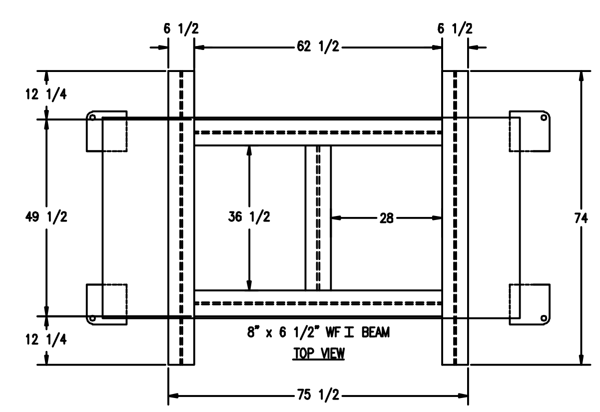
Height = 120.8125 inches = 3.07 metres

= 21.52 metres x (3.07 + 0.2) metres = **70.37 square metres**

Total Area = **28.66 square metres + 70.37 square metres = 99.03 square metres**

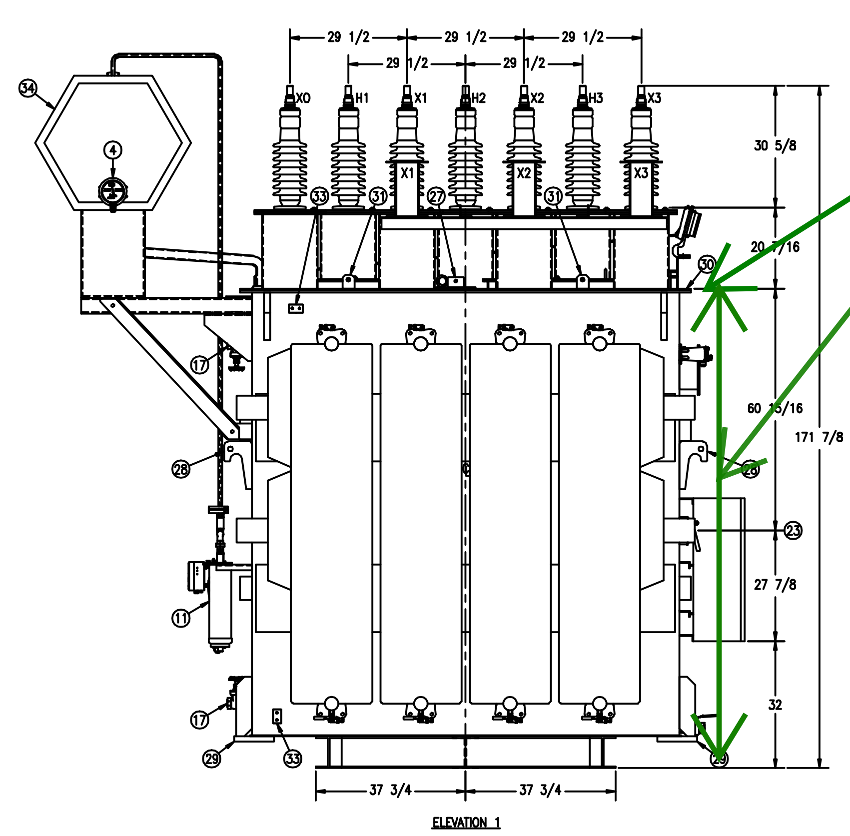


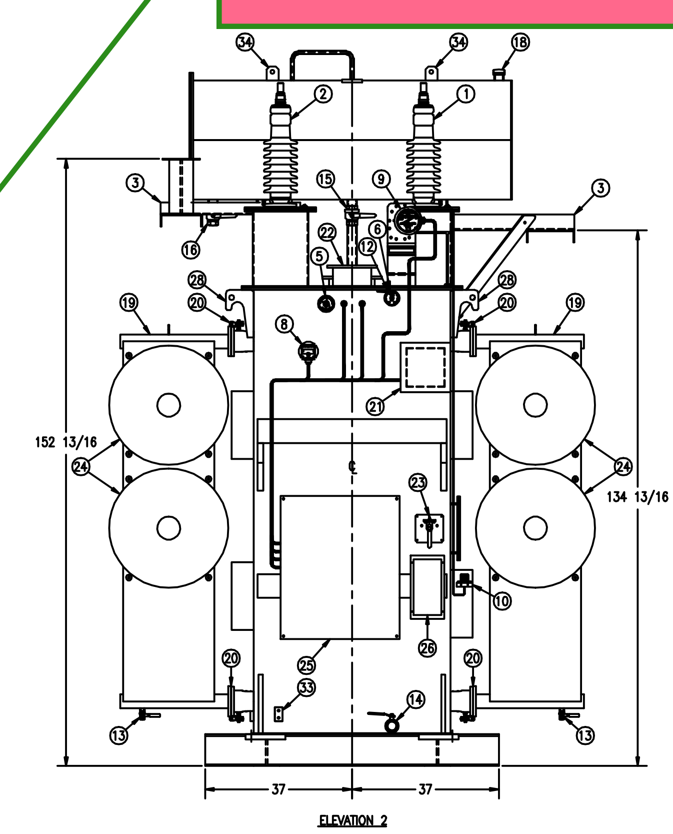



1 (3) HV BUSHINGS 46 KV 250 KV BIL 1200 A. ABB #T046W0412AU c/w 1 1/2" - 12 TH'D STUD 2.25" LG. (BOTTOM CONNECTION)
2 (4) LV BUSHINGS 46 KV 250 KV BIL 1200 A. ABB #T046W0412AU c/w 1 1/2" - 12 TH'D STUD 2.25" LG. (BOTTOM CONNECTION)
3 (1) HV/LV LIGHTNING ARRESTOR MOUNTING BRACKET GALVANIZED PROVISION FOR HV/LV LA SIEMENS #3EQ4 060-2PE31-4NH5/3EL2 030-2PC31-4NH5
4 (1) MAGNETIC LIQUID LEVEL GAUGE c/w 2 CONTACTS QUALITROL #042-027-01 CS-32072
5 (1) LIQUID TEMPERATURE GAUGE QUALITROL #151-103-01
6 (1) PRESSURE-VACUUM GAUGE QUALITROL #050-35E
7 (1) PRESSURE RELIEF DEVICE c/w 1 CONTACT & SHROUD QUALITROL #213-001-01/415-P73
8 (1) RAPID PRESSURE RISE RELAY c/w SEAL-IN-RELAY QUALITROL #900-009-03/909-200-01
9 (1) GAS ACCUMULATION INDICATOR ASS'Y c/w 1 CONTACT QUALITROL #038-003-01
10 (1) SAMPLING VALVE ASSEMBLY GAS DETECTOR RELAY QUALITROL #VLV-602-2
11 (1) DEHYDRATING BREATHER MAINTENANCE FREE MESSKO
12 (1) 1/4" PRESSURE-VACUUM GAUGE SHUT OFF S.S. BALL VALVE
13 (8) 3/4" RADIATORS DRAIN S.S. BALL VALVE c/w PLUG
14 (1) 2" DRAIN S.S. BALL VALVE c/w 3/8" SAMPLER
15 (1) 2" CONSERVATOR SHUT OFF S.S. BALL VALVE c/w PLUG
16 (1) 2" CONSERVATOR DRAIN S.S. BALL VALVE c/w PLUG
17 (2) 2" S.S. GLOBE VALVE PROVISION FOR SERVERON MOISTURE MONITORING EQUIPMENT c/w PLUGS
18 (1) 2" CONSERVATOR TOP FILTER PRESS CONNECTION, CAPPED S.S.
19 (8) COOLING RADIATORS DETACHABLE
20 (16) COOLING RADIATORS SHUT OFF VALVES
21 (1) CT LEAD TERMINATING BOX
22 (1) CORE GROUND TERMINATING BOX
23 (1) TAP CHANGER HANDLE 46 KV, 250 KV BIL, 400 A c/w PADLOCKING PROVISION QUALITY SWITCH #1L0402505BD3-WLT-01
24 (8) FANS 120 V 1 PH 1/6 HP
25 (1) CONTROL BOX STAINLESS STEEL NEMA 4x (36" x 30" x 12") c/w REMOVABLE ALUMINUM BOTTOM PLATE & 2 BREATHERS
26 (1) RATING PLATE STAINLESS STEEL SEE DWG 2539-020C
27 (1) PORTABLE FALL-ARREST WELD-ON PLATE MODEL 8517412
28 (8) TRANSFORMER LIFTING LUGS
29 (4) JACK STEPS
30 (1) BOLTED COVER
31 (4) COVER LIFTING LUGS
32 (2) HANDHOLES c/w BOLTED COVERS
33 (7) COPPER FACED GROUND PADS c/w 1/2" UNC TAPPED HOLES @ 1-3/4" CTRS.
34 (1) CONSERVATOR c/w REMOVABLE END PLATE AND BLADDER
34 (1) CONSERVATOR LIFTING LUGS

Height for Calculation & Modeling:
120.8125 inches =3.07 m




| APPROXIMATE WEIGHT | LB | KG |
|---|---|---|
| CORE & COILS | 40496 | 18369 |
| TANK & FITTINGS | 17818 | 8082 |
| VOLTESSO N36 1997 GALS. 9078 L. | 17174 | 7790 |
| TOTAL | 75488 | 34241 |

| SHIPPING WEIGHTS | LB | KG |
|---|---|---|
| PARTS REMOVED | 2402 | 1090 |
| ASSEMBLED UNIT | 73086 | 33151 |
| TOTAL | 75488 | 34241 |

PARTS REMOVED FOR SHIPPING
CONSERVATOR & 113 GALS,
HV/LV BUSHINGS

TANK INSIDE SIZE L 107" X W 49" X H 112"
ALL GASKETS REQUIRE GASKET STOPS
FINISH EXTERIOR NOTE #1
TRANSFORMER COVER c/w SLIP RESISTANT PAINT
GASKET STOPS ON OUTER EDGE
SLOPPED COVER

NOTE:
1) PLEASE ADVISE FINISH COLOR

| REV. | REMARKS | DRAWN BY | APPRO. BY | DATE: |
|---|---|---|---|---|
| | | | | |

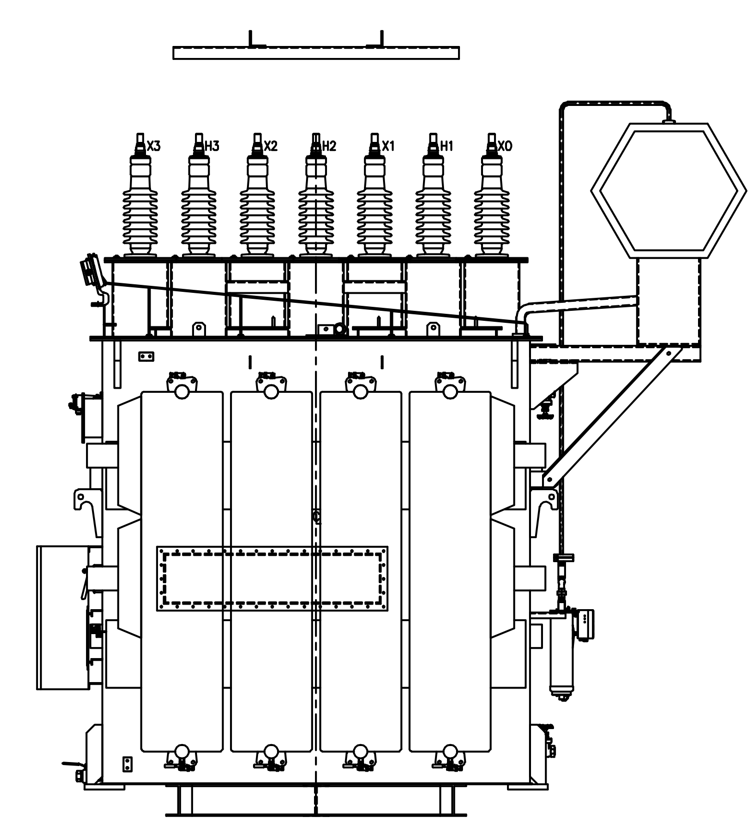
**Northern Transformer**

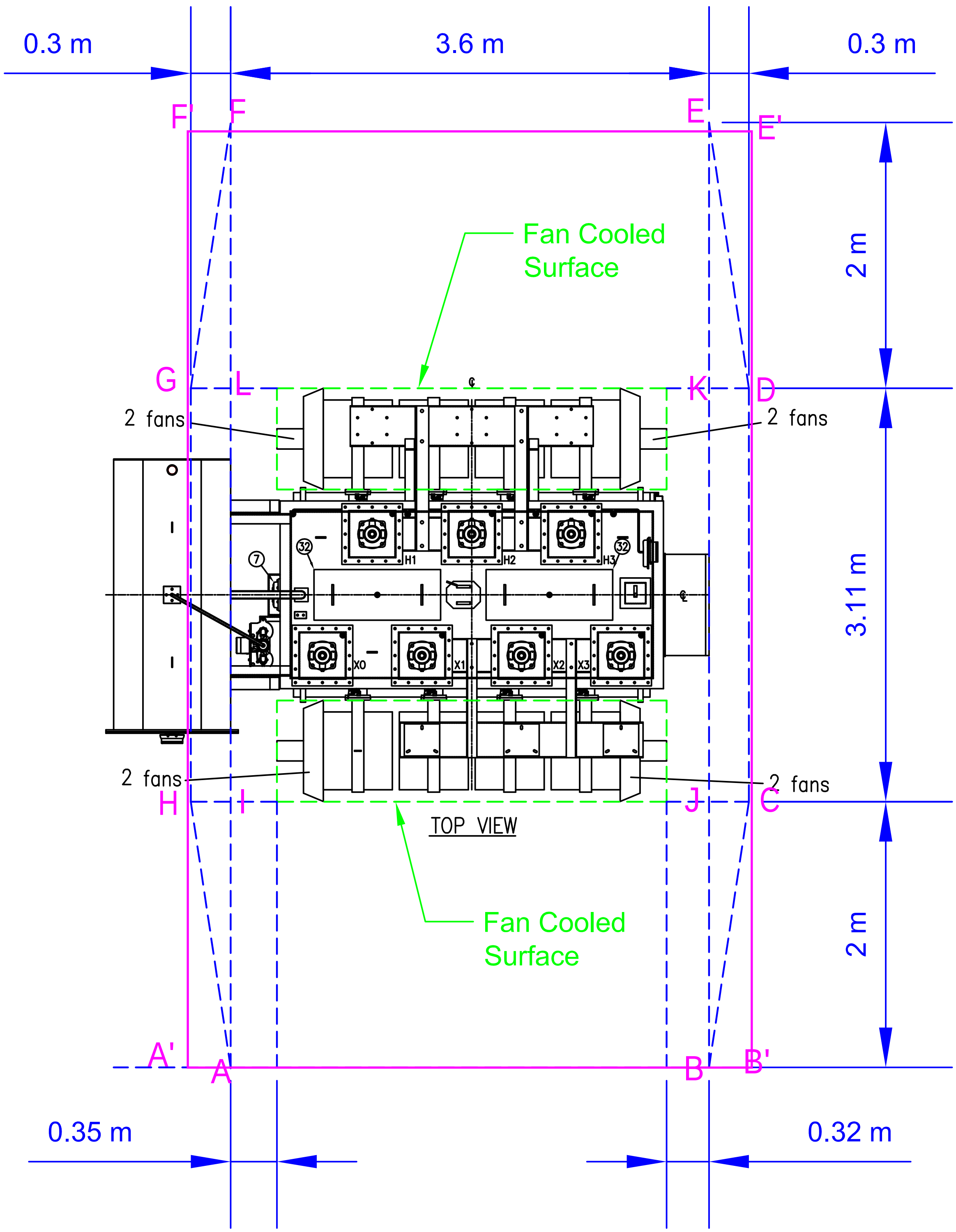
| PLOT 1=18 | DRAWN BY: JOHN PAUL FALZON | DATE: SEP 13/13 | REV. 0 |
|---|---|---|---|
| JOB: | APPROVED BY: | DATE: | S.O. NO. 13-2539 |

TITLE: OUTLINE
15000/20000/25000 KVA LIQUID FILLED TRANSFORMER ONAN/ONAF/ONAF
44000-34500Y/19919 V 3 PH 60 HZ 65°C

NEXTERA
PROJECT: EAST DURHAM WIND FARM

DRAWING NO. 2539-010D




0.3 m
3.6 m
0.3 m
F'
F
E
E'
Fan Cooled Surface
2 m
G
L
K
D
2 fans
2 fans
H1
H2
H3
X0
X1
X2
X3
3.11 m
2 fans
2 fans
H
I
J
C
TOP VIEW
Fan Cooled Surface
2 m
A'
A
B
B'
0.35 m
0.32 m

Noise Level at page 4 of page 5

NORTHERN TRANSFORMER

## INSPECTION & TEST PLAN

## COVER PAGE

| | |
|---|---|
| TO: | NextEra Energy Canada |
| ATT: | Jennifer Herron |
| FROM: | Tom Wang P.Eng |
| SERIAL NUMBER: | 13-2539 |

## CONTENTS

NORTHERN TRANSFORMER

# INSPECTION & TEST PLAN

# DESCRIPTION

| | |
|---|---|
| CUSTOMER : | NextEra Energy Canada |
| CUSTOMER ORDER NO : | 2000106008 |
| SPECIFICATION NO. : | 44-34.5 kV 15/20/25 MVA GENERATOR STEP-UP TRANSFORMER FOR EAST DURHAM CS |
| NORTHERN TRANSFORMER SO NO. : | 13-2539 |
| TAG: | TBD |
| PREPARED BY : | Tom Wang |
| ISSUE DATE : | August 22, 2013 |
| CUSTOMER APPROVAL : | |
| APPROVAL DATE : | |
| REVISION DATE : | |

NORTHERN TRANSFORMER

# INSPECTION & TEST PLAN

## INPROCESS & FINAL INSPECTION

| INSPECTION NUMBER | MANUFACTURING STAGE | APPLICABLE |
|---|---|---|
| I.P. 1 | CORE STACKING | X |
| I.P. 2 | COIL WINDING | X |
| I.P. 3 | COIL CLAMPING & BAKING | X |
| I.P. 4 | CORE & COIL ASSEMBLY | X |
| I.P. 5 | PRETANKING INSPECTION | X |
| I.P. 6 | INTANK INSPECTION | X |
| I.P. 7 | FINAL INSPECTION | X |

NORTHERN TRANSFORMER

# INSPECTION & TEST PLAN

# TEST PLAN

| SERIAL NO. | KVA | HV | LV |
|---|---|---|---|
| 13-2539 | 15000/20000/25000 | 44000 | 34500 |

| Description of test | **Req.** | **Performed** | |
|---|---|---|---|
| CORE INSULATION MEGGER | X | | |
| INSULATION POWER FACTOR CAPPACITANCE & MEGGER ALL TERMINALS | X | | |
| RATIO & POLARITY | X | | ALL TAPS 1 TO 5 |
| RESISTANCE | X | | LV & HV ALL TAPS |
| CORE LOSS & EXCITATION CURRENT @ 100% & 110% RATED VOLTAGE | X | | 12000 Watts @ 100% rated voltage |
| LOAD LOSSES and IMPEDANCE | X | | TAPS 1 to 5, 64000 Watts & 7.5% @ Tap 3 |
| ENERGIZE TRANSFORMER FOR 12 HOUR | X | | @ 110% OF RATED VOLTAGE |
| OIL | X | | ASTM D-3612 DGA Before HEAT RUN<br>DGA After HEAT RUN |
| HEAT RUN | X | | 15MVA ONAN, 25MVA ONAF@ TAP 5 |
| PRESSURE TESTS | X | | |
| INSULATION OF AUXILIARY | X | | |
| DEVICE/WIRING | X | | |
| GAS DETECTION SYSTEM TEST | | | |
| AUXILIARY DEVICE LOSS | X | | |
| SOUND LEVEL | X | | ONAN & ONAF, MAX. 73dBA |
| TESTING AT GE – STONEY CREEK | | | |
| | | | |
| CORE LOSS BEFORE IMPULSE | X | | |
| IMPULSE TEST HV LINE TERMINALS H1- H2- H3 | X | | 250 kV one RFW, and two FW |
| IMPULSE TEST LV LINE TERMINALS X1- X2- X3 | X | | 200 kV one RFW, and two FW |
| IMPULSE TEST LV NEUTRALTERMINAL X0 | X | | 200 kV one RFW and two FW |
| APPLIED POTENTIAL – HV | X | | 95 kV for one (1) minute |
| APPLIED POTENTIAL – LV | X | | 70 kV for one (1) minute |
| INDUCED POTENTIAL | X | | 2 times rated voltage for 7200 cycles |

NORTHERN TRANSFORMER

## INSPECTION & TEST PLAN

| | | | |
|---|---|---|---|
| PARTIAL DISCHARGE | X | | PD & RIV 1.5 times rated voltage for one |
| | | | hour |
| CORE LOSS AFTER IMPULSE | X | | |
| OIL | X | | ASTMD-3612 DGA After Dielectric Tests |
| OIL AFTER ALL TESTS | X | | D-1533B Moisture<br>D-971 Interfacial Tension<br>D-974 Acidity<br>D-1500 Colour<br>D-1524 Visual / Sediment<br>D-1298 Specific Gravity<br>D-877 Dielectric<br>PCB |
| SFRA with DOBLE M5400 | X | | Fully assembled and shipping conditions |
| VISUAL INSPECTION PRIOR TO LOADING | X | | |

Notes:

1. Current transformer tests reports from CT supplier
2. Test as per: C 88 – M90, ANSI/IEEE C57.12.90 and Technical Specification

Approved by: ______________________________ Date: ______________

## REVISION LOG

| REVISION # | REVISION DATE | PAGE # | REASON FOR REVISION |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

Reference 1

# 86

# SOUND POWER LEVEL PREDICTIONS FOR INDUSTRIAL MACHINERY

ROBERT D. BRUCE AND CHARLES T. MORITZ

## 1 INTRODUCTION

Procedures for calculating the sound power level or sound pressure level of industrial machinery, such as boilers, fans, motors, pumps, and turbines, are presented in this chapter. These procedures can be used for modeling the sound levels in a space or for developing purchase specifications for new eqnipment. With any project, acoustical data for individual equipment, specifically sound pressure or sound intensity measurements and sound power level calculations in accordance with recognized standards, should be obtained. Many manufacturers provide the estimated sound power level or the measured sound pressure level at 1 m from their equipment as well as offer special low-noise options. If information from the manufacturer is unavailable, efforts should he made to measure a similar unit in operation at an installation. If this is not possible or if an estimate for a preliminary study is required, then the material in this chapter can be used. The equations presented are either entirely based on measured data or are semiempirical and tend to be conservative, usually predicting higher sound levels than are measured in the field. For some equipment, a large database has not yet been established so estimates of the sound power level for similar equipment are presented.

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*Encyclopedia of Acoustics*, edited by Malcolm J. Crocker
ISBN 0-471-80465-7 © 1997 John Wiley & Sons, Inc.

## 2 POWER SOURCES

### 2.1 Boilers[1]

***Main Steam Boilers*** The sound power level for main steam boilers (between 125 and 800 MWe) can be calculated using the equation

$$L_w = 84 + 15 \log \text{ MWe}, \qquad (1)$$

where $L_w$ is the overall sound power level and MWe is the electrical generating rating of the unit.

The octave baud sound power levels can be obtained by subtracting the values shown in Table 1.

***Auxiliary Boilers*** The noise produced by auxiliary boilers is often due primarily to the blower and the burner and not the walls of the boiler. An estimate of the sound power level for auxiliary boilers between 50 and 2000 boiler horsepower (bhp) can be calculated using the equation

$$L_w = 95 + 4 \log \text{bhp}, \qquad (2)$$

where 1 bhp = 15 kg steam/h. The octave band sound power levels can be obtained by subtracting the values showu in Table 1.

### 2.2 Electric Motors

***Motors under 750 kW[2]*** For totally enclosed fan-cooled (TEFC) motors, the sound power level can be cal-

**TABLE 1 Octave Band and A-Weighted Sound Power Level Adjustments**

| Source | 31.5 | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 | A |
|---|---|---|---|---|---|---|---|---|---|---|
| Main steam boiler | 4 | 5 | 10 | 16 | 17 | 19 | 21 | 21 | 21 | 12 |
| Auxiliary boiler | 6 | 6 | 7 | 9 | 12 | 15 | 18 | 21 | 24 | 9 |
| TEFC motors nnder 750 kW | 14 | 14 | 11 | 9 | 6 | 6 | 7 | 12 | 20 | 1 |
| Drip-proof motors under 750 kW | 9 | 9 | 7 | 7 | 6 | 9 | 12 | 18 | 27 | 4 |
| Gas turbine casing | 10 | 7 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 2 |
| Gas turbine exhaust | 12 | 8 | 6 | 6 | 7 | 9 | 11 | 15 | 21 | 4 |
| Gas turbine intake | 19 | 18 | 17 | 17 | 14 | 8 | 3 | 3 | 6 | 0 |
| Reciprocating engines (<600 rpm) | 12 | 12 | 6 | 5 | 7 | 9 | 12 | 18 | 28 | 4 |
| Reciprocating engines (600–1500 rpm) | 14 | 9 | 7 | 8 | 7 | 7 | 9 | 13 | 19 | 3 |
| Reciprocating einges (600–1500 rpm with blower) | 22 | 16 | 18 | 14 | 3 | 4 | 10 | 15 | 26 | 1 |
| Reciprocating engines (>1500 rpm) | 22 | 14 | 7 | 7 | 8 | 6 | 7 | 13 | 20 | 2 |
| Reciprocating engine air inlet (turbocharged) | 4 | 11 | 13 | 13 | 12 | 9 | 8 | 9 | 17 | 3 |
| Reciprocating engine exhaust | 5 | 9 | 3 | 7 | 15 | 19 | 25 | 35 | 43 | 12 |
| Steam turbines | 11 | 7 | 6 | 9 | 10 | 10 | 12 | 13 | 17 | 5 |
| Steam turbine generator units | 9 | 3 | 5 | 10 | 14 | 18 | 21 | 29 | 35 | 12 |
| Transformers | −3 | 3 | 5 | 0 | 0 | −6 | −11 | −16 | −23 | 0 |
| Centrifugal compressor casing | 10 | 10 | 11 | 13 | 13 | 11 | 7 | 8 | 12 | 2 |
| Centrifugal compressor air inlet | 18 | 16 | 14 | 10 | 8 | 6 | 5 | 10 | 16 | 0 |
| Rotary and reciprocating air compressors | 11 | 15 | 10 | 11 | 13 | 10 | 5 | 8 | 15 | 2 |
| Feed pumps (1000–9000 kW) | 11 | 5 | 7 | 8 | 9 | 10 | 11 | 12 | 16 | 4 |
| Feed pumps (9500–18,000 kW) | 19 | 13 | 15 | 11 | 5 | 5 | 7 | 19 | 23 | 1 |
| Centrifugal fan | 11 | 9 | 7 | 8 | 9 | 9 | 13 | 17 | 24 | [a] |
| Centrifugal fan casing | 3 | 6 | 7 | 11 | 16 | 18 | 22 | 26 | 33 | [a] |
| Gas recirculation fan casing | 10 | 7 | 4 | 7 | 18 | 20 | 25 | 27 | 31 | 12 |
| Axial-flow fan | 11 | 10 | 9 | 8 | 8 | 8 | 10 | 14 | 15 | 3 |
| Generators | 11 | 8 | 7 | 7 | 7 | 9 | 11 | 14 | 19 | 4 |
| Motor-driven pumps | 13 | 12 | 11 | 9 | 9 | 6 | 9 | 13 | 19 | 2 |
| Mechanical-draft cooling towers (full speed) | 9 | 6 | 6 | 9 | 12 | 16 | 19 | 22 | 30 | 10 |
| Mechanical-draft cooling towers (half speed) | 9 | 6 | 6 | 10 | 10 | 11 | 11 | 14 | 20 | 5 |
| Chiller with reciprocating compressor | — | 19 | 11 | 7 | 1 | 4 | 9 | 14 | — | 0 |
| Chiller with rotary-screw compressor | 25 | 19 | 15 | 3 | 6 | 10 | 15 | 20 | 22 | 5 |
| Centrifugal chillers, internal geared | — | 8 | 5 | 6 | 7 | 8 | 5 | 8 | — | 0 |
| Centrifugal chillers, direct drive | — | 8 | 6 | 7 | 3 | 4 | 7 | 12 | — | 0 |
| Centrifugal chillers, >1000 tons | — | 11 | 11 | 8 | 8 | 4 | 6 | 13 | — | 0 |
| Diesel powered, mobile equipment | — | 11 | 6 | 3 | 8 | 10 | 13 | 19 | 25 | 5 |

[a] Dependent on blade passage frequency.

culated using the following equations:

$$L_w = 17 + 17 \log \text{kW} + 15 \log \text{rpm} + 10 \log A \quad (\text{under } 40 \text{ kW}), \tag{3}$$

$$L_w = 28 + 10 \log \text{kW} + 15 \log \text{rpm} + 10 \log A \quad (\text{over } 40 \text{ kW}), \tag{4}$$

where kW is the nameplate motor rating, rpm is the speed at which the motor is operating, and $A$ is the conformal surface area (in square metres) at 1 m from the motor. For TEFC motors between 300 and 750 kW, use the value 300 kW in Eq. (4).

The octave band sound power levels can be obtained by subtracting the values shown in Table 1.

For drip-proof motors, the sound power level can be calculated using the following equations:

$$L_w = 12 + 17 \log \text{kW} + 15 \log \text{rpm} + 10 \log A \quad (\text{under } 40 \text{ kW}), \tag{5}$$

$$L_w = 23 + 10 \log \text{kW} + 15 \log \text{rpm} + 10 \log A \quad (\text{over } 40 \text{ kW}). \tag{6}$$

For drip-proof motors between 300 and 750 kW, use the value 300 kW in Eq. (6).

The octave band sound power levels can be obtained by subtracting the values shown in Table 1.

**TABLE 3 Sound Power Level Correction Terms for Casing Noise of Reciprocating Engines**

| Correction Term | Correction Type | Qualifying Condition | dB |
|---|---|---|---|
| *A* | Speed | Less than 600 rpm | −5 |
| | | 600–1500 rpm | −2 |
| | | Over 1500 rpm | 0 |
| *B* | Fnel | Diesel only | 0 |
| | | Diesel and/or natural gas | 0 |
| | | Natural gas only (with small amonnt of "pilot oil") | −3 |
| *C* | Cylinder arrangement | In-line | 0 |
| | | V-type | −1 |
| | | Radial | −1 |
| *D* | Air intake | Unducted air inlet to nnmuffled Roots blower | +3 |
| | | Dncted air from outside the engine compartment enclosnre | 0 |
| | | Ducted air to muffled Roots blower | 0 |
| | | All other types of inlets (with or without a turbocharger) | 0 |

measured in accordance with a recognized standard. The overall sound power level for steam turbines can be estimated using the expression

$$L_w = 93 + 4 \log \text{kW}. \qquad (13)$$

The octave band sound power levels can be obtained by subtracting the values shown in Table 1.

## 2.6 Steam Turbine–Generator Units[1]

The sound power level for main steam turbine–generator units (between 200 and 1100 MWe) can be calculated using the equation

$$L_w = 113 + 4 \log \text{MWe}, \qquad (14)$$

The octave band sound power levels can be obtained by subtracting the values shown in Table 1. Equation (14) takes into account sound contributions from the high- and low-pressure turbines, generators, and shaft-driven exciters. Noisy couplings and steam control valves can cause higher sound power levels than those predicted with this equation.

## 2.7 Transformers[1]

Noise from the body of the transformer is made up of tones at the even harmonics of the line frequency (120, 240, 360, 480, ... Hz) with the 120-Hz tone being the dominant sound at normal receiving distances. When additional cooling of the transformer is needed, noise from the cooling fans can become the dominant noise source. Lower fan speeds and optimal blade shapes have helped make newer fans much quieter, which is particularly helpful in noise-sensitive applications.

The National Electrical Manufacturers Association (NEMA) sound pressure level rating is the A-weighted sound pressure level one foot from the transformer and can be estimated from the following formulas:

$$\text{NEMA sound rating} = 55 + 12 \log \text{MV(A)} \quad \text{for a standard transformer,} \qquad (15)$$

$$\text{NEMA sound rating} = 45 + 12 \log \text{MV(A)} \quad \text{for a quieted transformer.} \qquad (16)$$

These equations are valid for transformers between 20 and 450 MV(A). The A-weighted sound power level can be calculated using the formula

$$L_w = \text{NEMA sound rating} + 10 \log S, \qquad (17)$$

where $L_w$ is the A-weighted sound power level and $S$ is the surface area of the four side walls in square metres.

The term $10 \log S$ may be estimated from the MV(A) rating by using the formula

$$10 \log S = 14 + 2.5 \log \text{MV(A)}. \qquad (18)$$

Octave band sound power and pressure levels can be obtained by *adding* the appropriate octave band correction factors shown in Table 1.

## 3 DRIVEN EQUIPMENT

### 3.1 Air Compressors

***Centrifugal Compressors*[3]** The sound power level radiated from the casing or discharge piping for large centrifugal compressors can be calculated using the equation

$$L_w = 3 + 20\log \text{kW} + 50\log U - 17\log(mf), \qquad (19)$$

where $U$ is impeller tip speed in metres per second ($30 < U < 230$), $m$ is the surface weight of the casing or pipe wall in kilograms per square metre, and $f$ is the octave band center frequency.

The frequency of the maximum sound power is given as

$$f_p = 4.1U. \qquad (20)$$

For the octave band containing $f_p$, the sound power level is the value from Eq. (19) minus 4.5 dB. The adjacent octave bands above and below $f_p$ should roll off at a rate of 3 dB/octave.

***Reciprocating Compressors*[3]** The octave band sound power levels radiated from the casing or discharge piping for large reciprocatiug compressors can be calculated using the equation

$$L_w = 154.5 + 10\log \text{kW} - 17\log(mf), \qquad (21)$$

where kW is the power of the driver motor, $m$ is the surface weight of the casing or pipe wall in kilograms per square metre, and $f$ is the octave band center frequency.

This equation assumes that the sound power is radiated from 15 m of discharge piping. To determine the octave band levels, first calculate the fundamental frequency [$f_p = B$ (rpm)/60, where $B$ is the number of cylinders]. For the octave band containing $f_p$, the sound power level is the value from the equation minus 4.5 dB. The adjacent octave bands above and below $f_p$ should roll off at a rate of 3 dB/octave.

If only the rated power of the compressor is known, the following may be used to calculate the sound power level of centrifugal, rotary, and reciprocating compressors.

***Centrifugal Air Compressors*[1]** The sound power level for the casing noise of centrifugal compressors between 1100 and 3700 kW can be calculated using the equation

$$L_w = 79 + 10\log \text{kW}, \qquad (22)$$

where $L_w$ is the overall sound power level of the casing and kW is the rated power of the compressor. The octave band sound power levels can be obtained by subtracting the values shown in Table 1.

The sound power level for the unmuffled air inlet of centrifugal compressors can be calculated using the equation

$$L_w = 80 + 10\log \text{kW}. \qquad (23)$$

The octave band sound power levels can be obtained by subtracting the values shown in Table 1.

***Rotary and Reciprocating Air Compressors*[1]** The sound power level for rotary and reciprocating air compressors, including partially muffled air inlets, can be calculated using the equation

$$L_w = 90 + 10\log \text{kW} \qquad (24)$$

where kW is the rated power of the compressor. The octave band sound power levels can be obtained by subtracting the values shown in Table 1.

### 3.2 Boiler and Reactor Feed Pumps[1]

The sound power level for large boiler and reactor feed pumps driven by either motors or steam turbines can be estimated by using Table 4.

The larger pumps, which are generally driven by steam turbines, have high tonal noise components that increase the noise levels by several decibels in the

**TABLE 4 Sound Power Levels of Boiler and Reactor Feed Pumps**

| Pump Power Rating (kW) | Sound Power Level | |
|---|---|---|
| | Linear | A-Weighted |
| 1,000 | 108 | 104 |
| 2,000 | 110 | 106 |
| 4,000 | 112 | 108 |
| 6,000 | 113 | 109 |
| 9,000 | 115 | 111 |
| 9,500 | 113 | 112 |
| 12,000 | 115 | 114 |
| 15,000 | 119 | 118 |
| 18,000 | 123 | 122 |