

TUGE Energia OÜ

DURATION TEST

REPORT

SCOPE OF WORK

Duration Test Report for the TUGE10 turbine tested at the Intertek SEMKO Small Wind test site / foundation 2 / Lilla Båtskär ÅLAND

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DURATION TEST REPORT

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Subject: Duration Test Report for the TUGE10 turbine tested at the Lilla Båtskär / Åland test site.

Dear Mr. Gregor,

This report represents the results of the evaluation and tests of the above referenced equipment to the requirements contained in the following standard:

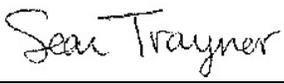
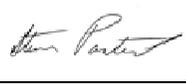
*AWEA 9.1 American Wind Energy Association Small Wind Turbine Performance and Safety Standard
First Edition; December 2009*

*IEC 61400-2 Wind turbines – Part 2: Small wind turbines
Third edition; December 2013*

This investigation was authorized through signed Proposal# Qu-00821511-0, dated 21 September 2017, and is identified within Intertek Sweden as Project No. 1717503, and Intertek US as Project No. G103254243. Duration testing began on February 6, 2018 and data collection completed on December 17, 2018. A detailed post-test inspection was performed on January 22nd and 23rd, 2019.

This Test Report completes the Duration testing phase of the TUGE10 wind turbine covered under Intertek Project No. G103254243.

If there are any questions regarding the results contained in this report, or any of the other services offered by Intertek, please do not hesitate to contact your dedicated Intertek Project Manager.

Completed by:	Sean Traynor	Reviewed by:	Steven Pasternack
Title:	Project Engineer	Title:	Senior Staff Engineer
Signature:		Signature:	
Date:	5/17/2019	Date:	5/17/2019

Please note: this Test Report on its own does not represent authorization for the use of any Intertek certification marks.

DURATION TEST REPORT

**Wind Turbine Generator System
Duration Test Report
for the
TUGE10
at
Lilla Båtskär / Åland**



DURATION TEST REPORT

SECTION 1.0 TEST SUMMARY

This test was conducted in accordance with the *American Wind Energy Association Small Wind Turbine Performance and Safety Standard* dated December, 2009. The duration test was also conducted in accordance with the third edition of the *International Electrotechnical Commission's (IEC) 61400-2 Wind turbines – Part 2: Small wind turbines*, dated December, 2013. Hereafter, these testing standards and their procedures are referred to as the “Standards.” For the duration test, and the results contained within this report, the following considerations apply:

- The turbine system is connected to the electrical network at the test site via a subpanel. All wiring and components on the turbine side of this subpanel are considered part of the turbine system.
- The turbine system includes all control equipment including wiring between the up-tower equipment and the equipment located in the data shed. The test configuration consists of:
 - Up-tower turbine assembly – Rotor assembly, nacelle housing, lightning arrestor, system anemometer & vane, nacelle frame with yaw bearing, alternator, rotor shaft brake, yaw motor, yaw brake, alternator cooling fan, and up tower junction box
 - Down-tower assembly – Monopole tower, down tower electrical cabinet (WT controller, inverter, turbine disconnect, grid disconnects), dump loads, and foundation
 - Equipment inside data shed – Intertek subpanel with circuit breakers
 - Meteorological tower, test instrumentation, junction boxes and wiring, and data acquisition
 - Power measurement equipment; installed between the AC output of the inverter and the Intertek subpanel referenced in 1 above

The tower is a steel tube construction, hydraulically raised, and divided into 3 parts. The base is connected to a concrete foundation. The tower height is 18 m. The wire run from the base of the tower to the power measurement equipment in the data shed is an approximate wire run length of 81.5 meters (267.4 feet); which satisfies the required wire run length of greater than 8 rotor diameters, as specified in AWEA 9.1. Table 1 further defines the configuration of the wind turbine system tested for this report and also provides the manufacturers declared ratings and specifications.

The power measurement equipment used for measurement of electric power consists of both a current transformer and power transducer used to measure current and voltage to determine electric power output in accordance with the Standards. The power measurement equipment is connected between the AC output of the grid-tie inverter and the Intertek subpanel. The location of power measurement equipment encompasses the combined consumption and production of the entire turbine system. A typical wiring diagram is shown in the Appendix, which matches the test turbine system installed at the test site.

The database analyzed to produce the results within this report is sufficient to satisfy the hourly test requirements of the Duration Test. No significant wear, corrosion, or degradation of turbine system components of the TUGE10 turbine was found as a result of the detailed post-test inspection. As a result of satisfactory completion of the duration test and post-test inspection, the TUGE10 turbine has met the criteria for reliable operation that is a requirement of the Duration Test. Therefore, the TUGE10 turbine has successfully completed all requirements for the Duration Test. Additional supporting detail can be found within this report. Hourly power production data can be found in Section 9 of this report.

DURATION TEST REPORT

Turbine Manufacturer	TUGE Energia OÜ
Model	TUGE10
Rotor Diameter	10.2 m
Hub Height	18.5 m
Swept Area	82 m ²
IEC 61400-2 SWT Class	Class I
Rated Electrical Power	9900 Watts
Cut-in Wind Speed	3,5 m/s
Cut-out Wind Speed	25 m/s
Rated Wind Speed	11.0 m/s
Survival Wind Speed	50 m/s
Rated Rotational Speed	69 RPM
Rotor Speed Range	0-80 RPM
Generator Identification	TUGE Energia OÜ, GEN1069225 (serial number 001)
Inverter Identification	Orbital Grid Feed Inverter GFI-310K
Controller Identification	Orbital TMC3
Number of Blades	3
Fixed or variable pitch	Fixed
Blade Pitch Angle	0° at root
Blade Specification	Fiberglass / polyester, 8.9° twist, 4900mm blade length, 2.29 m ² blade areas, 18 embedded nuts for mounting (10 mm / 8.8 grade), tip brakes
Hub type	Rigid
Slip Ring Identification	N/A
Slip Ring Specification	N/A
Brake/Furl System Components and Identification	Rotor Brake: Intorq GmbH, BFK455-28

Table 1 - Manufacturer Turbine Specifications

DURATION TEST REPORT

SECTION 2.0

BACKGROUND

The TUGE10 turbine is designed for grid-connected power delivery, with a rated power output of 9.9 kW. It is a horizontal-axis wind turbine that is specified as SWT Class I according to IEC 61400-2. The turbine's control system uses an active yaw mechanism. The TUGE10 turbine utilizes a three-phase AC permanent magnet synchronous generator. Grid interconnect is provided by an Orbital control Power System, GFI-310K together with TMC3 controller. The tower is a steel tube construction hydraulically raised divided into 3 parts & base connected to a concrete foundation. The tower height is 18 m.

The TUGE10 turbine is installed at test foundation 2 on Lilla Båtskär at the Intertek SEMKO Small Wind test site on Åland, Finland.

SECTION 3.0

TEST OBJECTIVE

The purpose of the duration test was to validate the operational abilities of the TUGE10 turbine shown on page 3 and described in detail in Table 1. This is achieved through monitoring "reliable operation" of the turbine over a period of at least 6 months. Factors such as structural integrity, material degradation, quality of protection of the wind turbine, and dynamic behavior of the wind turbine help determine if the product operates as designed by the manufacturer.

SECTION 4.0

JUDGMENTS, EXCEPTIONS, AND DEVIATIONS

As shown in Appendix F, noticeable wear was identified on the turnbuckles employed in the hub to tension the tip brake shaft of the blades. This wear was due to overlapping turnbuckles making contact and rubbing against each other during the operation of the turbine when the tip brakes were employed. This degradation is not considered significant as the complete failure of these component would activate the tip brakes of the blades, thus the wind turbine would be in a safe state. Furthermore, the wind turbine maintenance instructions require a complete inspection every two years, during which a degraded turnbuckle can be identified and replaced.

SECTION 5.0

TEST SITE DESCRIPTION

The test site has class I winds, and can accommodate turbines that produce 240V/400V, 50 Hz power. It is on an island in the edge of the archipelago of Åland Island, with previous use for the Coastal Pilots, near the township of Mariehamn. It was surveyed, analyzed and developed to be a test site for Intertek's customers. The TUGE10 turbine was tested at station 2, which has no prominent obstructions in the valid measurement sector, resulting from obstacle assessment in accordance with the Standards.

The meteorological equipment tower is due west, 20.4 m (66.9 ft) from the turbine, approximately 2.00 times the diameter of the rotor, and is within the required range of 2 – 4 rotor diameters as defined in the Standards.

DURATION TEST REPORT

Figure 1 below is an aerial image that displays the final valid measurement sector resulting from the combination of obstacle assessment and site calibration in accordance with IEC 61400-12-1. A circle indicating 20 rotor diameters is also shown on the map.

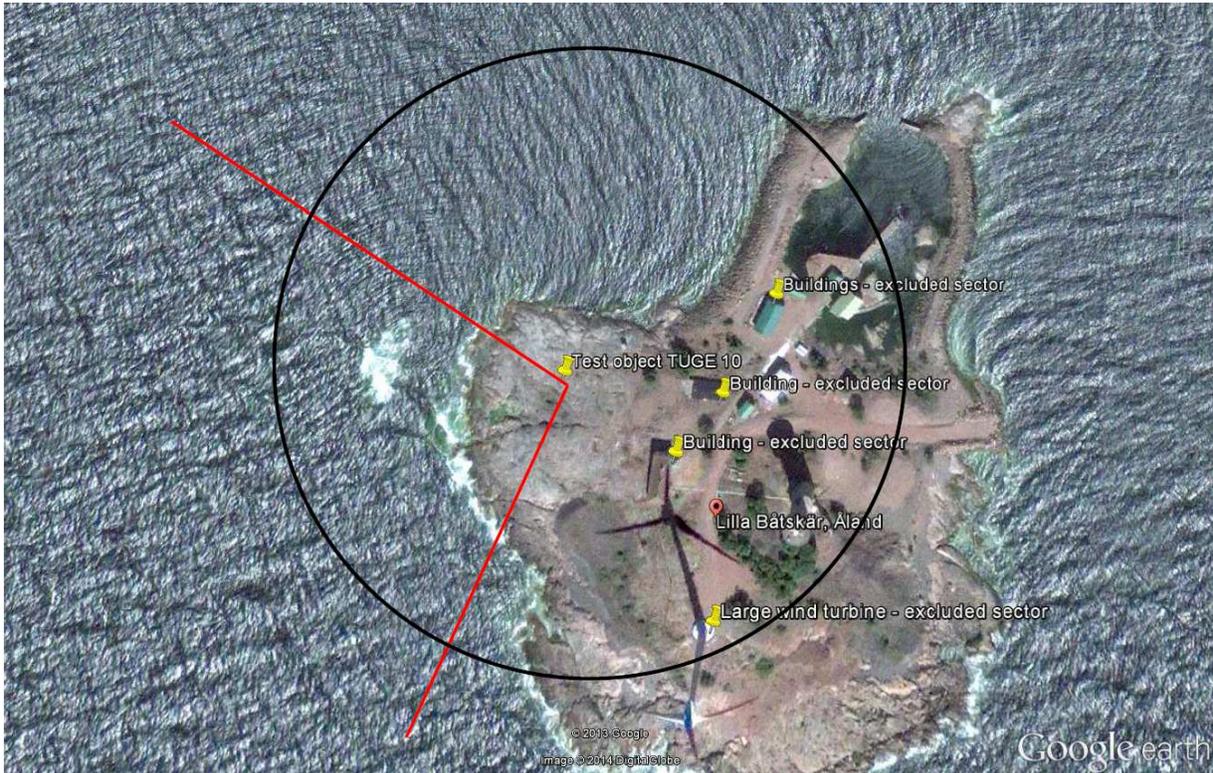


Figure 1 – Aerial view and final valid measurement sector of the TUGE10 test turbine

DURATION TEST REPORT

SECTION 6.0 TEST EQUIPMENT

Table 2 below shows the test equipment utilized during the Duration Test program of the TUGE10. Calibration Certificates can be found in the Appendix.

Measurement	Manufacturer	Model	Serial / Asset	Cal Date	Cal Due
**Site Calibration Anemometer	Thies Clima	4.3351.00.141	01110057 / 9876	07/26/2013	07/26/2013
**Primary Anemometer at site calibration	Thies Clima	4.3351.00.141	01110056 / 9875	07/26/2013	07/26/2014
Primary Anemometer (original)	Thies Clima	4.3351.00.141	01110056 / 9875	11/16/2017	11/30/2018
Secondary Anemometer (original)	Thies Clima	4.3351.00.141	01110057 / 9876	11/16/2017	11/30/2018
Primary Anemometer (replacement)	Thies Clima	4.3351.00.141	01110058 / 9877	11/26/2018	11/30/2019
Secondary Anemometer (replacement)	Thies Clima	4.3351.00.141	01110059 / 9878	11/26/2018	11/30/2019
Wind Vane (original)	Thies Clima	4.3150.00.141	01110055 / 9879	11/16/2017	11/30/2018
Wind Vane (replacement)	Thies Clima	4.3150.00.141	01110056 / 9880	11/26/2018	11/30/2019
Temperature & Humidity Sensor	Thies Clima	1.1005.54.241	93123 / 9882	11/30/2017	11/30/2018
Barometric Pressure Sensor	LUFFT	8355.03	004.1110.0002.P12 .2.1.00 / 9881	11/24/2017	11/30/2018
Power/frequency Transducer*	Ohio Semitronics	DMT-1042E	10121160 / 31731	11/30/2017	11/30/2018
Current Transformers*	Ohio Semitronics	200:5A class 0.3	2222500, 2222503, 2355051 / 31732, 31733, 31734	11/30/2017	11/30/2018
Data Acquisition Module	National Instruments	NI 9203	0x168B64D and 0x156943D	-	-
Loop Calibrator	Fluke	707 LOOP CALIBRATOR	31839	2019-01-08	2020-01-31
*PT/CT calibrated as a system					
**Site calibration performed on a previous project with TUGE at same test location and hub height.					

Table 2 – Test equipment and calibrations

A National Instruments cDAQ-9178 backplane and NI-9203 +/- 20 mA 8-channel current module were used for logging the outputs signals from the sensors in Table 2 above. A proprietary LabVIEW program was used to collect and filter data that is stored in raw and 1 Hz data files on the test site computer.

Prior to testing, signal verification procedures were carried out on the data acquisition system by Intertek to verify the signals of each transducer against recorded values from the LabVIEW program. Results of that verification are given in Table 3 and 3a below. A similar check was performed to verify the continued accuracy of the overall data acquisition system when the sensors were replaced on December 12, 2018, and similarly no significant error was seen and thus no offset was applied.

DURATION TEST REPORT

Applied values (mA)	4	8	12	16	20
Channels					
Wind speed 1 (mA)	3,98-4,03	7,97-8,00	11,96-12,00	15,93-15,99	19,98-20,01
Wind speed 2 (mA)	3,99-4,02	7,99-8,01	11,99-12,01	15,99-16,00	19,97-20,00
Wind direction (mA)	3,98-4,02	7,98-8,01	11,98-12,01	15,98-16,00	19,98-20,00
Current (mA)	3,98-4,02	7,98-8,02	11,97-12,01	15,96-16,00	19,97-20,01
Voltage (mA)	3,97-4,01	7,97-8,01	11,98-12,02	15,97-16,02	19,96-20,00
Frequency (mA)	3,98-4,02	7,98-8,01	11,97-12,01	15,99-16,01	19,96-20,00
Power (mA)	3,97-4,00	7,99-8,03	11,98-12,02	15,98-16,01	19,97-20,01
Temperature (mA)	3,99-4,00	7,99-8,00	11,98-12,01	15,99-16,00	19,97-20,04
Humidity (mA)	3,99-4,00	7,99-8,00	11,98-12,01	15,99-16,00	19,97-20,06
Air pressure (mA)	3,99-4,05	8,0-8,07	11,94-12,01	15,99-16,08	20,00-20,03

Table 3 – Signal verification results

Applied values (mA)	4	8	12	16	20
Channels					
Wind speed 1 (mA)	3,99-4,01	7,94-8,01	11,99-12,02	15,94-16,15	19,99-20,05
Wind speed 2 (mA)	3,99-4,07	7,99-8,01	11,99-12,01	15,94-16,01	19,94-20,15
Wind direction (mA)	3,99-4,01	7,98-8,01	11,98-12,02	15,96-16,00	19,96-20,10
Current (mA)	3,98-4,07	7,98-8,05	11,98-12,09	15,98-16,13	19,90-20,14
Voltage (mA)	3,99-4,13	7,96-8,09	11,89-12,14	15,99-16,16	19,99-20,11
Frequency (mA)	3,99-4,16	7,99-8,14	11,97-12,13	15,99-16,12	19,90-20,11
Power (mA)	3,93-4,16	7,99-8,14	11,88-12,05	15,90-16,11	19,88-20,08
Temperature (mA)	4,06-4,24	8,20-8,23	12,20-12,23	16,17-16,20	20,15-20,20
Humidity (mA)	4,22-4,26	8,21-8,23	12,20-12,22	16,17-16,20	20,16-20,17
Air pressure (mA)	4,11-4,13	8,10-8,12	12,08-12,10	16,06-16,08	20,05-20,06

Table 3a – Post-test signal verification results

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The data acquisition system is located inside the test data shed. All signals are measured at this location. The data is stored on two separate computers at the Intertek RTC, and also stored in the Intertek project file. The power measurement equipment is located inside the control building at an approximate wire run length of 81.5 meters (267.4 feet); which satisfies the required wire run length of greater than 8 rotor diameters, as specified in AWEA 9.1.

Figure 2 below displays the arrangement of the meteorological tower with dimensions of instrument locations.

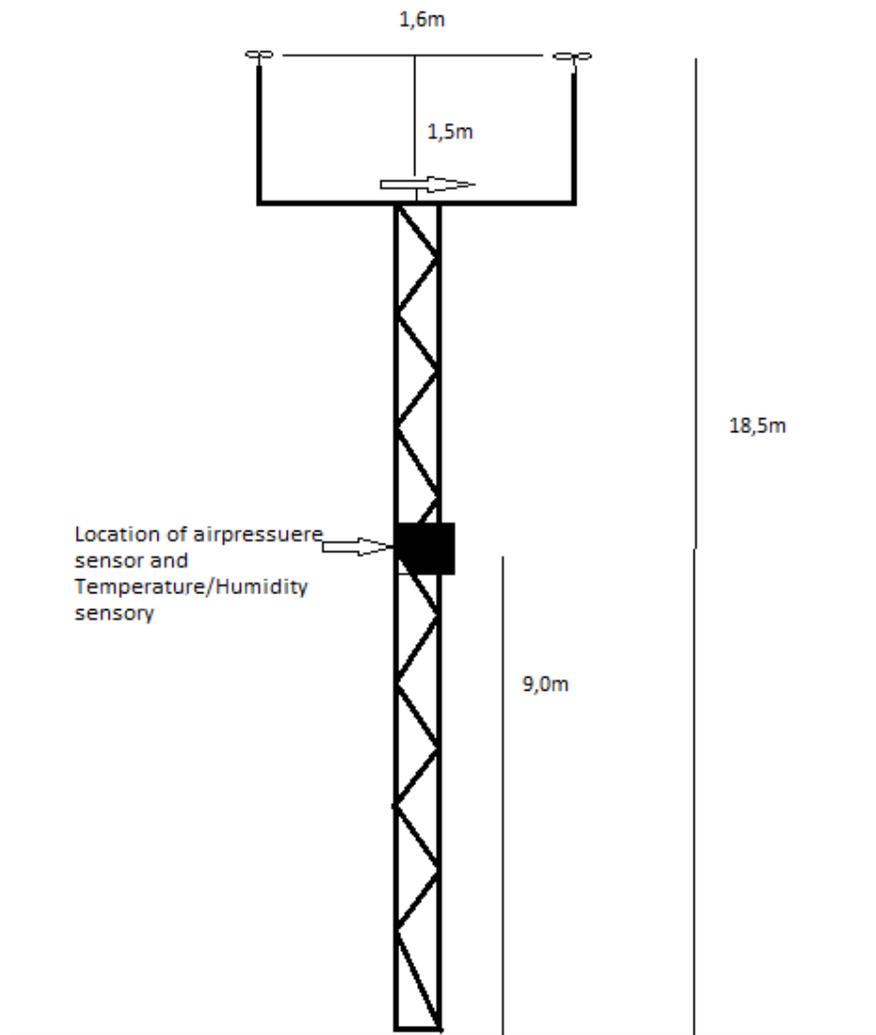


Figure 2 – Meteorological Equipment Tower

The anemometers were calibrated prior to and after the testing was completed. The calibration results were compared and indicated regression lines were within $\pm 0,1$ m/s.

DURATION TEST REPORT

SECTION 7.0 TEST PROCEDURE

7.1 TEST REQUIREMENTS

According to the Standard, the turbine will pass the duration test when it has achieved:

- *Reliable operation* during the test period
- 6 months of operation
- 2500 hours of power production in winds of any velocity
- 250 hours of power production in winds of 1.2 Vave (12 m/s for Class I) and above
- 25 hours of power production in winds of 1.8 Vave (18 m/s for Class I) and above
- 10 minutes in winds of 2.2 Vave (22 m/s for Class I) and above, during which the turbine shall be in normal operation

Additional guidance is given in IEC 61400-2, clause 13.4.1 regarding hours of power production. *Reliable operation* is defined as:

- Operational time fraction of at least 90%
- No major failure of the turbine or components in the turbine system
- No significant wear, corrosion, or damage to the turbine components
- No significant degradation of produced power at comparable wind speeds

7.2 DATA COLLECTION

Measurement procedures and data collection were conducted in accordance with the Standards. Data was sampled at a rate of 1 Hz. The period for all average, maximum, minimum, and standard deviation values was 10 minutes, as required by the Standards. No turbine status signal is provided by the turbine controller; therefore, one was not monitored during this test.

The definition of “hours of power production” is taken from IEC 61400-2 Edition 3 for the purposes of the results in this report, meaning that a 10-minute dataset was counted towards hours of power production if the 10-minute average was positive. No uncertainty was added or considered for the hours of power production calculation as a result of this.

Meteorological data and the turbine output power signals were gathered by the NI 9203 module and stored in daily spreadsheet files on the test computer. The spreadsheet files are filtered using proprietary where all analysis according to the Standards took place.

SECTION 8.0 UNCERTAINTY

The uncertainty of the following items is estimated in this section:

- Hours of power production
- Operational time fraction
- Highest instantaneous wind speed

DURATION TEST REPORT

8.1 HOURS OF POWER PRODUCTION

For the hours of power production in winds above 12 m/s and 18 m/s the uncertainty in the measured wind speed is the primary factor of uncertainty. Assuming a 0.18 and 0.26 m/s uncertainty in wind speed, respectively, the hours of power production reduce to 421.17 hours (above 12 m/s) and 27.33 hours (above 18 m/s). Both of these values are above the minimum number of hours required of 250 and 25 for winds above 12 m/s and winds above 18 m/s, respectively

8.2 OPERATIONAL TIME FRACTION

The total test time is 7543 hours. Assuming that the classification of time during which the turbine is known to be non-operational (TN) is incorrect by a very conservative assumption of 10%, the operational time fraction would still be greater than 93%.

8.3 HIGHEST INSTANTANEOUS WIND SPEED

The uncertainty in the wind speed measurement is based on 0.051 m/s calibration uncertainty, 0.0866 m/s + 0.866 % operational uncertainty, 0.0506 m/s uncertainty due to terrain (resulting max from site calibration), 1% uncertainty due to mounting, and 0.18% uncertainty in the data acquisition. For the maximum instantaneous wind gust of 25.639 m/s, the uncertainty is ± 0.35 m/s.

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SECTION 9.0 TEST RESULTS

9.1 OPERATIONAL TIME

The test turbine system was installed on November 27th, 2017. The system was commissioned and ready for testing on February 6th, 2018. The duration test started on February 6th, 2018 and was completed on December 17th, 2018, after sufficient data was collected to satisfy the hourly test requirements. The test covered a period of 314.5 days. During the test there two repairs were performed on the turbine, which paused the turbine operation:

- Change of the turbine anemometer after 6 month of production due to loss of two cups. This was material failure and did not impair the turbine function.
- Change one of the main bearing after 9 month. The manufacture of the bearing (SKF) declare that this was due to a production error that made the bearing self-destruct. The turbine did not become unsafe in any way as a result of this.

9.2 MONTHS OF OPERATION

The duration test was conducted over a period of 10 months, or 314.5 days, from February 6th, 2018 through December 17th, 2017. The turbine was removed from the tower on January 22nd for post-test inspection.

9.3 HOURS OF POWER PRODUCTION

Table 4 indicates the number of power production hours observed during the 10 month test duration.

Class I	Power Production Hours Measured	Power Production Hours Required	Complete/Incomplete
> cut in	5298.83	2500	Complete
>12 m/s	421.17	250	Complete
>18 m/s	27.33	25	Complete
>15.0 m/s	125.83	25	Complete

Table 4 – Duration test hourly power production results for the TUGE10

9.4 OPERATIONAL TIME FRACTION

The operational time fraction is defined by the following equation:

$$O = \frac{T_T - T_N - T_U - T_E}{T_T - T_U - T_E} \times 100 \%$$

where:

T_T is the total time period under consideration,

T_N is the time during which the turbine is known to be non-operational,

T_U is the time during which the turbine status is unknown, and

T_E is the time which is excluded in the analysis.

The overall operational time fraction of the combined wind turbine system in the total test period was 93.79%. Table 5 below displays the values that were used for determination of overall operational time fraction.

DURATION TEST REPORT

Operational Time Fraction Values	
Variable	Hours
T _T	7543.92
T _N	460.17
T _U	17.33
T _E	122.03

Table 5 – Hourly results for operational time fraction values for the TUGE10

The turbine system downtime (TN) was majorly due to the repairs as mentioned above.

The primary reason for time related to unknown status (TU) of the turbine system during the test period, is related to grid faults of the local grid at the test site, which in turn caused the inverter / wind turbine to shutdown.

The primary reasons for excluded time (TE) in the analysis are related to time during which safety & function and acoustic testing was conducted.

Please note that the time excluded under TE and TU are not counted against or in favor of the operational time fraction.

All values reported in Table 5 above were used in the final determination of power production hours in Table 4 above.

9.5 ENVIRONMENTAL CONDITIONS

In order to understand environmental conditions over the testing period, several statistics are required by the Standard. These values are summarized in Table 6 below.

Environmental Conditions During Test Period	
Description	Value
Highest instantaneous wind speed	25.639 m/s
Highest 10-minute average wind speed	20.908 m/s
Highest 10-minute average temperature	29.42°C
Lowest 10-minute average temperature	-15.25°C
Average turbulence intensity at 15 m/s bin	6.10%

Table 6 – Environmental conditions during test

9.6 POWER DEGRADATION

One of the criteria for reliable operation is that the turbine should experience no significant power degradation over the test period at comparable wind speeds. For each month of the duration test, the power levels were binned by wind speed at integer values. For each wind speed, a plot was made with the binned power levels as a function of time. The plot was analyzed for any visible trends in power production. Figure 3 below shows the plot for each wind speed over the duration of the test period. No visible trends that are consistent over the entire operating range of the TUGE10 turbine system. Data points are only included on the plot if there are more than 6 data points (60 minutes) in the wind speed bin.

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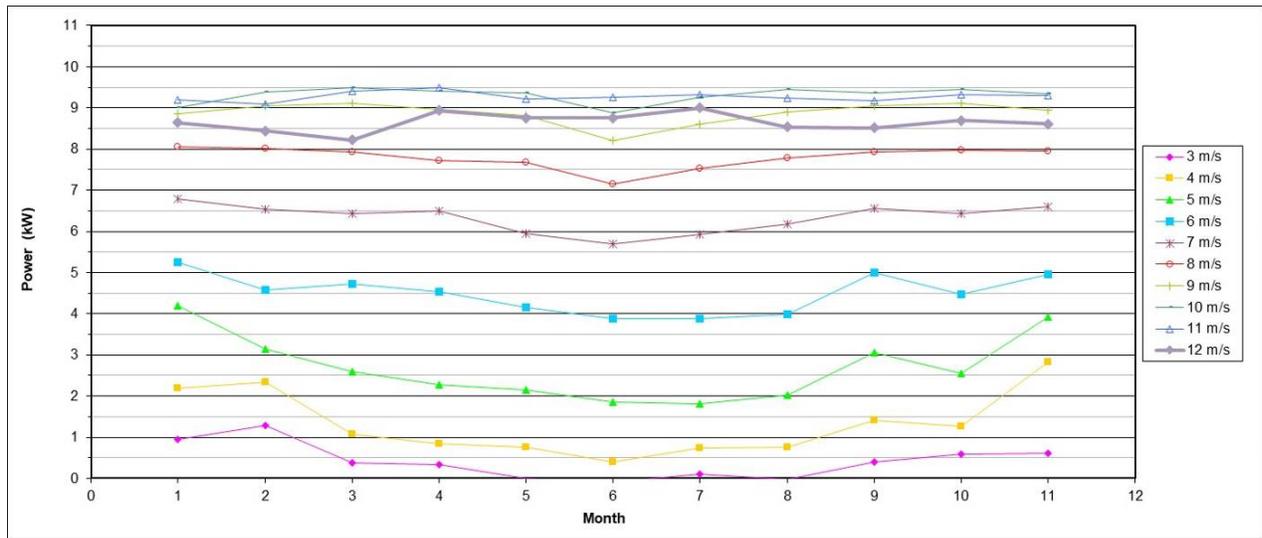


Figure 3 – Power degradation plot for the TUGE10

9.7 DYNAMIC BEHAVIOR

During the test period, the turbine and tower were observed for any potentially harmful turbine or tower dynamics. The dynamic behavior of the TUGE10 turbine was observed under all operating conditions in wind speeds ranging from below cut-in to above 13 m/s. See Annex G for logbook entries.

9.8 POST TEST INSPECTION

A detailed post-test inspection was performed on January 22nd and 23rd, 2019. All mechanical and electrical components were disassemble and checked for any access wear and extra attention was taking to check the main bearings. All parts was showing no or minimal wear except for the turnbuckle that keeps the tip break springs in place (see pictures in appendix F). The total wear over 10 months of operation is still within acceptable parameters and will be checked and replaced according to normal service instructions.

DURATION TEST REPORT**APPENDIX**

The following sections can be found within this Appendix:

A Wiring Diagram

B Pictures of the test site

C Calibration Certificates

D Revision History

E Commissioning Checklists

F Post Test Inspection

G Logbook

DURATION TEST REPORT

Appendix A – Wiring diagram

