# Spiral Blade Wind-turbine (Liam-F1)

# Field Test Report

2015. 05

This report has been reviewed by the following experts:

| | | |
|---|---|---|
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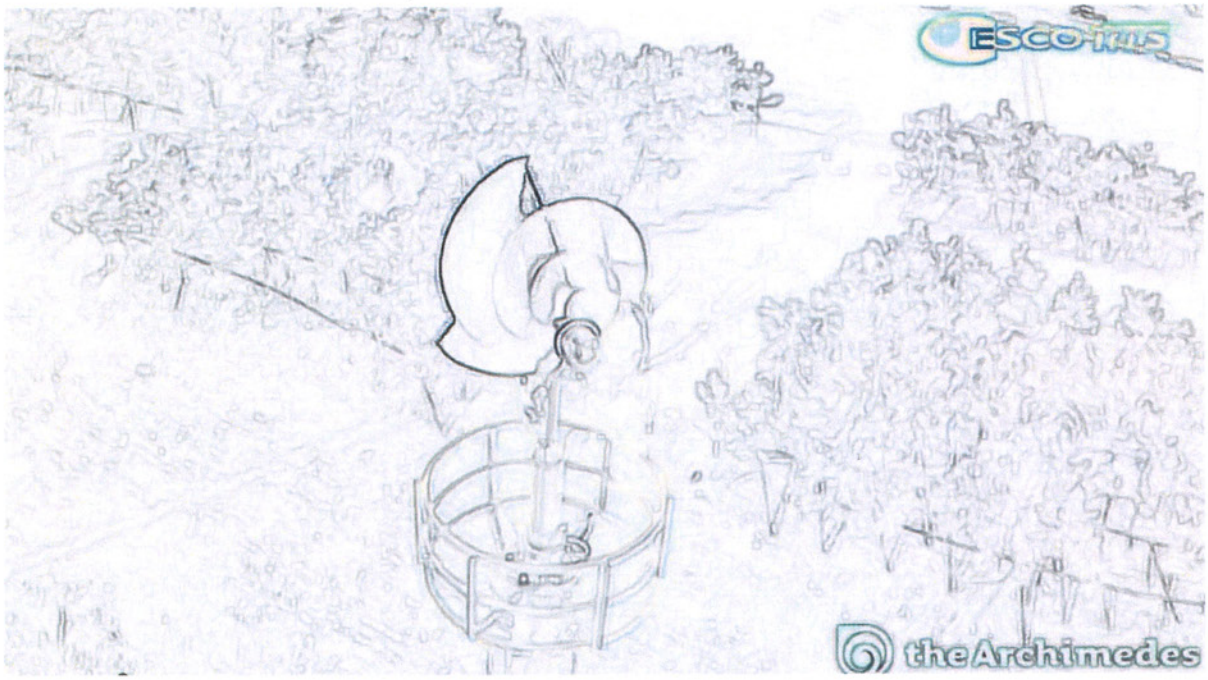
| | | |

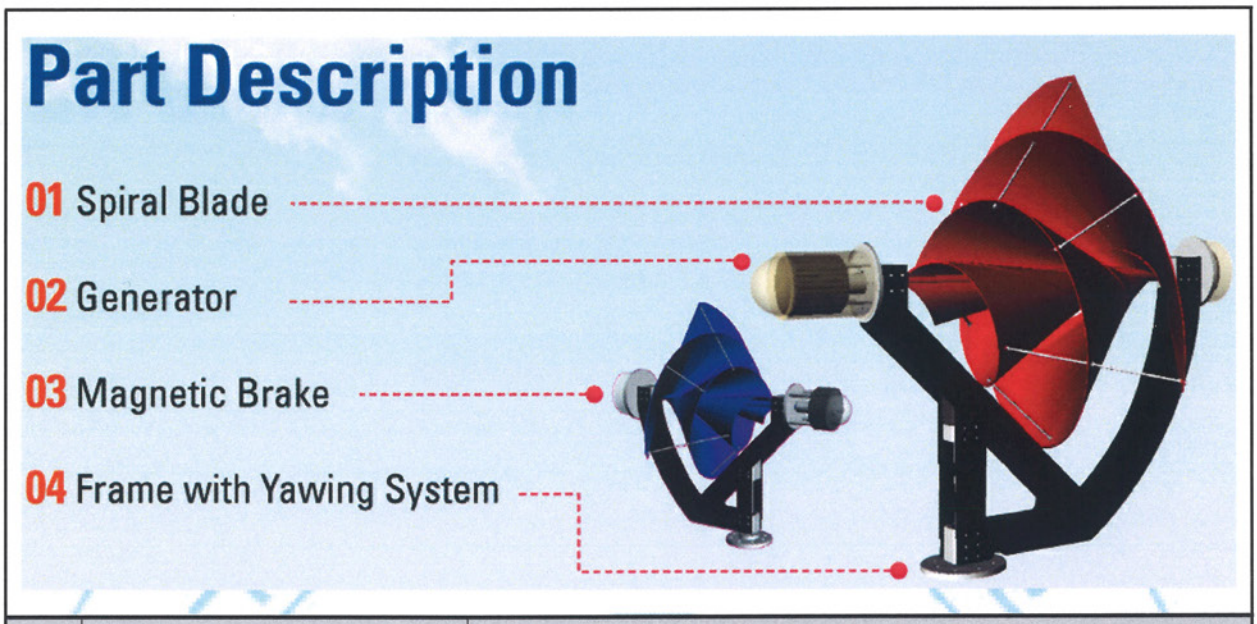
# LONG TERM FIELD TEST




Location: Incheon University, Songdo Campus

Duration: 2014.01.26.~2015.05.06. (Excluding Repair Time ⇨ Total 216 days)

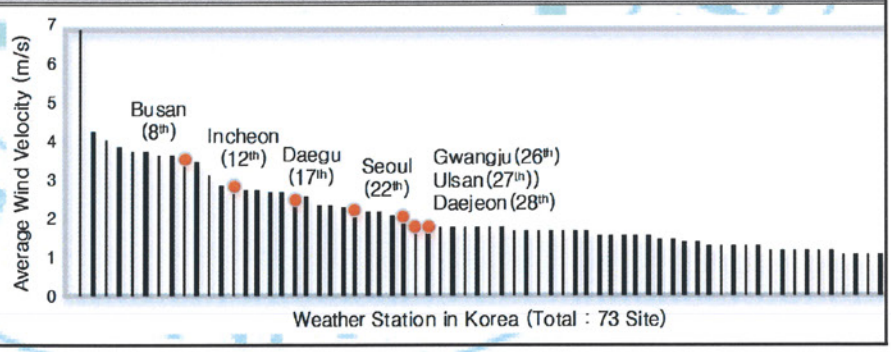
## 1. Liam-F1 Characteristics & Specifications




| No. | Part | Description |
|---|---|---|
| 1 | Spiral Blades | Diameter: 1.5m / Spiral type Blades |
| 2 | Generator | Rated power: 1.0kw (at 400rpm) / Max. 1.5kW |
| 3 | Magnetic Brake | Torque: 175 N·m |
| 4 | Frame with Yawing System | Frame : Steel Plate<br>Yawing System: Automatically adjust for the wind-direction |

## 2. Outline of the field test Liam-F1.0 Prototype

### 2.1 Outline of selected field test site

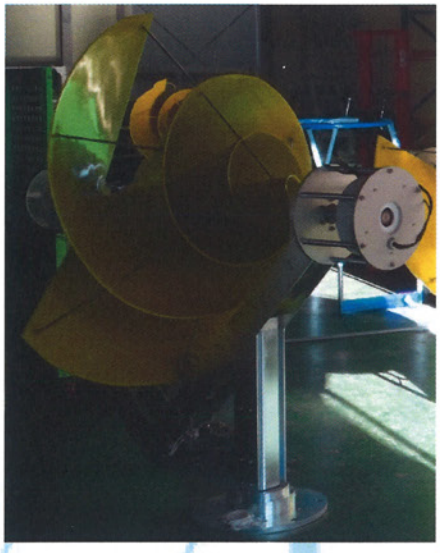
| Main city in Korea | Average wind velocity (2001~2010, Average for 10years) |
|---|---|
|  |  |

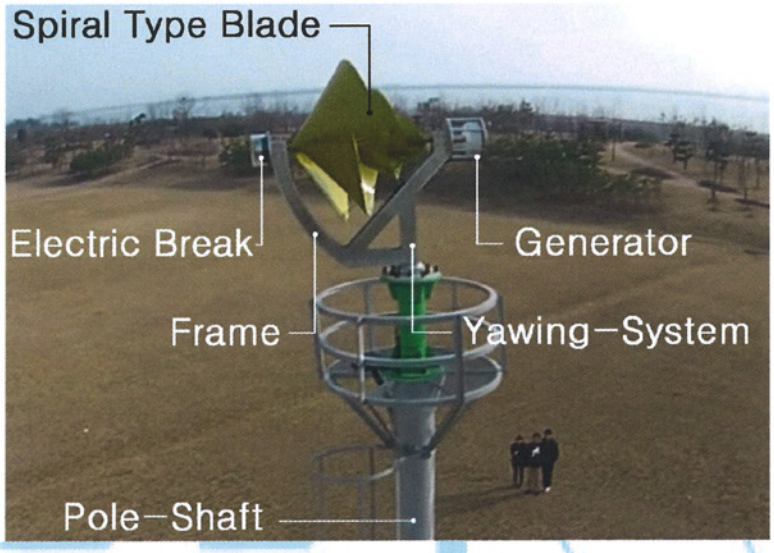


- Incheon is ranked the second best city (population over 1 mil.) for excellent wind conditions.
- The average annual temperature in Incheon is 12.1 ℃, the lowest monthly average temperature is in January (-2.1 ℃), the highest monthly average temperature is in August (25.2 ℃).
- The annual average wind speed is 2.9m/s. The highest wind speeds occur in March (3.7m/s), the lowest in September (2.1m/s). These speeds are averages.

## 2.2 Liam-F1 at the field test

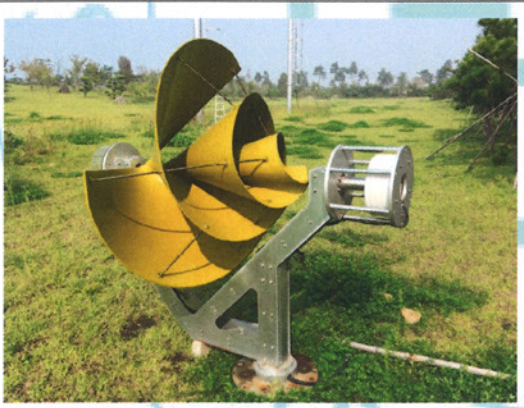
The Liam F1 Archimedes Turbine

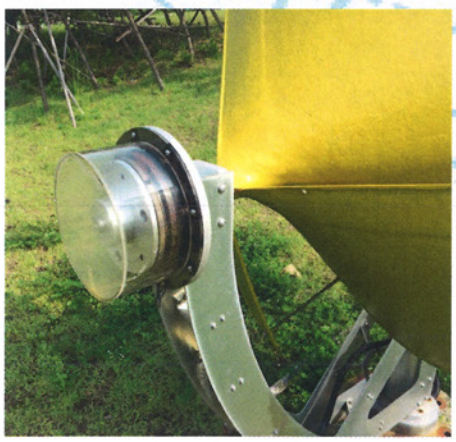





· Description of the field test model and setup

Part inspection

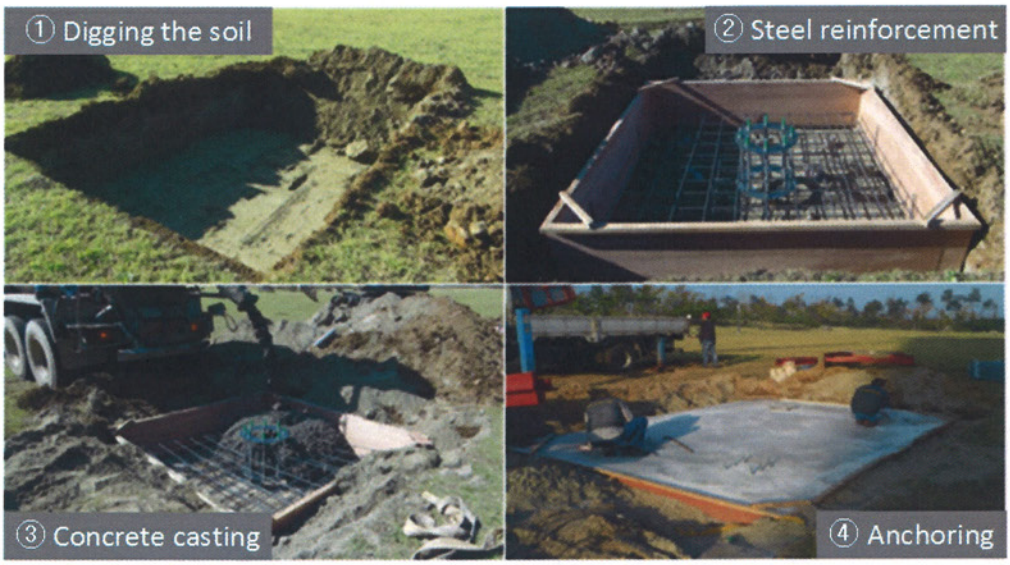




·After 216 days all the parts are still in good shape

## 3. The method of Field testing

### 1.1 Concrete foundation




- The wind turbines and its supporting poles are installed above the concrete foundations.
- the concrete foundation dimensions are set at 3X3X0.5 meter (LxWxD), considering the safety and to withstand forces by the momentum on the wind turbine and the pole by wind.
- The reinforced concrete foundation can withstand seismic shock, fire etc.
- After a curing period, anchors for installation of the poles are installed to the concrete foundation

### 1.2 Pole installation

· The steel pole has a diameter of 300mm and a height of 10m. To ensure a safe and efficient work-condition on the upper deck, a safety ladder and fences are applied to the pole and upper deck.

· Once the assembly of all the components are completed, the pole is attached to the base-plate, using the anchor bolts of the concrete foundation. For this job a crane is used.

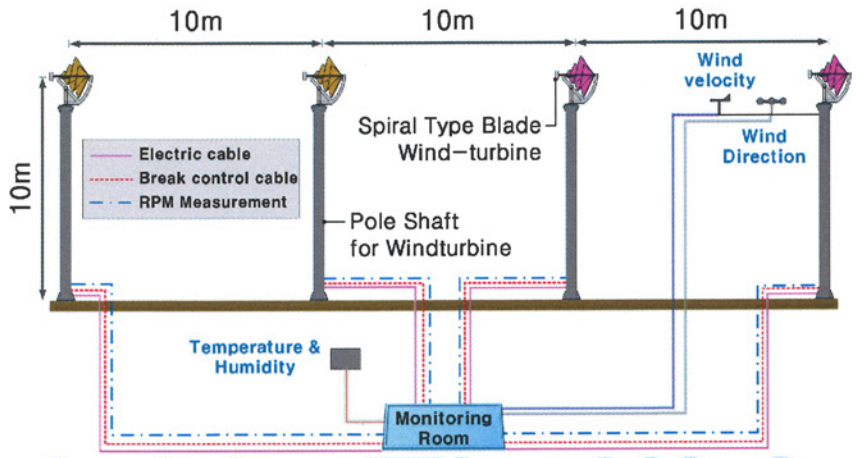
· The foundation was levelized until the pole is exactly perpendicular to the ground. Then the wind-turbine was installed on top.

### 1.3 Liam-F1 installation



· The wind turbine was installed on the top of the pole. The foundation and installation of the pole and turbine should be considered as important part of a well functioning system. In all cases professionals should handle this process. A good performance can't be guaranteed if the foundation and installation of the pole and turbine are flawed.

## 1.4 Sensor installation

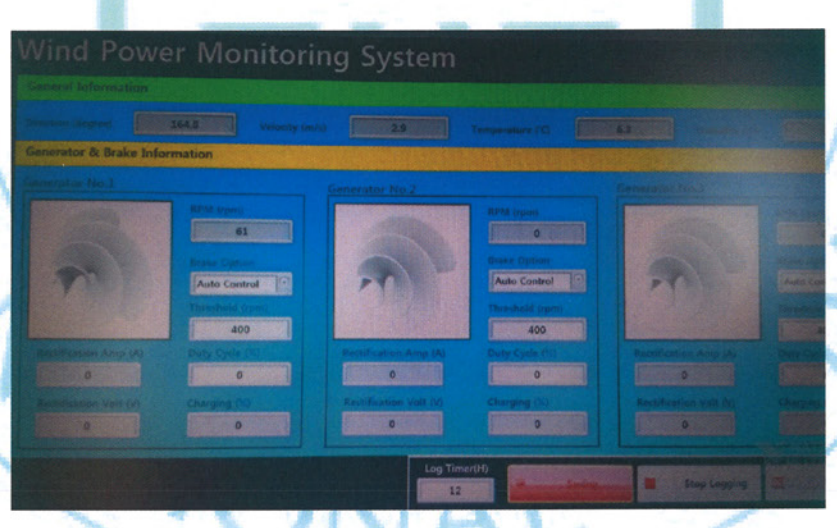



· The 4 poles were installed 10m apart from each other. This minimizes the chance of interference or turbulence caused by the other close-by turbines.

·Weather condition sensors collect real-time data of the temperature, humidity, wind speed and wind direction. The data was stored in a monitoring room.

· A RPM meter is installed. The transmitted data is monitored by an electric brake controller, to protect the turbine for over speeding.

## 1.5 Monitoring System




· All collected data is managed by an integrated management system in the on-site monitoring room.

· Data on wind speed, wind direction, temperature, humidity, power generation and RPM are collected with an interval of 1 sec.

# 4. Field Test results

## 4.1 Operating ratio

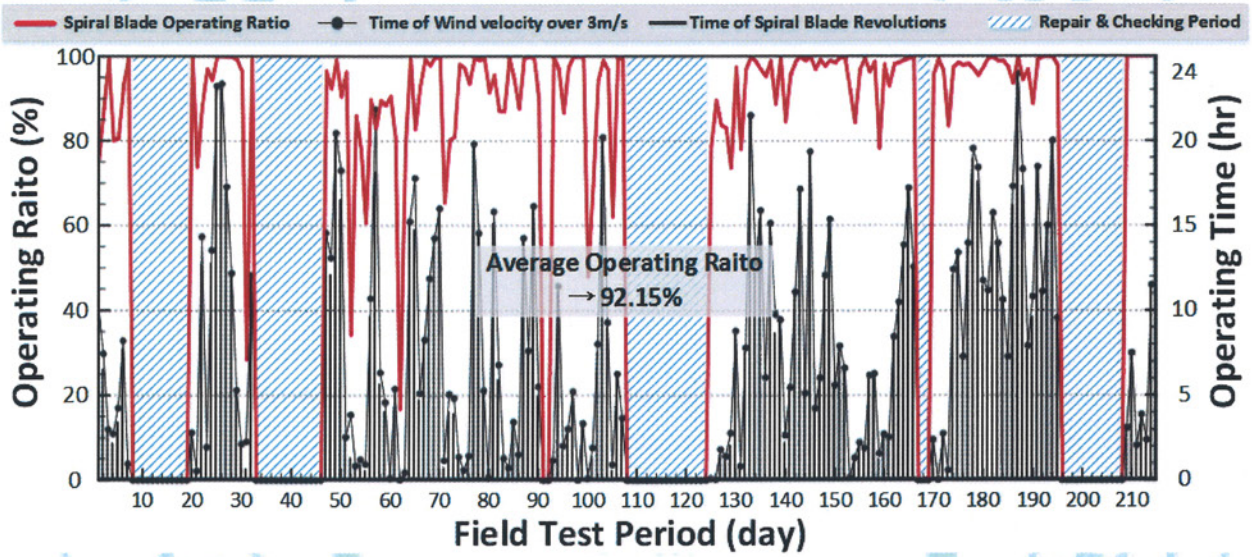
$$O = \frac{T_T - T_N - T_U - T_E}{T_T - T_U - T_E} \times 100(\%)$$

$T_T$: Period time, $T_N$: Non operating time, $T_U$: Error time , $T_E$: Except time, O: Operating Ratio

· The operating Ratio is a measure of performance. It shows the percentage of time the turbine is rotating when the wind speed is above the cut-in wind velocity.

· This field test is used to study the behavior of the turbine design.

· The Cut-in wind speed (3 m/s) is determined by the rotation of the blades.




· The field test lasted for 216 days. Due to repair, overhaul or other errors the test was paused for 65 days. 151 days the wind velocity was above the cut-in wind speed.

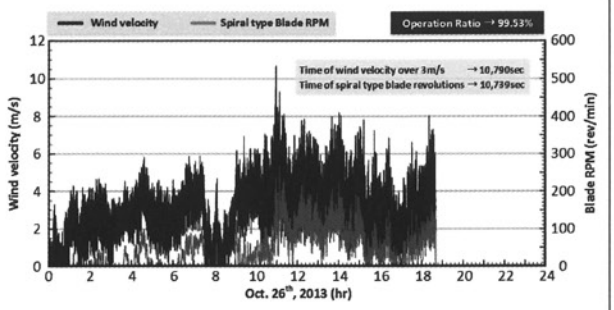
· The operating ratio was determined by using the cut in velocity of 3 m/s, which is typical for the wind turbine start-up wind speed.

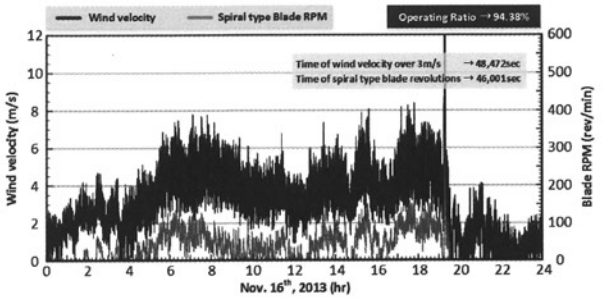
· The total amount of time above the cut-in wind speed was 4.507.289 seconds (about 1250 hours). The total time of rotation was 4.321.072 seconds (about 1200 hours). The established operation ratio is 92.15%

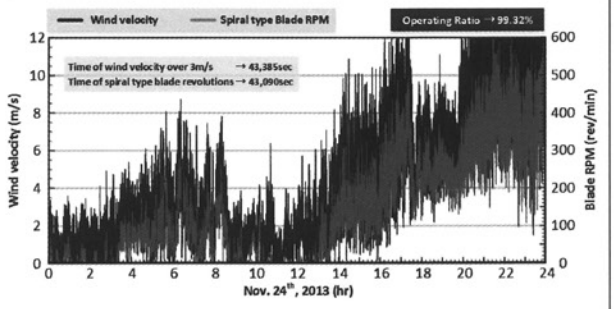
·A operating ratio above 90% is considered to be of superior quality.

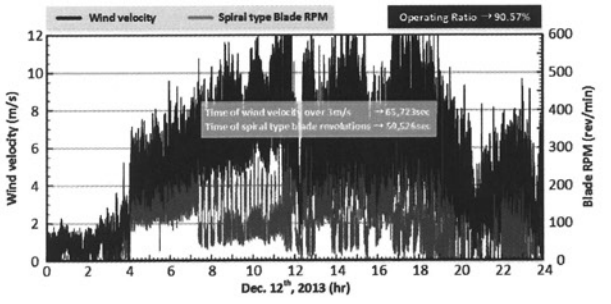
· Therefore it's possible to check the performance of the Liam F1 by this test.

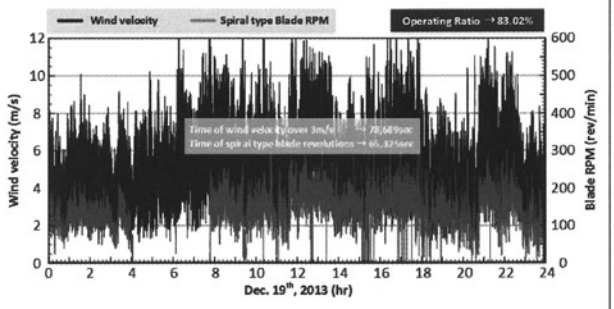
# Daily Data

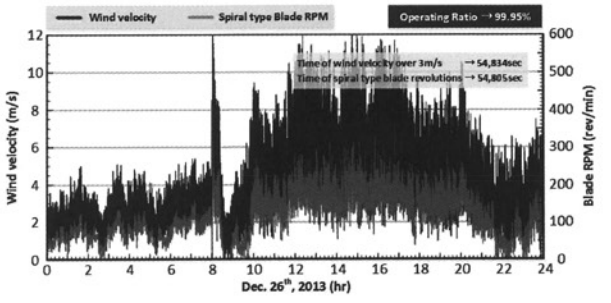

Wind velocity
Spiral type Blade RPM
Operation Ratio → 99.53%
Time of wind velocity over 3m/s → 10,790sec
Time of spiral type blade revolutions → 10,739sec
Wind velocity (m/s)
Blade RPM (rev/min)
Oct. 26th, 2013 (hr)

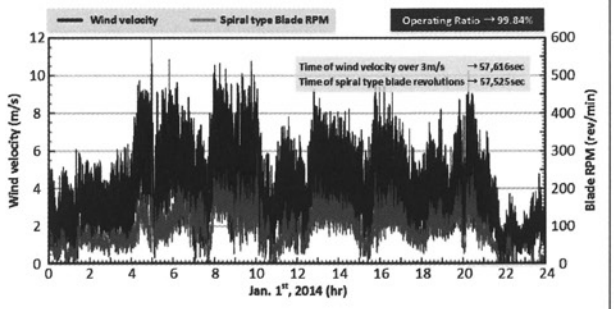

Wind velocity
Spiral type Blade RPM
Operating Ratio → 94.38%
Time of wind velocity over 3m/s → 48,472sec
Time of spiral type blade revolutions → 46,001sec
Wind velocity (m/s)
Blade RPM (rev/min)
Nov. 16th, 2013 (hr)

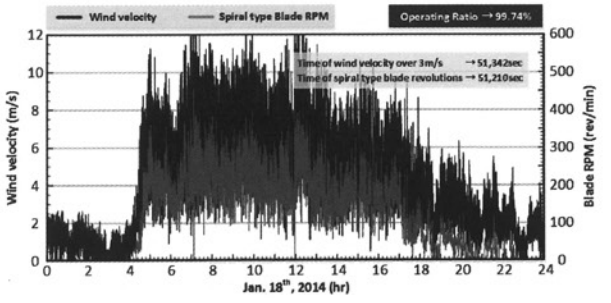

Wind velocity
Spiral type Blade RPM
Operating Ratio → 99.32%
Time of wind velocity over 3m/s → 43,385sec
Time of spiral type blade revolutions → 43,090sec
Wind velocity (m/s)
Blade RPM (rev/min)
Nov. 24th, 2013 (hr)

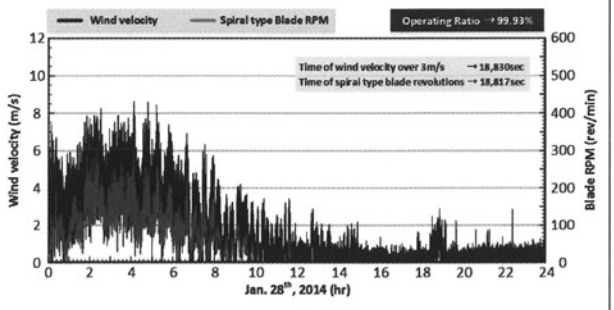

Wind velocity
Spiral type Blade RPM
Operating Ratio → 90.57%
Time of wind velocity over 3m/s → 65,723sec
Time of spiral type blade revolutions → 59,526sec
Wind velocity (m/s)
Blade RPM (rev/min)
Dec. 12th, 2013 (hr)

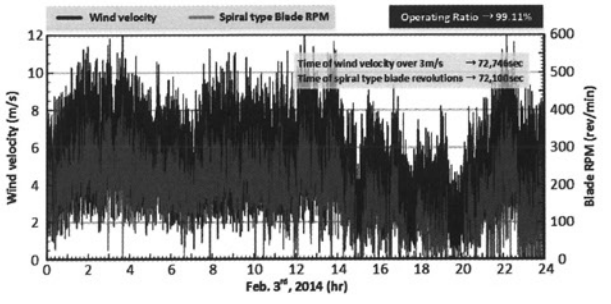

Wind velocity
Spiral type Blade RPM
Operating Ratio → 83.02%
Time of wind velocity over 3m/s → 78,689sec
Time of spiral type blade revolutions → 65,325sec
Wind velocity (m/s)
Blade RPM (rev/min)
Dec. 19th, 2013 (hr)


Wind velocity
Spiral type Blade RPM
Operating Ratio → 99.95%
Time of wind velocity over 3m/s → 54,834sec
Time of spiral type blade revolutions → 54,805sec
Wind velocity (m/s)
Blade RPM (rev/min)
Dec. 26th, 2013 (hr)

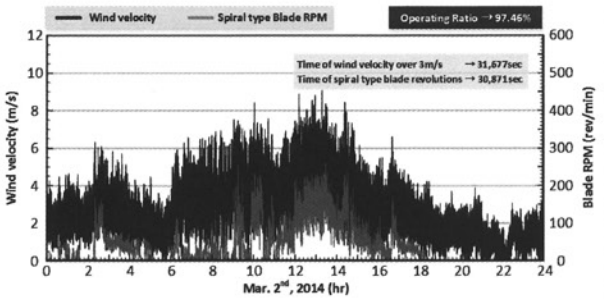

Wind velocity
Spiral type Blade RPM
Operating Ratio → 99.84%
Time of wind velocity over 3m/s → 57,616sec
Time of spiral type blade revolutions → 57,525sec
Wind velocity (m/s)
Blade RPM (rev/min)
Jan. 1st, 2014 (hr)

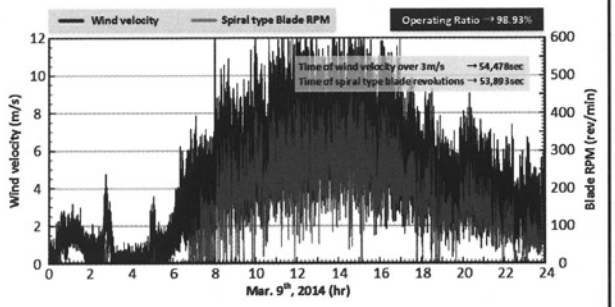

Wind velocity
Spiral type Blade RPM
Operating Ratio → 99.74%
Time of wind velocity over 3m/s → 51,342sec
Time of spiral type blade revolutions → 51,210sec
Wind velocity (m/s)
Blade RPM (rev/min)
Jan. 18th, 2014 (hr)

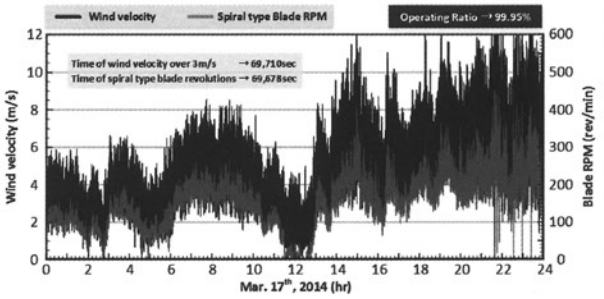

Wind velocity
Spiral type Blade RPM
Operating Ratio → 99.93%
Time of wind velocity over 3m/s → 18,830sec
Time of spiral type blade revolutions → 18,817sec
Wind velocity (m/s)
Blade RPM (rev/min)
Jan. 28th, 2014 (hr)

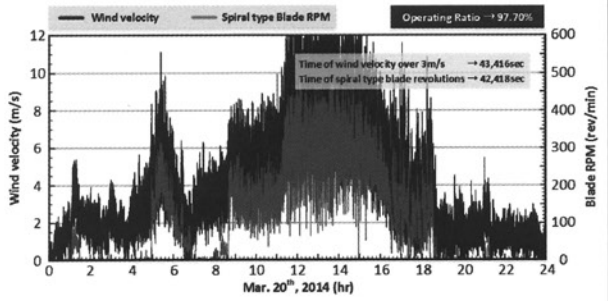

Wind velocity
Spiral type Blade RPM
Operating Ratio → 99.11%
Time of wind velocity over 3m/s → 72,746sec
Time of spiral type blade revolutions → 72,100sec
Wind velocity (m/s)
Blade RPM (rev/min)
Feb. 3rd, 2014 (hr)

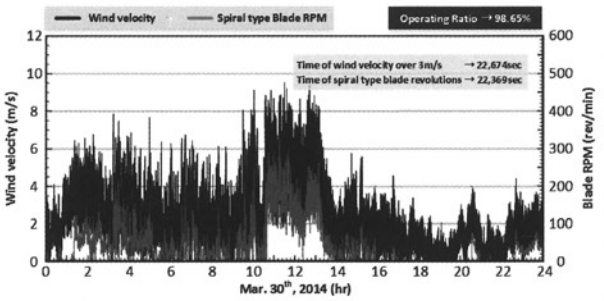
# Daily Data

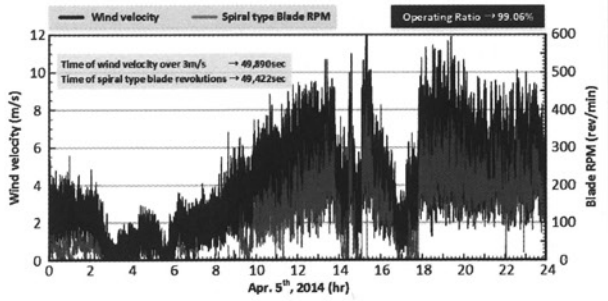

Wind velocity
Spiral type Blade RPM
Operating Ratio → 97.46%
Time of wind velocity over 3m/s → 31,677sec
Time of spiral type blade revolutions → 30,871sec
Wind velocity (m/s)
Blade RPM (rev/min)
Mar. 2nd, 2014 (hr)

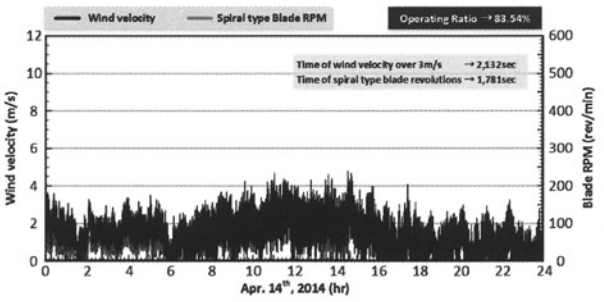

Wind velocity
Spiral type Blade RPM
Operating Ratio → 98.93%
Time of wind velocity over 3m/s → 54,478sec
Time of spiral type blade revolutions → 53,893sec
Wind velocity (m/s)
Blade RPM (rev/min)
Mar. 9th, 2014 (hr)

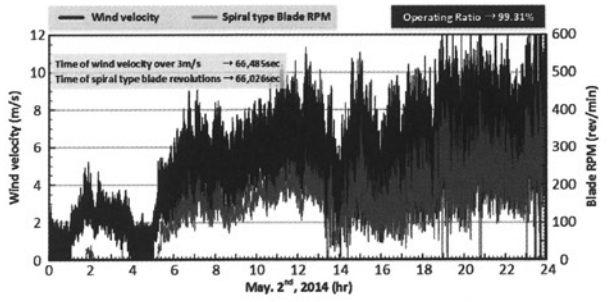

Wind velocity
Spiral type Blade RPM
Operating Ratio → 99.95%
Time of wind velocity over 3m/s → 69,710sec
Time of spiral type blade revolutions → 69,678sec
Wind velocity (m/s)
Blade RPM (rev/min)
Mar. 17th, 2014 (hr)

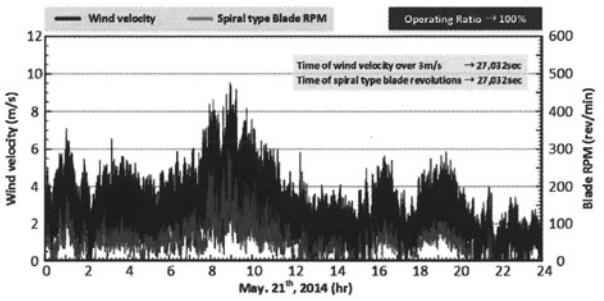

Wind velocity
Spiral type Blade RPM
Operating Ratio → 97.70%
Time of wind velocity over 3m/s → 43,416sec
Time of spiral type blade revolutions → 42,418sec
Wind velocity (m/s)
Blade RPM (rev/min)
Mar. 20th, 2014 (hr)


Wind velocity
Spiral type Blade RPM
Operating Ratio → 98.65%
Time of wind velocity over 3m/s → 22,674sec
Time of spiral type blade revolutions → 22,369sec
Wind velocity (m/s)
Blade RPM (rev/min)
Mar. 30th, 2014 (hr)

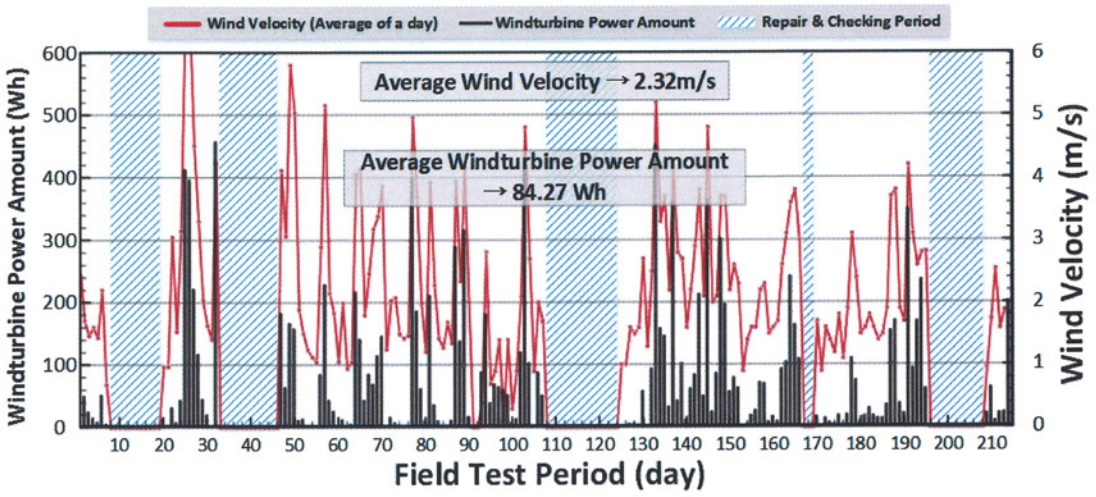

Wind velocity
Spiral type Blade RPM
Operating Ratio → 99.06%
Time of wind velocity over 3m/s → 49,890sec
Time of spiral type blade revolutions → 49,422sec
Wind velocity (m/s)
Blade RPM (rev/min)
Apr. 5th, 2014 (hr)


Wind velocity
Spiral type Blade RPM
Operating Ratio → 83.54%
Time of wind velocity over 3m/s → 2,132sec
Time of spiral type blade revolutions → 1,781sec
Wind velocity (m/s)
Blade RPM (rev/min)
Apr. 14th, 2014 (hr)


Wind velocity
Spiral type Blade RPM
Operating Ratio → 99.31%
Time of wind velocity over 3m/s → 66,485sec
Time of spiral type blade revolutions → 66,026sec
Wind velocity (m/s)
Blade RPM (rev/min)
May. 2nd, 2014 (hr)

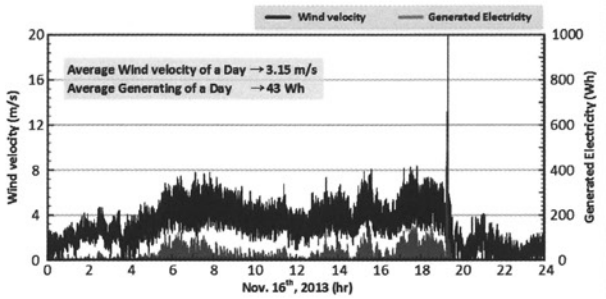

Wind velocity
Spiral type Blade RPM
Operating Ratio → 100%
Time of wind velocity over 3m/s → 27,032sec
Time of spiral type blade revolutions → 27,032sec
Wind velocity (m/s)
Blade RPM (rev/min)
May. 21th, 2014 (hr)

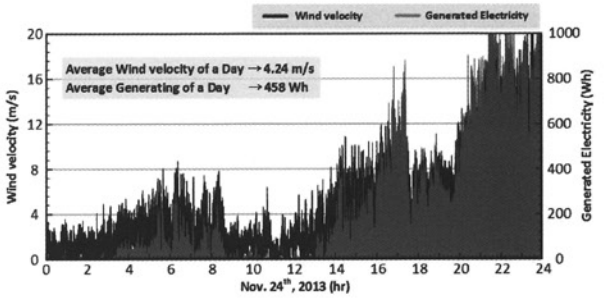
## 4.2 Electric Generation

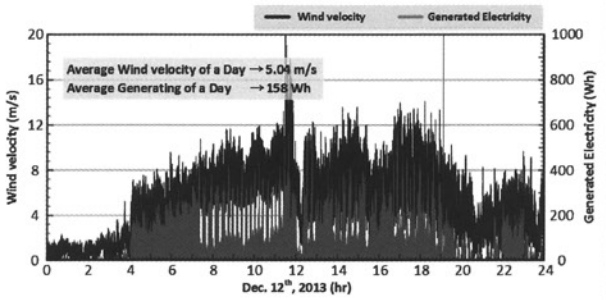


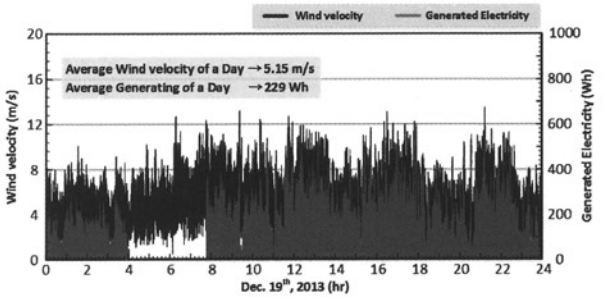

- The field test was conducted by the University of Incheon (Songdo Campus). The obtained results are shown in the wind and power generation graph (see above).
- The average wind speed during the field test period was measured to be about 2.32m/s, which is far below the annual average. According to the National Weather Service the annual average wind speed for Incheon Songdo is 4.8 m/s ("Korea climate table, meteorology, 2011" reference).
- During this field test the daily average power generation was calculated to be 84.27 Wh. Enough for the continuous power consumption of the used electronics (controller etc.) and electrical losses (all together a minimum of 60 Wh). A comparable propeller blade turbine can't produce energy at such low average wind speeds. The start-up wind speed has to be between 2~3m/s. Compared to other types of turbines the AWM proves to have a high efficiency.
- The Incheon Songdo field test shows the AWM can be certified as a 1 kW (1000W) grade wind turbine power generator. By producing electric power with a minimum of 60Wh under very low speed wind conditions, the prediction is roughly a daily 110Wh production when applied to the annual 10 year average wind speed of 4.8 m/s.
- The current analysis is generated from a 1kW-class electricity production capacity.

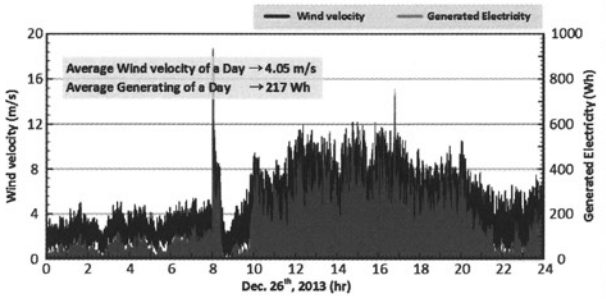
## Daily Data

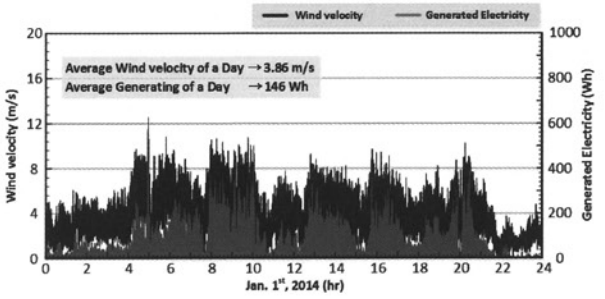

Wind velocity
Generated Electricity
Average Wind velocity of a Day →3.15 m/s
Average Generating of a Day →43 Wh
Wind velocity (m/s)
Generated Electricity (Wh)
Nov. 16th, 2013 (hr)

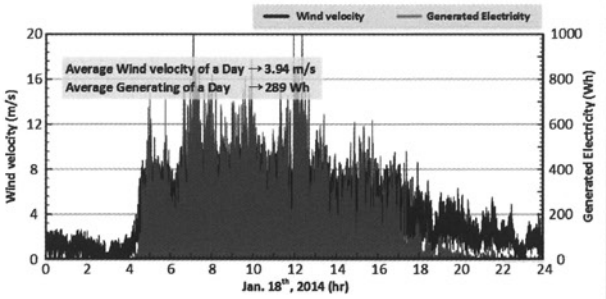

Wind velocity
Generated Electricity
Average Wind velocity of a Day →4.24 m/s
Average Generating of a Day →458 Wh
Wind velocity (m/s)
Generated Electricity (Wh)
Nov. 24th, 2013 (hr)

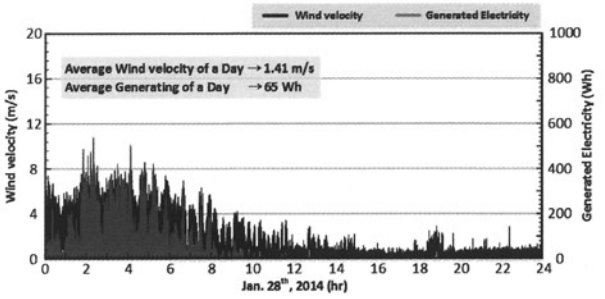

Wind velocity
Generated Electricity
Average Wind velocity of a Day →5.04 m/s
Average Generating of a Day →158 Wh
Wind velocity (m/s)
Generated Electricity (Wh)
Dec. 12th, 2013 (hr)

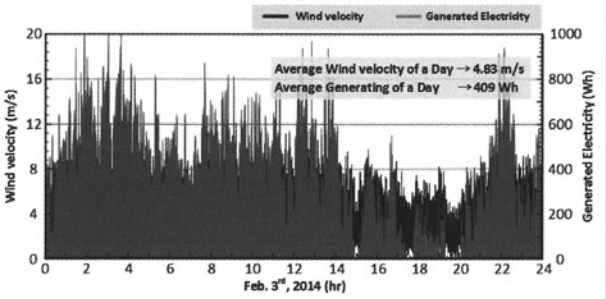

Wind velocity
Generated Electricity
Average Wind velocity of a Day →5.15 m/s
Average Generating of a Day →229 Wh
Wind velocity (m/s)
Generated Electricity (Wh)
Dec. 19th, 2013 (hr)

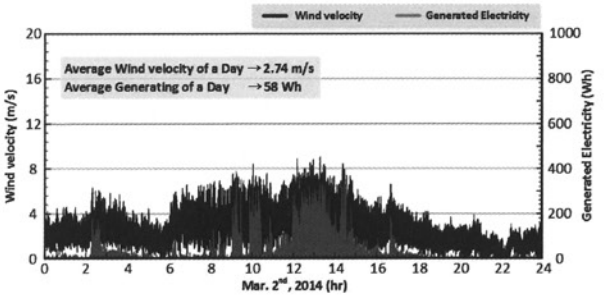

Wind velocity
Generated Electricity
Average Wind velocity of a Day →4.05 m/s
Average Generating of a Day →217 Wh
Wind velocity (m/s)
Generated Electricity (Wh)
Dec. 26th, 2013 (hr)


Wind velocity
Generated Electricity
Average Wind velocity of a Day →3.86 m/s
Average Generating of a Day →146 Wh
Wind velocity (m/s)
Generated Electricity (Wh)
Jan. 1st, 2014 (hr)

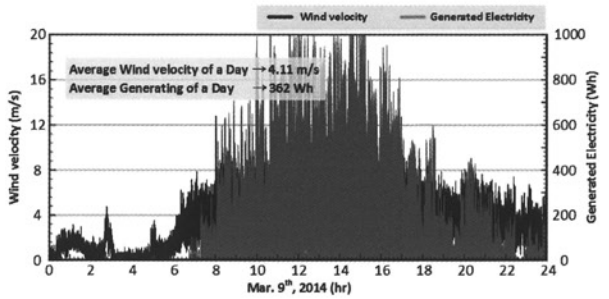

Wind velocity
Generated Electricity
Average Wind velocity of a Day →3.94 m/s
Average Generating of a Day →289 Wh
Wind velocity (m/s)
Generated Electricity (Wh)
Jan. 18th, 2014 (hr)

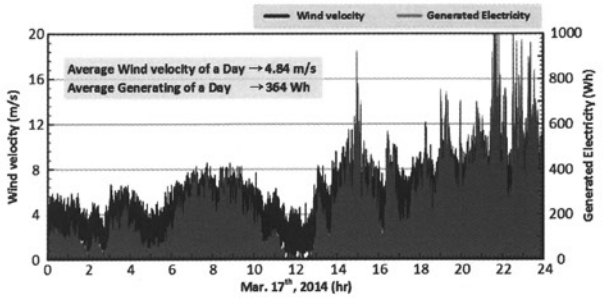

Wind velocity
Generated Electricity
Average Wind velocity of a Day →1.41 m/s
Average Generating of a Day →65 Wh
Wind velocity (m/s)
Generated Electricity (Wh)
Jan. 28th, 2014 (hr)

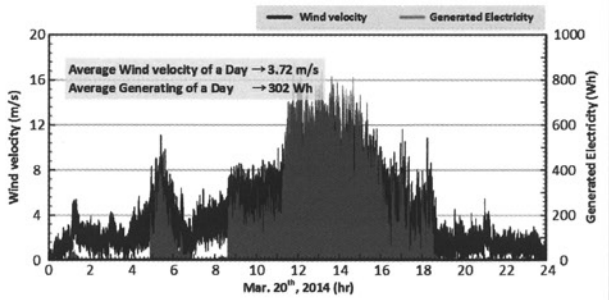

Wind velocity
Generated Electricity
Average Wind velocity of a Day →4.83 m/s
Average Generating of a Day →409 Wh
Wind velocity (m/s)
Generated Electricity (Wh)
Feb. 3rd, 2014 (hr)

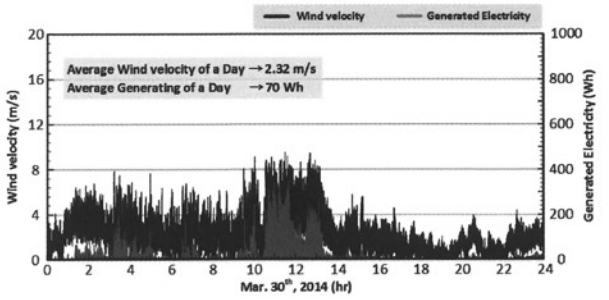

Wind velocity
Generated Electricity
Average Wind velocity of a Day →2.74 m/s
Average Generating of a Day →58 Wh
Wind velocity (m/s)
Generated Electricity (Wh)
Mar. 2nd, 2014 (hr)

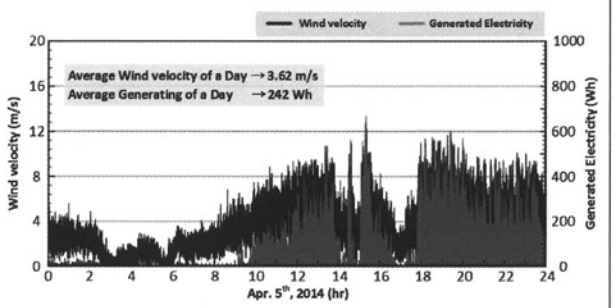
## Daily Data

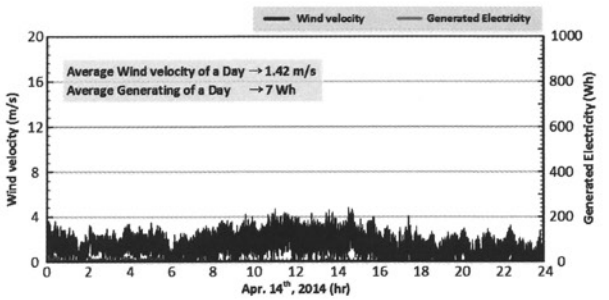

Wind velocity
Generated Electricity
Average Wind velocity of a Day →4.11 m/s
Average Generating of a Day →362 Wh
Wind velocity (m/s)
Generated Electricity (Wh)
Mar. 9th, 2014 (hr)

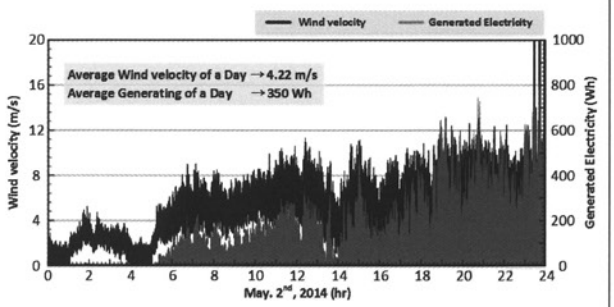

Wind velocity
Generated Electricity
Average Wind velocity of a Day →4.84 m/s
Average Generating of a Day →364 Wh
Wind velocity (m/s)
Generated Electricity (Wh)
Mar. 17th, 2014 (hr)

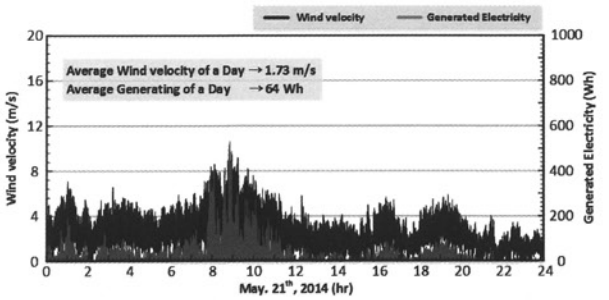

Wind velocity
Generated Electricity
Average Wind velocity of a Day →3.72 m/s
Average Generating of a Day →302 Wh
Wind velocity (m/s)
Generated Electricity (Wh)
Mar. 20th, 2014 (hr)


Wind velocity
Generated Electricity
Average Wind velocity of a Day →2.32 m/s
Average Generating of a Day →70 Wh
Wind velocity (m/s)
Generated Electricity (Wh)
Mar. 30th, 2014 (hr)

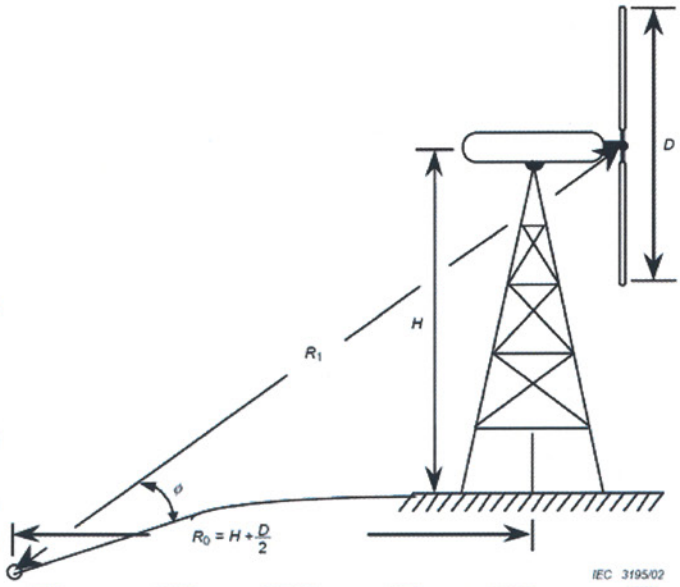

Wind velocity
Generated Electricity
Average Wind velocity of a Day →3.62 m/s
Average Generating of a Day →242 Wh
Wind velocity (m/s)
Generated Electricity (Wh)
Apr. 5th, 2014 (hr)


Wind velocity
Generated Electricity
Average Wind velocity of a Day →1.42 m/s
Average Generating of a Day →7 Wh
Wind velocity (m/s)
Generated Electricity (Wh)
Apr. 14th, 2014 (hr)


Wind velocity
Generated Electricity
Average Wind velocity of a Day →4.22 m/s
Average Generating of a Day →350 Wh
Wind velocity (m/s)
Generated Electricity (Wh)
May. 2nd, 2014 (hr)


Wind velocity
Generated Electricity
Average Wind velocity of a Day →1.73 m/s
Average Generating of a Day →64 Wh
Wind velocity (m/s)
Generated Electricity (Wh)
May. 21th, 2014 (hr)

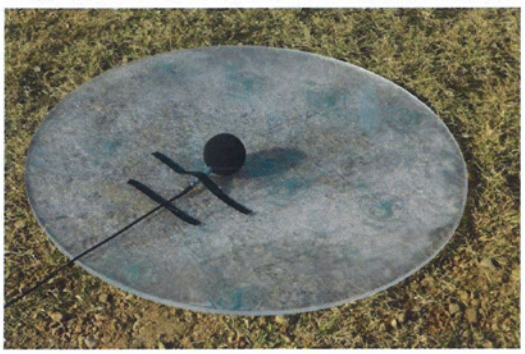
## 4.3 Sound Levels



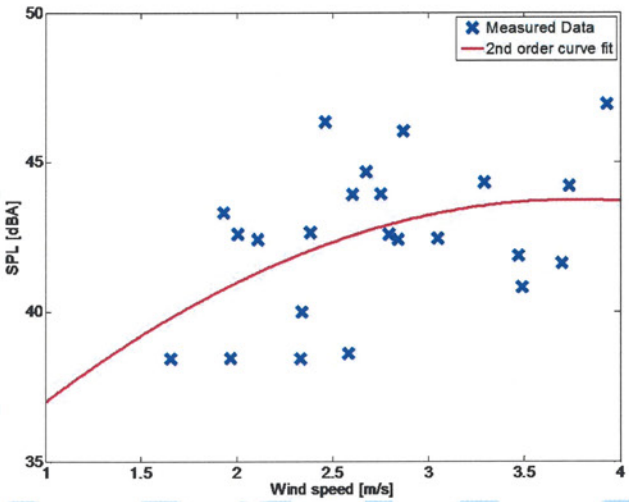

· Two conditions have to be established. The relative angle (Ø) between the horizontal distance and the height (H) of the noise producing wind turbine and the wind direction. These two conditions are shown in the figure above.

· The noise measurement position of the horizontal axis wind turbine shown in the figure, is determined by the following equation:

$$R_0 = H + \frac{D}{2}$$

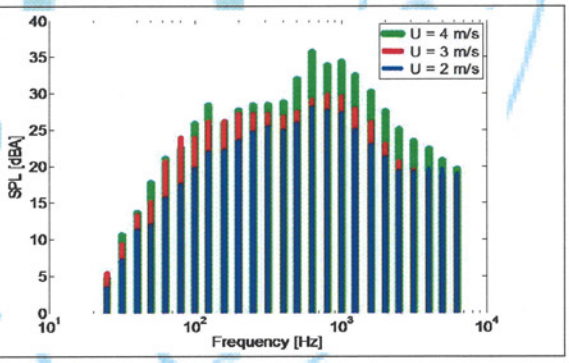


· The noise measurements were taken in accordance with IEC regulations. A windbreak net covered the microphone to minimize the effect of wind noise. The distance was calculated as: $R_0 = H + \frac{D}{2} = 9.0 + \frac{1.5}{2} = 9.75m$




· A summary of measurements of the noise level is shown at constant wind speeds. Wind speed from for example 1.6m/s to 2.4 m/s is shown as 2m/s. The above graph depicts the separate noise measurements as stars *. The curve is generated by curve fitting software. All in accordance with IEC regulations.

| Wind speed [m/s] | SPL [dBA] |
|---|---|
| 1 | 37.01 |
| 2 | 41.01 |
| 3 | 43.24 |
| 4 | 43.71 |




· Finally, noise levels are shown for each wind speed in a 1/3 Octave-band. The data for each wind speed is obtained by measurements longer than 1 minute. We can see that as the wind speed increases the sound pressure level also increases, as shown in the picture. The 500 ~ 1600Hz frequency range can be considered as the main noise component.

· The operation noise was tested to be about 45dBA or less.

## 5 Field test conclusions

Results from this field test are:

- Operation ratio of 92.15%
- Low start-up wind speed < 3m/s
- Operation ratio of 92.15%
- Power generation at very low average wind speed
- Sound level of the AWM is in all cases below 45 dBA.
- After 216 days all parts are in good condition

Conclusions:

The power generation at a low average wind and the high operating ratio prove that the yawing system is functioning as expected. For power generation the wind turbine must face the wind direction. A badly functioning yawing system would have resulted in a low operating ratio. We can conclude the yawing system is functioning as designed.

The power generation at a extremely low average wind speed and low cut-in wind speed, show the high efficiency of the AWM.

In 216 days the turbine experienced all kinds of weather conditions. Snow, rain, UV, cold, heat, gusts and high wind speeds. All parts were checked afterwards. No damaged or less functioning parts were detected.

The high efficiency, excellent yawing, low cut-in, high operation ratio and the extremely low sound level make the AWM suitable for every environment, including the urban environment. Also all parts prove to be designed as robust and durable.