

Small Wind Turbine Testing Results from NREL



**International Small Wind
Conference 2010**

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Independent Testing Project

To provide consumers with more product information and buying confidence regarding small wind turbines

Test results can be used to partially fulfill the requirements of IEC certification & the AWEA small wind turbine standard and to certify the turbine through the Small Wind Certification Council (SWCC)

Help stabilize the SWT market through testing and data presentation

Independent Testing Project

Turbine selection

- competitive solicitation
- commercially available in US
- <200m²
- data will be in public domain

Test turbines to International Electrotechnical Commission (IEC) testing standards

Rigorous requirements for site, instrumentation, & data

Advance the standards and procedures for testing small wind turbines

IEC Tests Performed

Power Performance – power curve, annual energy production

Duration – operational time fraction, power degradation, inspections, dynamic behavior

Safety and Function - verification of designed behavior

Acoustic Noise – sound power level, one-third octave, tonality

Power Quality – flicker, harmonics, voltage fluctuations

Independent Testing Project, Round 1



Gaia-Wind 11kW



ARE 442



EW50



Windspire



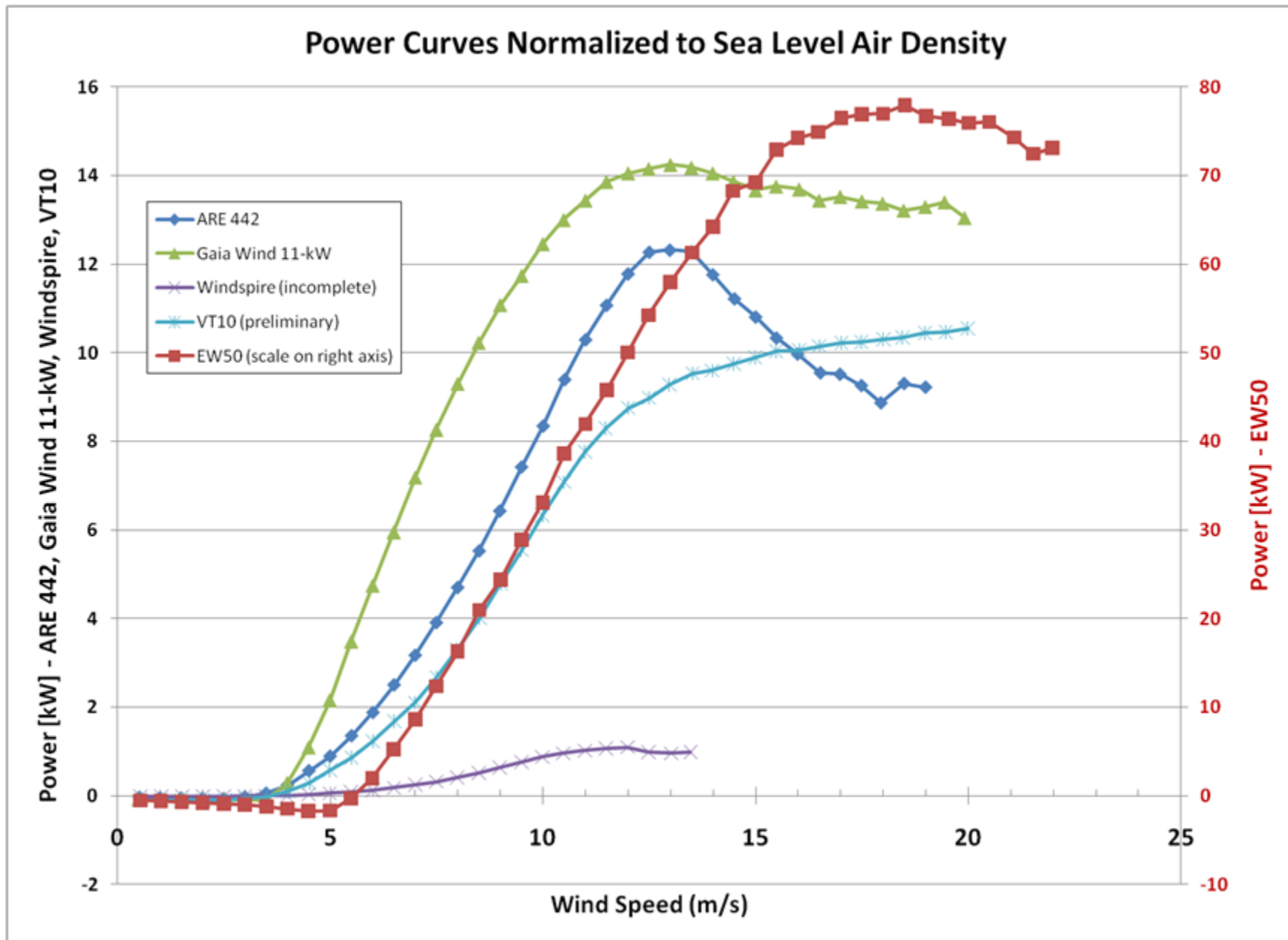
VT10

Small Wind Turbines

	Gaia-Wind 11kW	ARE 442	EW50	Windspire	VT10
Manufacturer	Gaia - Wind	Abundant Renewable Energy	Entegrity Wind	Mariah	Ventera Energy
Rotor size	13 m diameter	7.2 m diameter	15 m diameter	1.2 m width 6.1 m height	6.7 m diameter
Rated power	11 kW	10 kW	50 kW	1 kW	10 kW
Rotor center height	18.2 m	30.9 m	31.1 m	6.1 m	21.3 m
SWT class	III	II	II	IV	III
Installed	May 2008	June 2008	March 2009	May 2008	February 2010
Power Performance	Complete	Complete	Reporting in Progress	Complete	In progress
Duration	Data Collection complete	Complete	In progress	Terminated*	In progress
Safety and Function	Complete	Complete	In progress	Reporting in progress	In progress
Noise	Reporting in Progress	Reporting in Progress	In progress	Not tested*	Not started
Power Quality	Reporting in Progress	n/a	In progress	n/a	n/a

* Windspire Duration test terminated in Oct'08, other tests terminated in Jan'09

Power Performance



Power Performance

normalized to sea level air density

	Gaia-Wind 11kW	ARE 442	EW50	Windspire	VT10
$C_{p_{max}}$	29%	36%	30%	20%	30%
Sea-level power at 11m/s	14.2	9.2	40.0	1.0	7.8

<i>Hub height annual average wind speed</i>	Gaia-Wind 11kW <i>AEP-measured</i>	ARE 442 <i>AEP-measured</i>	EW50 <i>AEP-measured</i>	VT10 <i>AEP-measured</i>
<i>m/s</i>	<i>kWh</i>	<i>kWh</i>	<i>kWh</i>	<i>kWh</i>
4	17,716	7,884	11,006	5,213
5	32,122	15,327	41,796	11,318
6	46,292	23,516	83,543	18,688
7	58,690	30,967	130,785	26,267
8	68,525	36,718	178,132	33,129
9	75,474	40,459	220,869	38,639
10	79,617	42,350	255,754	42,531
11	81,326	42,770	281,396	44,854

Windspire power curve is incomplete, so no AEP estimates are provided

Duration: Gaia-Wind 11kW

data collection complete; post-test inspection pending

“The turbine tracks winds well in all observed wind speeds. No excessive vibration was observed. There is an occasional, slight audible thumping noise as blades pass behind the tower.”



Hours of Power Production Above:			Max Gust	TI @ 15 m/s (%)	T_T (hours)	T_U (hours)	T_E (hours)	T_N (hours)	O (%)
0 m/s	9 m/s	13.5 m/s							
2704.9	710.6	215.0	41.9	19.0	7094	172.5	152.0	624.6	90.8

Duration: ARE 442

Test complete

“During high winds, the rotor operates at yaw errors of between approximately 30 degrees and 60 degrees and the furl movements excite the tower slightly. Overall, it appears that no excessive vibrations are occurring. In winds of between 8 m/s and 12 m/s the turbine tracks the wind well.”



Hours of Power Production Above:			Max Gust	TI @ 15 m/s (%)	T_T (hours)	T_U (hours)	T_E (hours)	T_N (hours)	O (%)
0 m/s	10.2 m/s	15.3 m/s							
3240.6	552.6	156.7	42.9	18.9	7249	99.7	214.8	612.0	91.2

Duration: EW50

Preliminary results; test not complete

“In light winds the EW50 was observed yawing to face upwind, and remain stable in the upwind position. In the upwind position the EW50 consumed power, depending on the wind speed. After 10 minutes of consuming power, the EW50 controller shut down and act of stopping the EW50 returned it to the downwind position. After 10 minutes, the EW50 sensed sufficient wind, and the EW50 released the brakes and started again.”



Hours of Power Production Above:			Max	TI @ 15	T_T	T_U	T_E	T_N	O
0 m/s	10.2 m/s	15.3 m/s	Gust	m/s (%)	(hours)	(hours)	(hours)	(hours)	(%)
1383.0	266.1	40.3	36.1	19.5	8706	1000.5	116.5	140.0	98.2

Preliminary data

Duration: Windspire

Testing was terminated after 5 months

“The turbine was exhibiting unsteady behavior periodically. There was a noise that seemed to come from the tower approximately three times per revolution. The washers at the foundation base were loose and the bolts and nuts on the foundation had shifted.”

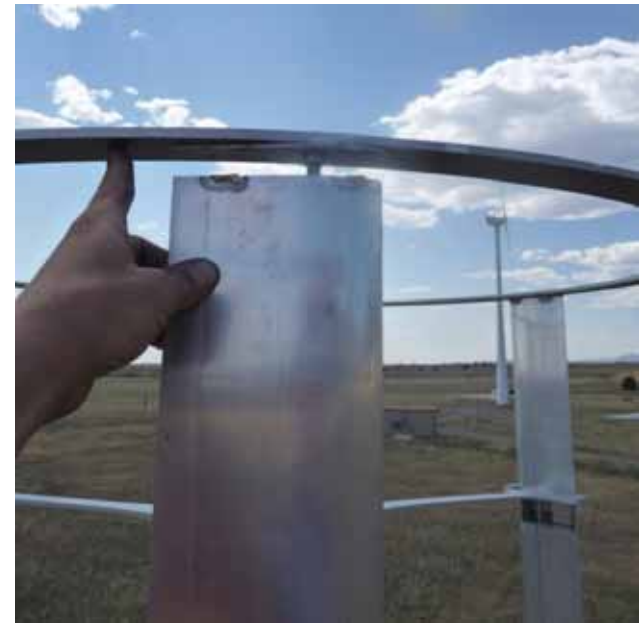


Table incomplete

Hours of Power Production Above:			Max	TI @ 15	T_T	T_U	T_E	T_N	O
0 m/s	7.2 m/s	10.8 m/s	Gust	m/s (%)	(hours)	(hours)	(hours)	(hours)	(%)
831.1	132.5	12.3	26.9	18.1	3091	93.7	79.3	198.1	93.2

Duration: VT10

Testing started April 2010

“The turbine tracks the wind well. Its blade tips govern rotor speed by pitching to stall, as designed. The turbine rotor emits more noise while governing than during normal operation, but no excessive vibrations observed during governing or normal operation.”



Hours of Power Production Above:			Max	TI @ 15	T_T	T_U	T_E	T_N	O
0 m/s	9 m/s	13.5 m/s	Gust	m/s (%)	(hours)	(hours)	(hours)	(hours)	(%)
95.5	41.8	16.3	31.8	19.9	538	12.7	396.2	0.0	100.0

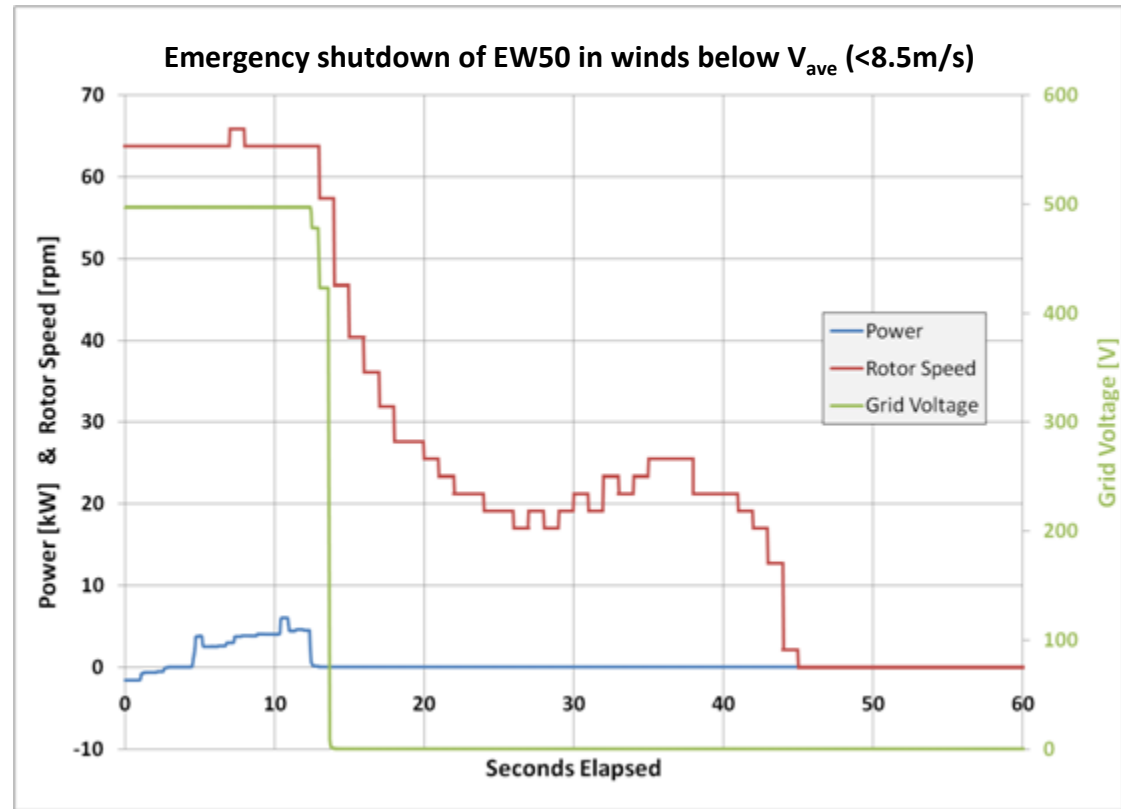
Preliminary data

Safety and Function

Test critical functions

- power control
- rotor-speed control
- normal start-up
- normal shutdown
- behavior at loss of load
- emergency shutdown
- fault detection

Turbine Specific tests



Testing examines the designed functions of the turbine, but it does not judge whether a turbine is safe

Preliminary Safety and Function Results

<i>Test method</i>	<i>Gaia 11 kW</i>	<i>ARE 442</i>	<i>EW50</i>	<i>Wind spire</i>	<i>VT10</i>	<i>Comments</i>
Power control	✓	✓	✓	✓	✓	
Rotor speed control	✓	x	✓	✓	x	ARE 442 - Data with rpm greater than design rpm VT10 - governing rpm is lower than design
Normal Start up	✓	✓	✓	✓	✓	Gaia - Error on start up after manual shut down Windspire - Normal resonance mode during start up
Normal shutdown	✓	✓	✓	✓	n/a	Windspire - Idling (3-10rpm) when braked, no high wind shut down
Loss of grid	✓	✓	✓	✓	✓	ARE - IGBTs failed twice when diversion loads engaged
Emergency stop	✓	✓	✓	✓	✓	EW50 - controller "stop" is overridden with grid failure VT10 - rotor can not be stoped in winds above 13m/s

- ✓ = successfully demonstrated
- x = not successfully demonstrated

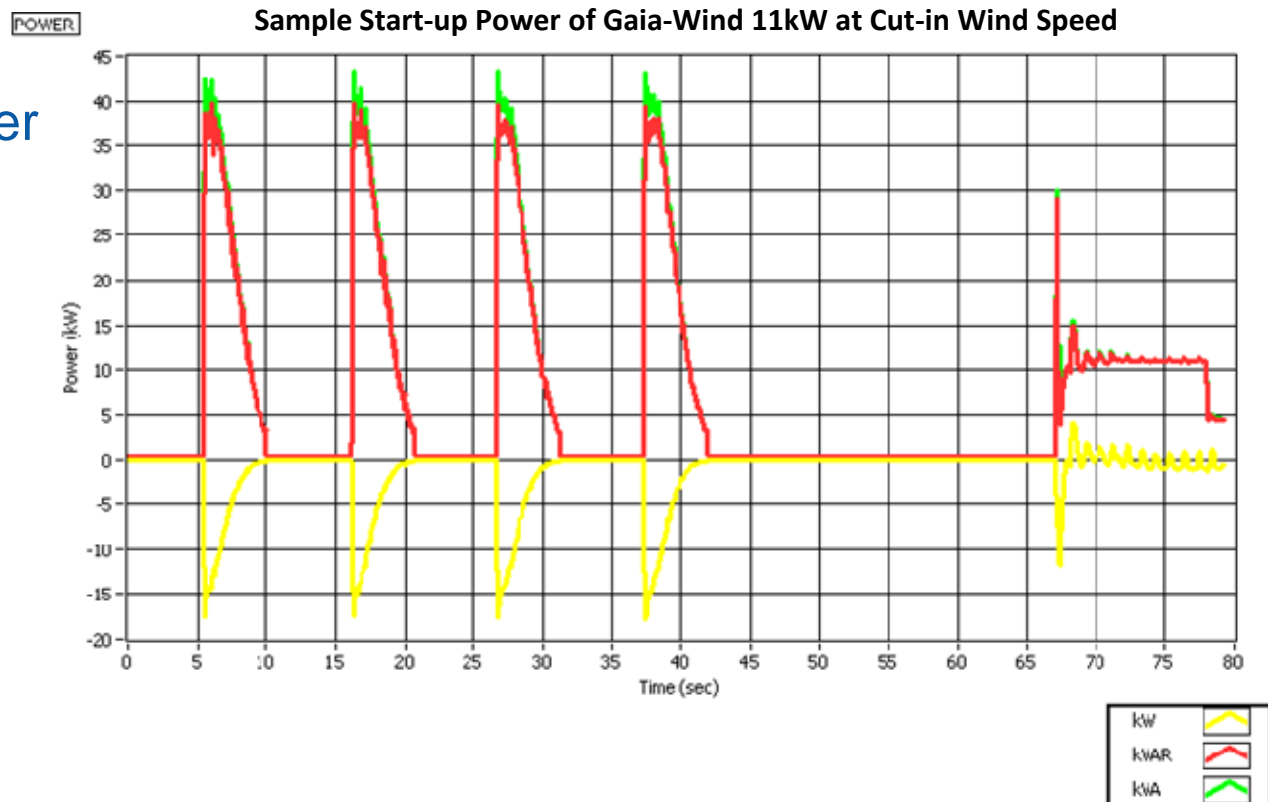
Power Quality

Applies to three-phase systems

- Gaia-Wind 11 kW (awaiting publication)
- Entegry EW50 (collecting data)

Measurements include

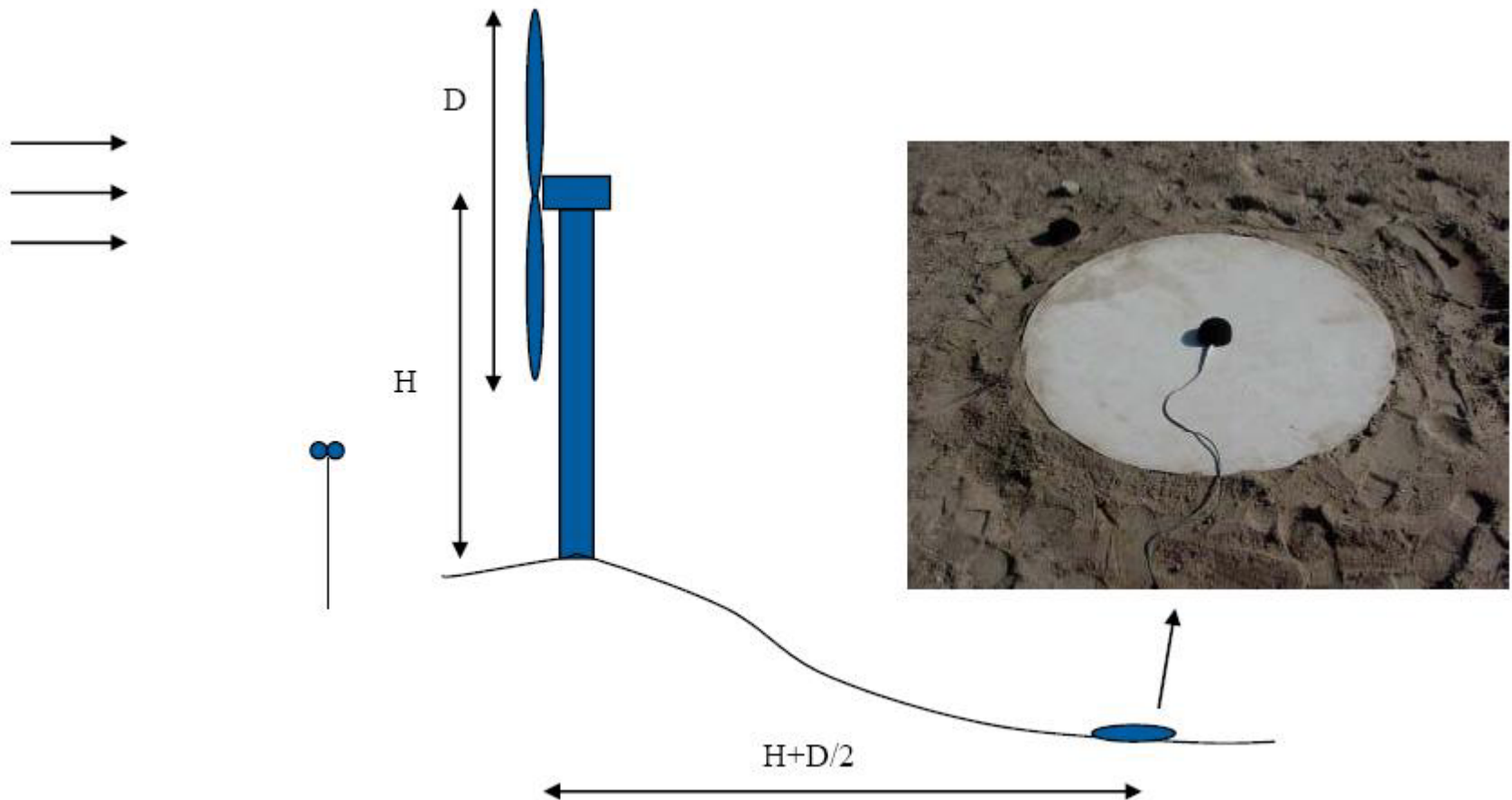
- voltage fluctuations
- flicker
- reactive power
- Harmonics



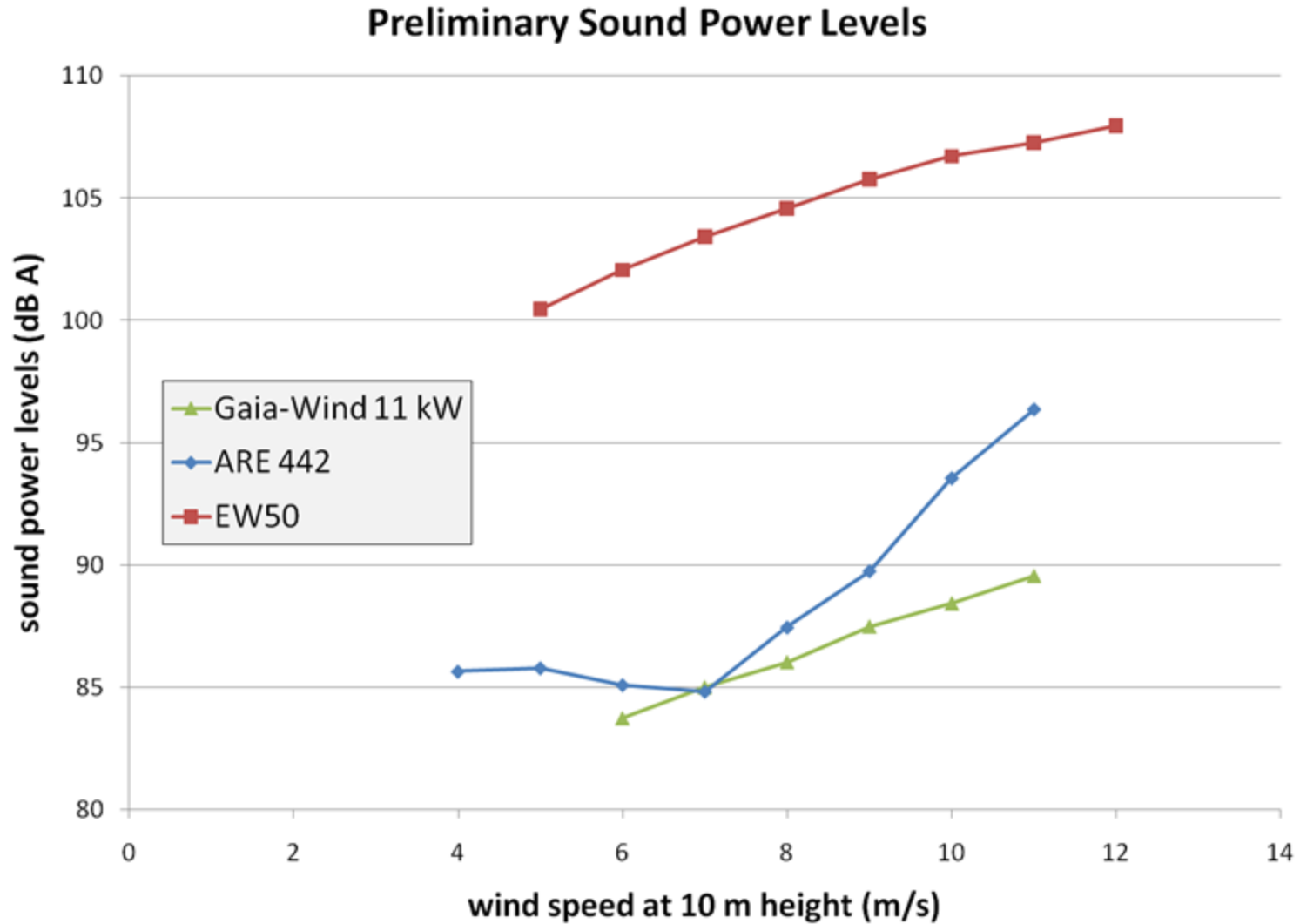
Noise Sound Power Level Results

Sound **power** level is a measure of the source strength, L_{WA}

Sound **pressure** level is a measure of the level at a receptor/distance (neighbor, microphone), L_{Aeq}



Noise Sound Power Level Results



Sound power level is a measure of the energy at the source,
for wind turbines the rotor center is the source

Independent Testing Website

www.nrel.gov/wind/smallwind/independent_testing.html

- Updated frequently
- Final results will include test reports and final summary
- Also includes past testing activities for small wind turbines

Thanks to the Independent Testing team

Arlinda Huskey
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