Testing of Wind Turbines

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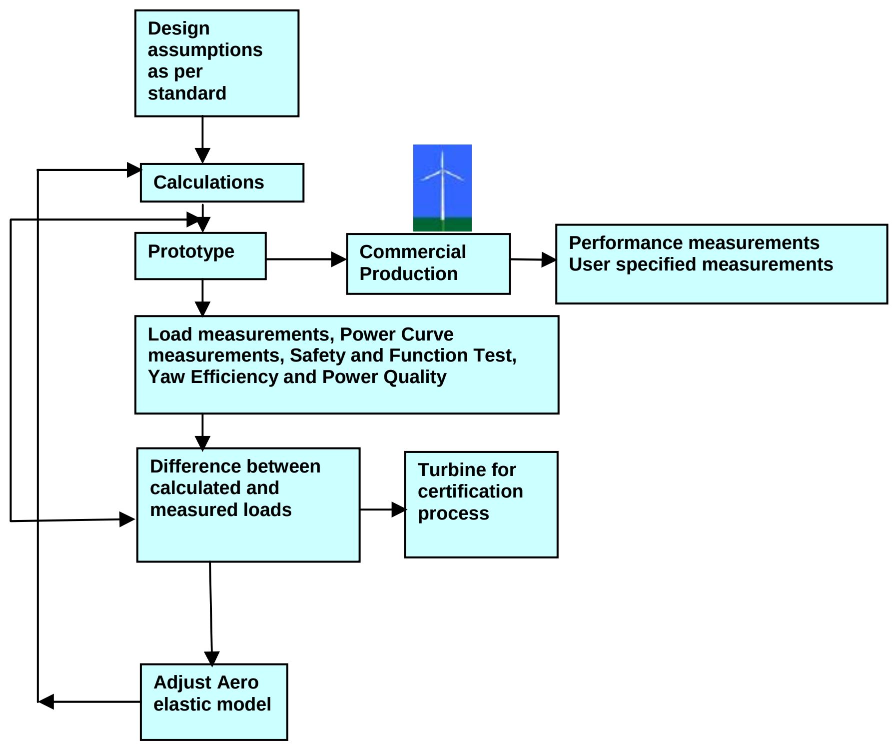
Wind turbine Testing is an important activity whereby calculations enabled by an aero elastic model are validated to improve the confidence in the design to ensure that the wind turbine can operate safety and optimally for a predicted lifetime. The design can also be improved subsequently for better performance by the evaluation of specific issues regarding terrain, environment and grid conditions vis-à-vis site specific measurements.

1. Requirement of Testing

The following flow chart gives the process from the design, design validation to commercial production of a wind turbine.

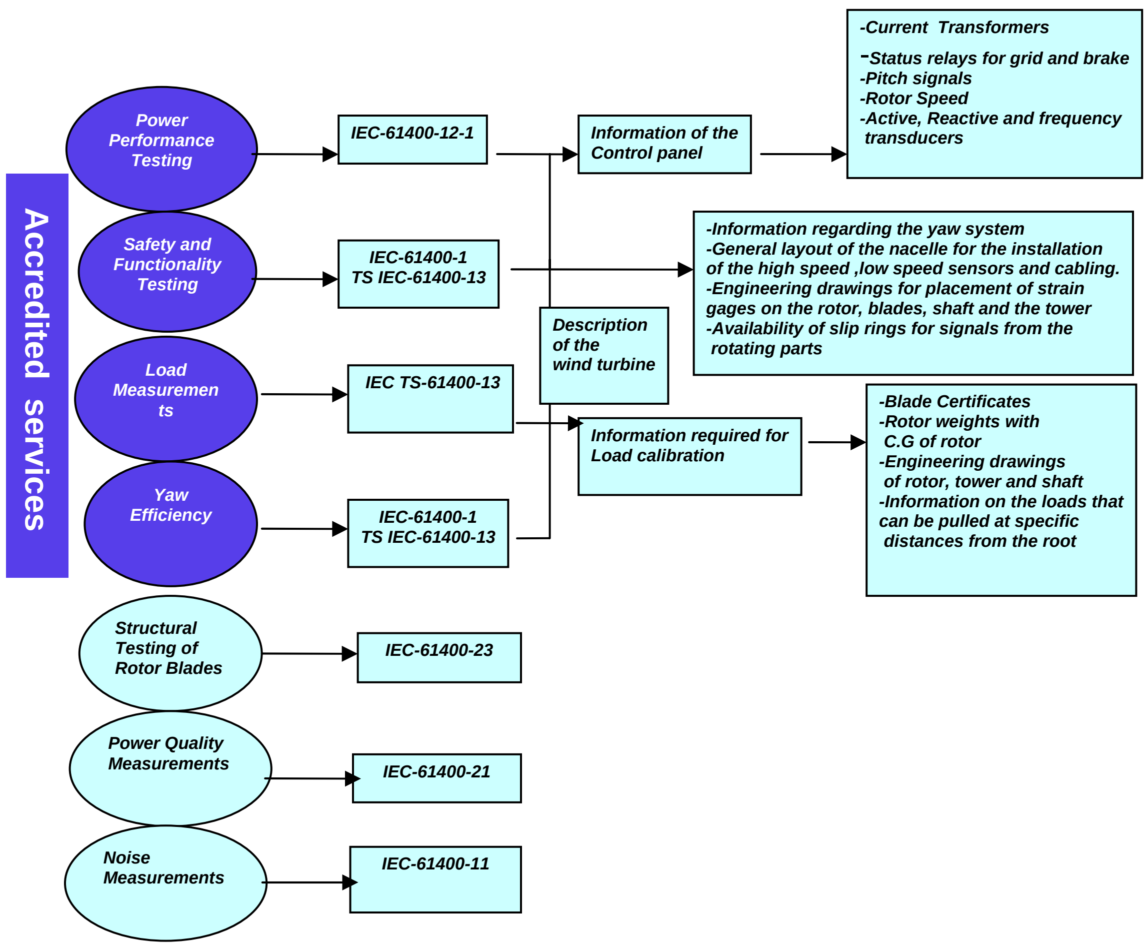


2. Benefits of Testing

Measurements are important inputs for the Designer, Manufacturer, Investor, Policy makers and for Research and development. These inputs are an integral part of the Type Certification process of a wind turbine wherein evaluation is made between the measured load vis-à-vis design loads.

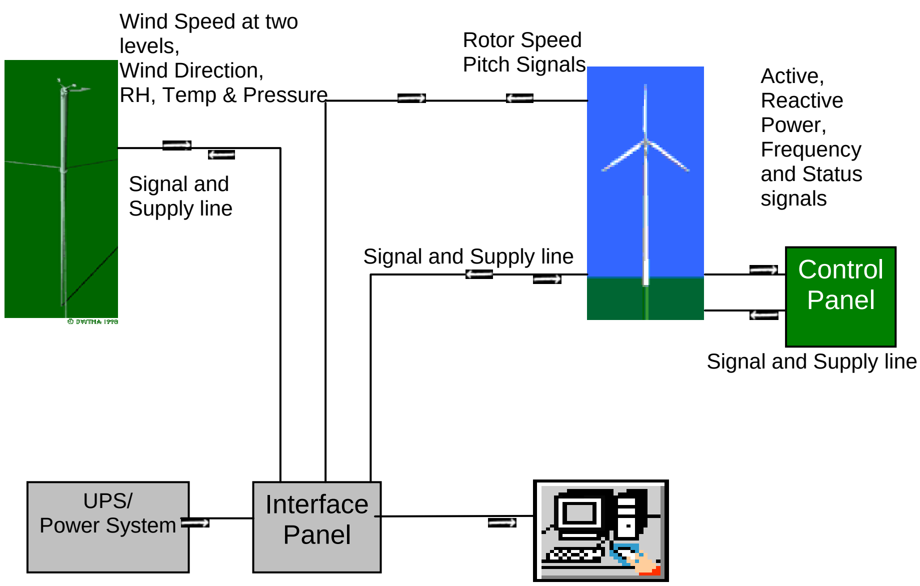
3. Overview of testing

The methodology of tests carried out on a wind turbine is as per the requirements of the specific International Standards issued by the International ElectroTechnical Commission (IEC). The reports issued by an accredited laboratory based on the IEC standards are accepted internationally. In order to carry out tests on a wind turbine the designer or the manufacturer has to draft a test plan which shall include information on technical details of site, wind turbine, instrumentation, data acquisition and details regarding scope of responsibilities and schedule of implementation. The overview of all tests and the corresponding International Standards is given below.



4. Power performance Testing

The power curve (or performance curve) is the most important characteristic of a Wind Turbine Generator (WTG). It describes the amount of electricity generated at different wind speeds. Experience has shown that measured power curves are much more reliable than calculated power curves that tend to be too optimistic. As a result measurements have the character of references, serving as sales arguments for the WTG manufacturers. Potential investors are therefore well advised to pay attention on the reliability of the power curve. It should be measured by an independent institute according to international standards and not calculated or estimated. A typical scheme is shown in the figure below. The measured power curve is often used by developers and manufacturers for a realistic estimate of the annual energy production at a particular terrain and environment condition.



The electrical power and coefficient of Power (Betz limit) are given by the equations 1 & 2

$$P = \frac{1}{2}\rho_{air} C_p A_r v_w^3 = \frac{1}{2}\rho_{air} C_p(\lambda, \theta)\pi r^2 v_w^3 \qquad - \qquad 1$$

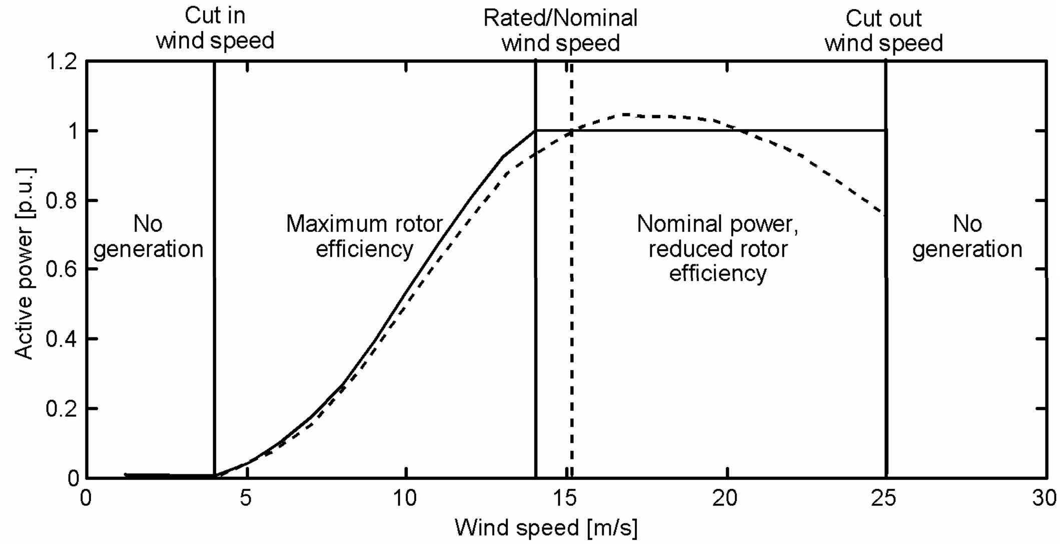
$$Cp = \frac{1}{2}[1 + [\frac{V2}{V1}] - [\frac{V2}{V1}]^2 - [\frac{V2}{V1}]^3] \qquad - \qquad 2$$

where

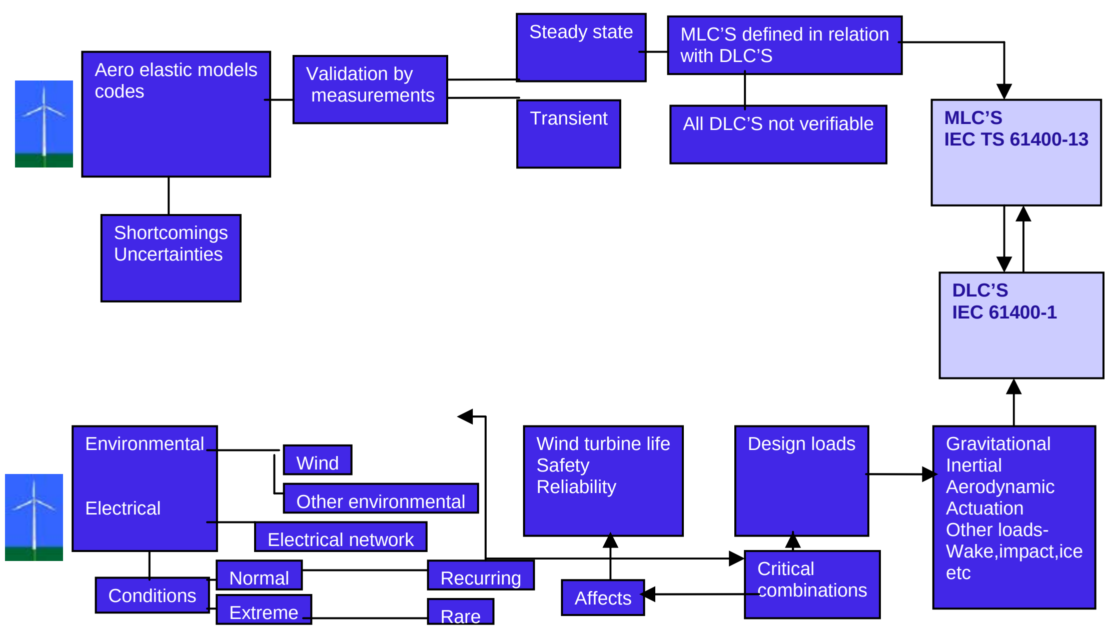
P is the electrical power in kW
P_{air} is the air density in kg/m^3
C_p is the coeffiecient of power []
A is the rotor swept area in m^2
V is the wind speed in m/sec^2
V_1 is the upstream free flow wind speed in m/sec^2
V_2 is the downstream wake wind speed in m/sec^2

The power depends on the air density, swept area, wind speed and the rotor extraction efficiency and the performance can be improved if the design of the wind turbine is optimized for specific terrain, environmental and grid conditions.

A typical power curve is given below .The important issues of a power curve are cut-in and cut-out, cut-in and cutout hysteresis, power in the operating range and regulation. The power curve gives a very realistic indication of the performance and the safety of the wind turbine.



5. Load measurements



The mechanical loads which affect the wind turbine during its operational, transient and stand still conditions are required to be quantified. These loads are mainly from the rotor (the unit which constitutes three blades), nacelle (the unit which constitutes the main rotor shaft) and tower (the unit that holds the whole rotor and nacelle unit). The Measurement Load Cases (MLCs) are defined in relation to Design Load Cases (DLCs) described in 61400-1. All DLCs cannot be reasonably verified by measurements. The following are the mechanical loads in general which are related to specific DLCs and MLCs in the relevant IEC standards.

Blade loads

1. Edge-wise bending moment
2. Flap-wise bending moment

Rotor loads

1. Tilt moment
2. Yaw moment

Shaft loads

1. Shaft torque
2. Shaft bending moment in XX axis
3. Shaft bending moment in YY axis

Tower loads

1. Bending moments in XX axis at tower bottom
2. Bending moments in YY axis at tower bottom
3. Torsion at tower top

Measurement of Loads

The reference standard adopted for measurement of wind turbine loads is the "Technical Specification: IEC TS 61400-13, Wind turbine generator systems-Part 13: Measurement of mechanical loads"

Measurement Techniques

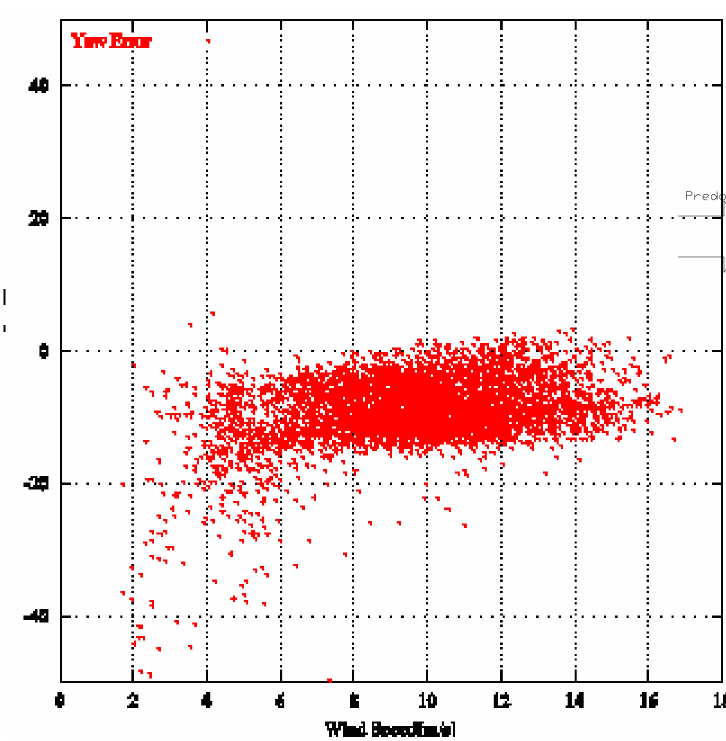
The measurement techniques for the various types of quantities in load measurements include

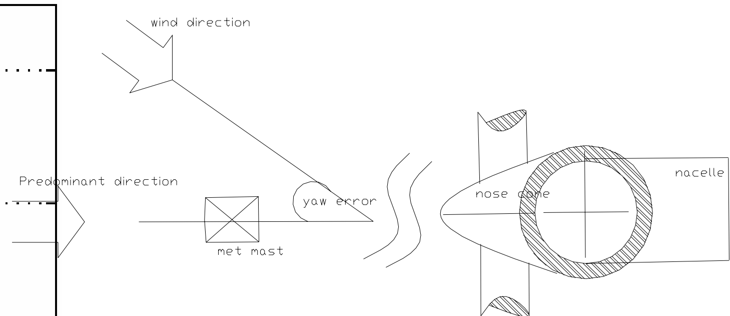
1. Instrumentation
2, Calibration
3. Signal Conditioning

Load measurements are used to determine the natural frequencies and equivalent loads on wind turbine components. The equivalent loads are evaluated using rain flow counting technique. The concept of the equivalent load is a convenient, short handed description of the fatigue impact of a given load measurement time history. The equivalent load is conceptually the single load equivalent that when applied with the total number of cycles in a given time history appearing at a given frequency does the same fatigue damage as the sum of all the different rain-flow counted load amplitudes in the measured load spectrum. The advantage of the equivalent load is that it provides a single descriptor of the fatigue damaging potential of a particular loading during a given time period. The equivalent loads are calculated for different wind speeds.

6. Yaw Efficiency

The yaw efficiency test indicates the capability of the wind turbine to follow the wind. It is the difference between the wind direction and the yaw position. The wind turbine is designed for the loads corresponding to the misalignment of specific values of yaw error. The measurement of the yaw error assists in the comparison of the measured values vis-à-vis the designed values. The rate at which the yaw system is enabled as defined in the controller during operating and fault conditions is also measured and compared. The yaw error at low winds are generally higher when compared to higher wind speeds as the winds are generally consistent at higher wind speeds.





7. Safety and Function Testing

The function and safety testing demonstrates the capability of the wind turbine to respond to the designed functions and to operate safely as per control and protection strategy of the wind turbine.

The following function and protection tests are carried out

Function
-Start up
-Normal stop Test
-Emergency stop Test

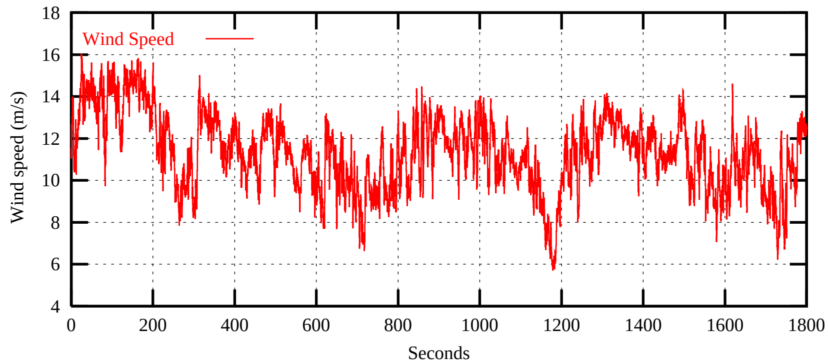
-Vibration Test
-Yawing
-Cable Twist

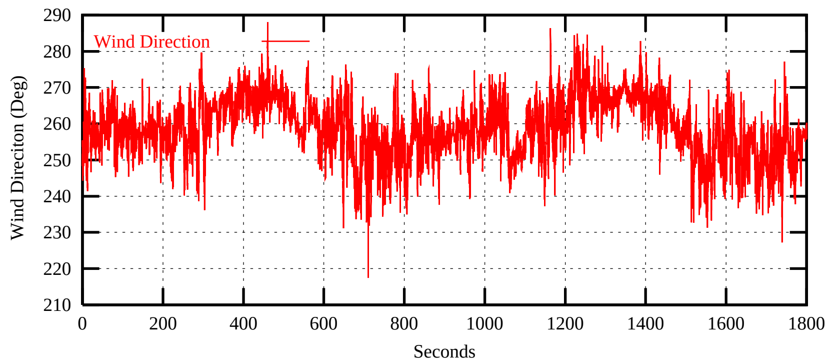
Protection
-Start up
-Normal stop Test
-Emergency stop Test
-Vibration Test
-Yawing
-Cable Twist

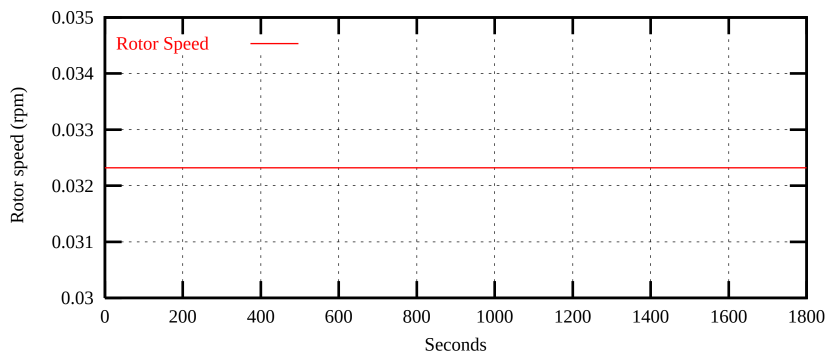
The parameters which are measured during the safety and function testing are given in the following table

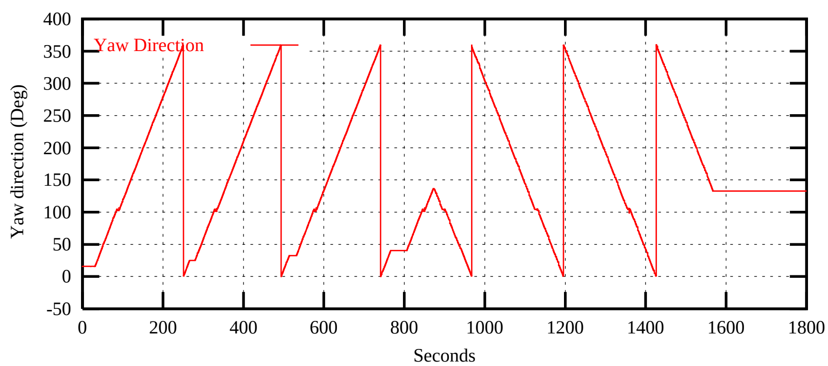
Safety & Function testing	**Parameters ***											
	WS	**WD**	**RS**	**RP**	**YD**	**EBM**	**FBM**	**ST**	**AP**	**TC**	**GS**	**BS**
Startup test	✓		✓			✓	✓	✓	✓		✓	✓
Normal stop test	✓		✓			✓	✓	✓	✓		✓	✓
Emergency stop test	✓		✓			✓	✓	✓	✓		✓	✓
Vibration test	✓		✓			✓	✓	✓	✓		✓	✓
Grid failure test	✓		✓			✓	✓	✓	✓		✓	✓
Overspeed test	✓		✓			✓	✓	✓	✓		✓	✓
Cutin to grid test	✓					✓	✓	✓	✓			
Yaw functionality	✓	✓	✓		✓			✓			✓	✓
Cable twist test	✓	✓	✓		✓			✓			✓	✓
Backwind operation	✓	✓	✓	✓	✓							
Cutin measurement								✓	✓	✓		

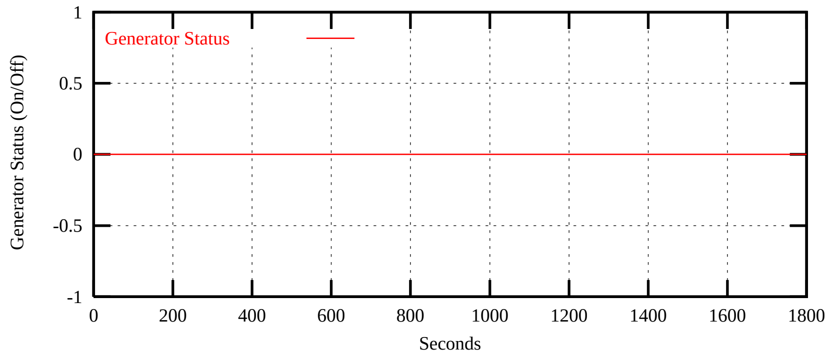
The following figures demonstrate the capability of function and the protection of the wind turbine during a cable twist test.

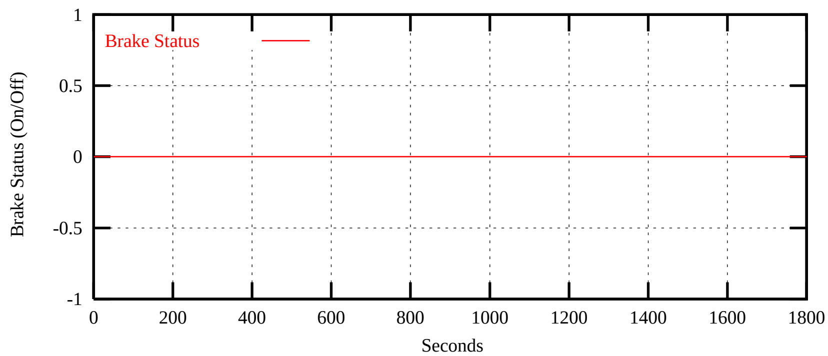

Wind Speed
Wind speed (m/s)
18
16
14
12
10
8
6
4
0
200
400
600
800
1000
1200
1400
1600
1800
Seconds


Wind Direction
Wind Direciton (Deg)
290
280
270
260
250
240
230
220
210
0
200
400
600
800
1000
1200
1400
1600
1800
Seconds


Rotor Speed
Rotor speed (rpm)
0.035
0.034
0.033
0.032
0.031
0.03
0
200
400
600
800
1000
1200
1400
1600
1800
Seconds


Yaw Direction
Yaw direction (Deg)
400
350
300
250
200
150
100
50
0
-50
0
200
400
600
800
1000
1200
1400
1600
1800
Seconds





8. Conclusion

Measurements assists in understanding performance and safety issues at specific environment, terrain and grid conditions which enables design improvements. The awareness to the requirements of testing and its importance is the need of the hour to understand the operation of the wind turbine, improve the design and performance and to realize the benefits of wind turbine technology as envisaged by the entire stake holders in the wind energy sector.