

Testing of Wind Turbines

S.A.Mathew

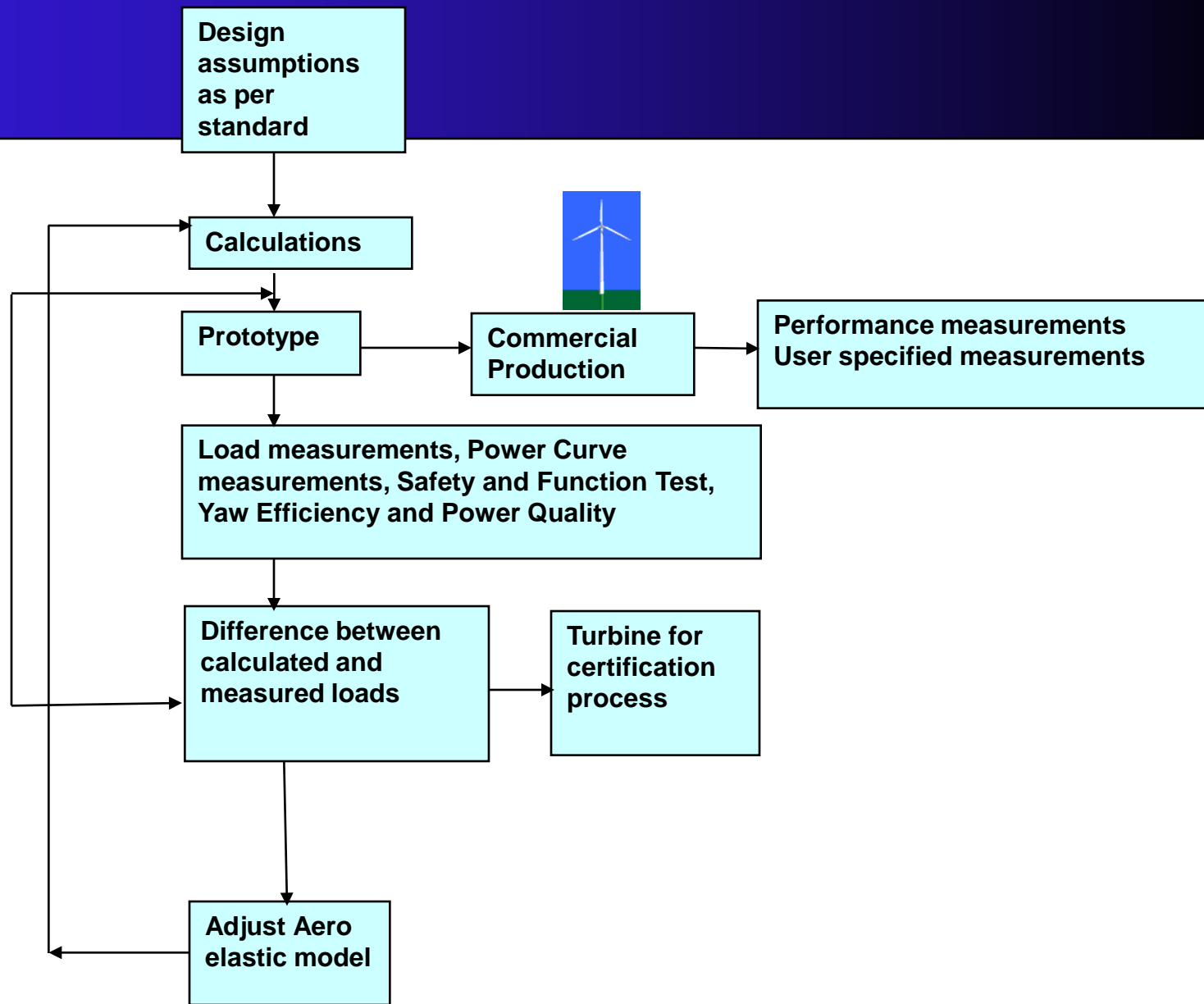
Unit Head-Testing

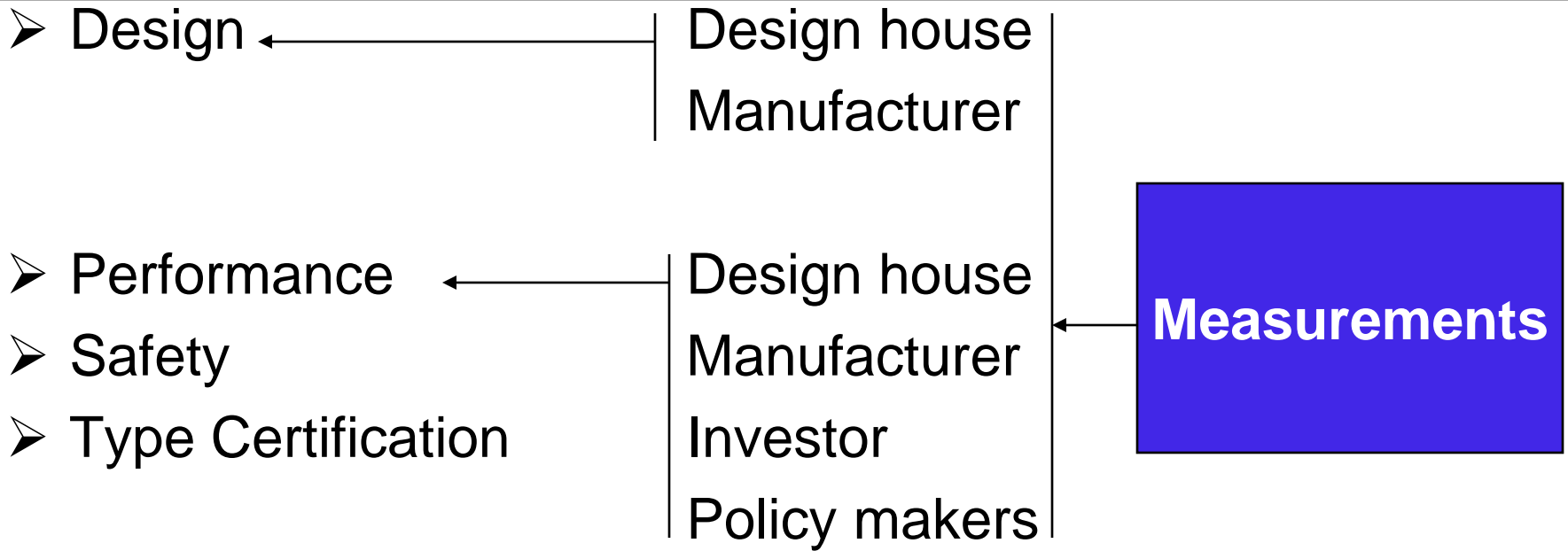
Centre for Wind Energy Technology, Chennai

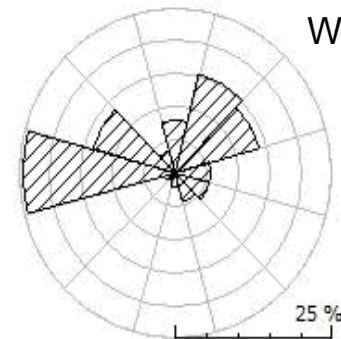


- Requirement of Testing
- Benefits of Testing
- Overview of testing
- Power performance Testing
- Load measurements
- Yaw Efficiency
- Safety and Function Testing
- Instrumentation









Wind Rose at WTTS

Located around 650 Kms from Chennai towards South.

Winds predominantly from the western direction

Site conforms to the recommendations of IEC standards regarding obstacles, terrain and wind

Two test beds with necessary infrastructure to test wind turbine capacities upto 400 kW and 1250 kW available and can be upgraded as per the requirements of customers

Services accredited as per the requirements of ISO/IEC 17025:2005





Accredited services

Power Performance Testing

IEC-61400-12-1

Information of the Control panel

- Current Transformers
- Status relays for grid and brake
- Pitch signals
- Rotor Speed
- Active, Reactive and frequency transducers

Safety and Function Testing

IEC-61400-1
IEC TS -61400-13

- Information regarding the yaw system
- General layout of the nacelle for the installation of the high speed, low speed sensors and cabling.
- Engineering drawings for placement of strain gages on the rotor, blades, shaft and the tower
- Availability of slip rings for signals from the rotating parts

Load Measurements

IEC TS-61400-13

Description of the wind turbine

Information required for Load calibration

- Blade Certificates
- Rotor weights with C.G of rotor
- Engineering drawings of rotor, tower and shaft
- Information on the loads that can be pulled at specific distances from the root

Yaw Efficiency

IEC-61400-1
IEC TS -61400-13

Structural Testing of Rotor Blades

IEC-61400-23

Power Quality Measurements

IEC-61400-21

Noise Measurements

IEC-61400-11

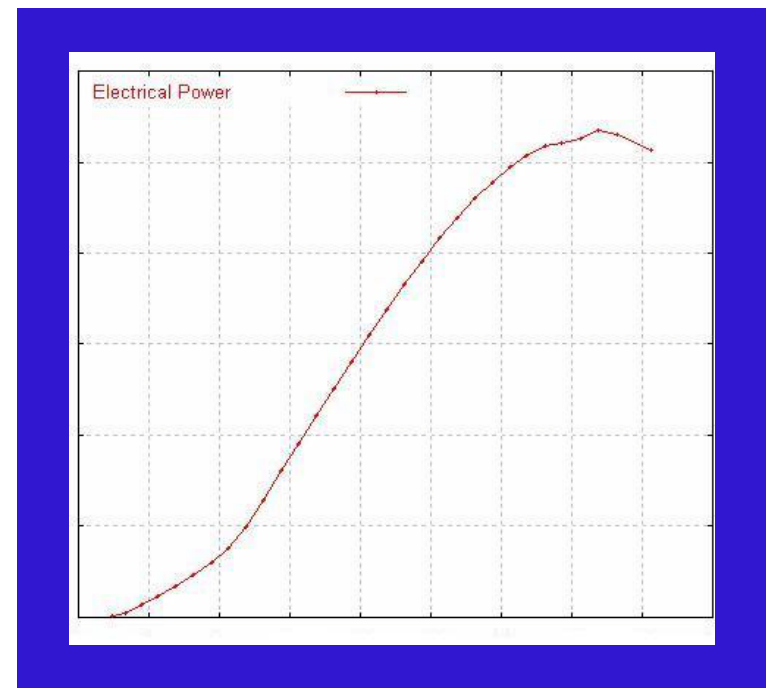
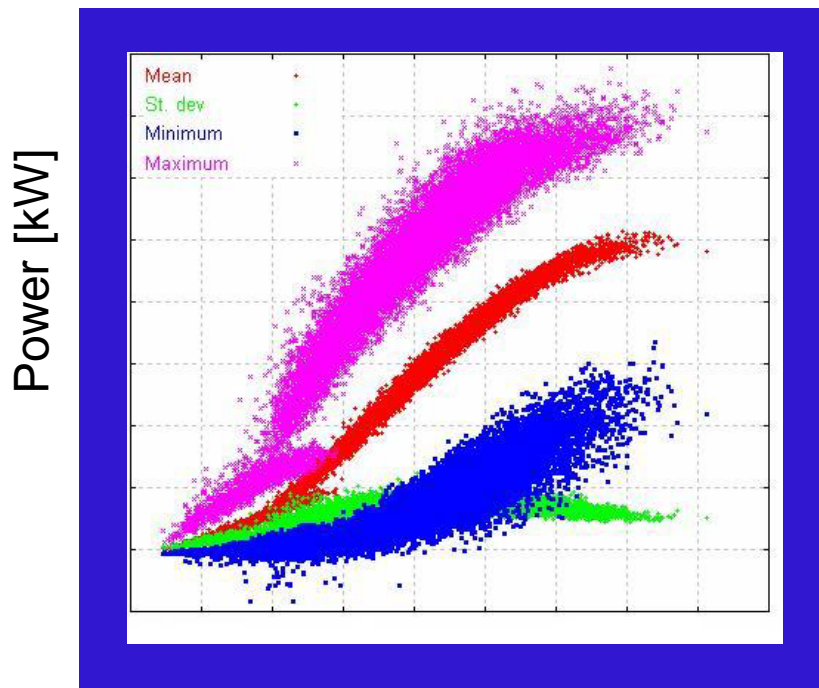
Overview of Testing

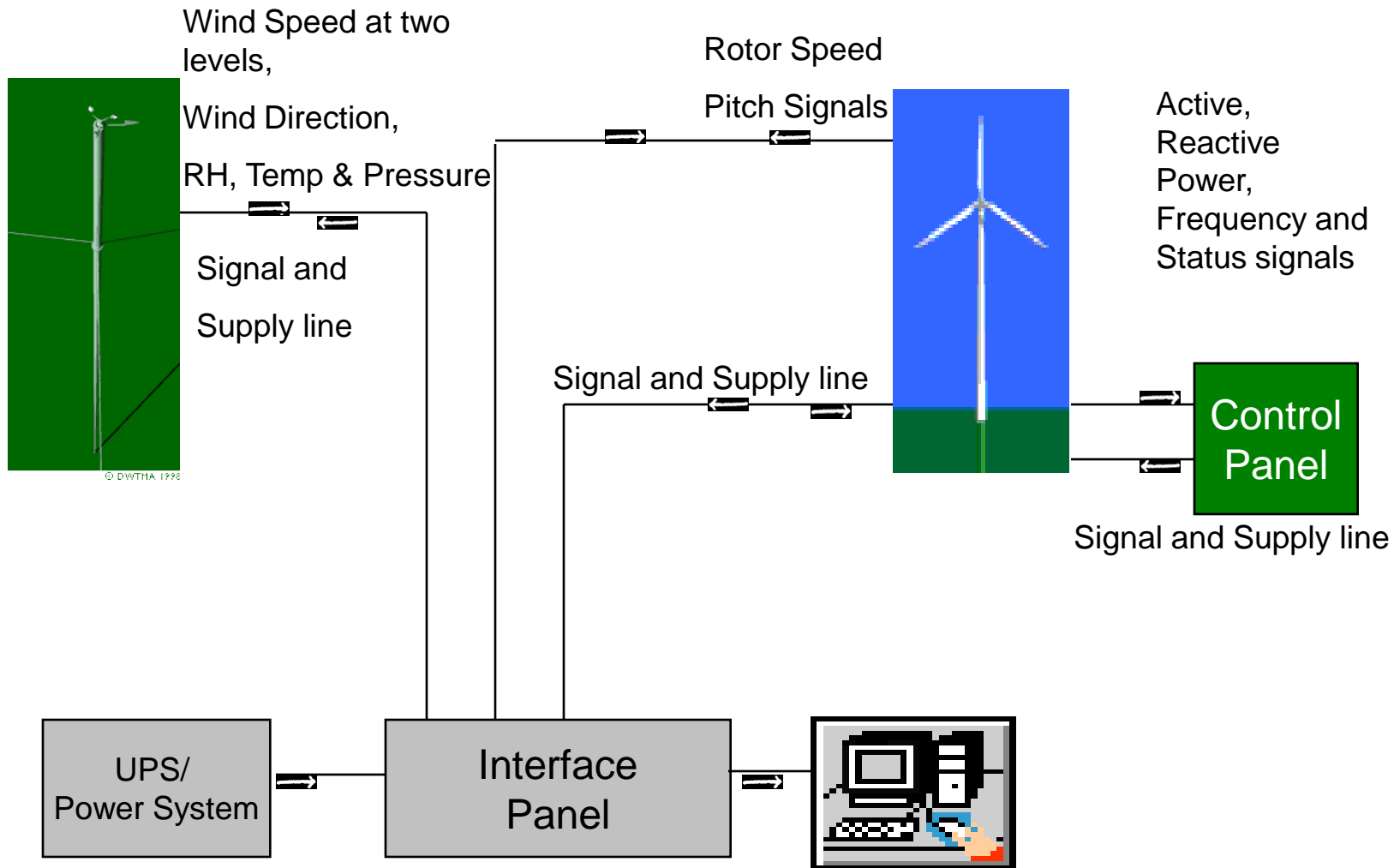


International Standards

Power Performance measurements

- Demonstrates the capability of a wind turbine to produce electrical power at different wind speeds





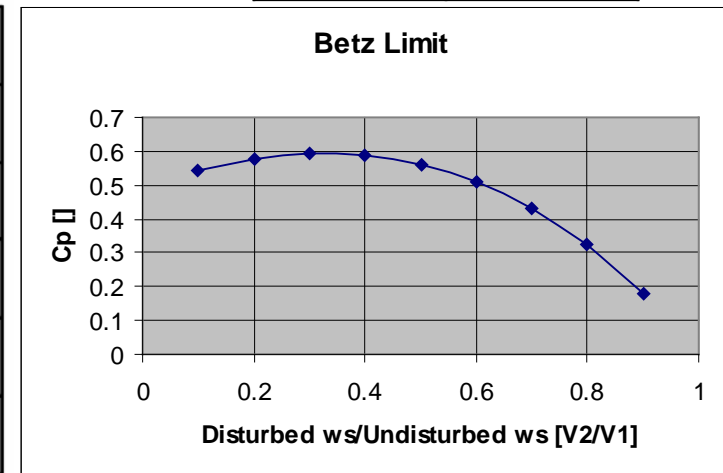
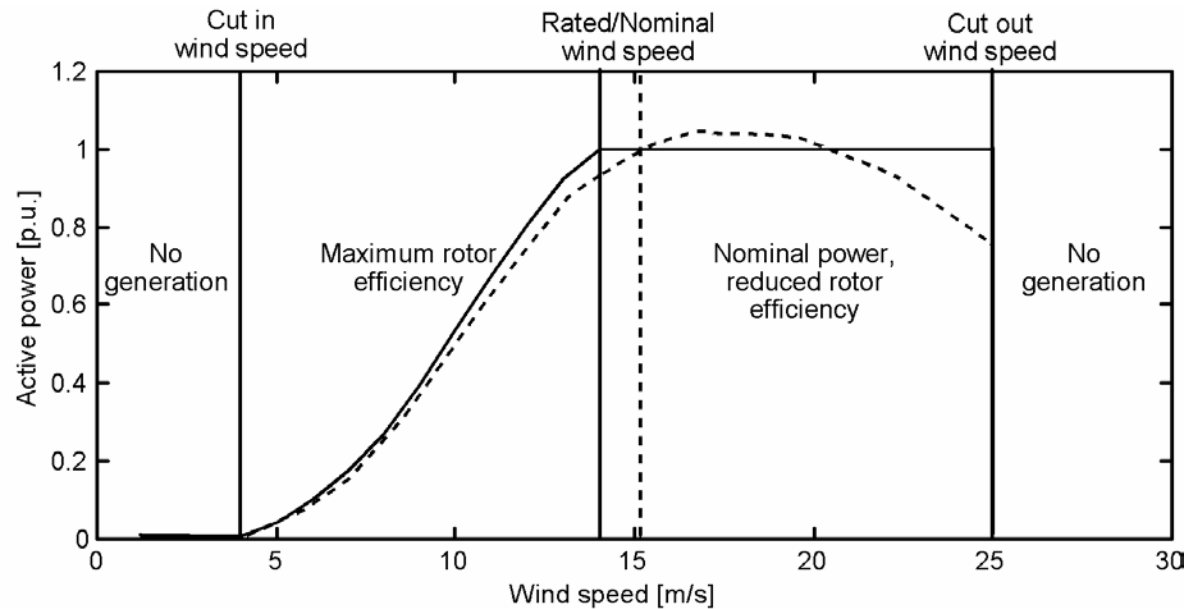
- **Evaluation of the site and Selection of the site**
- **Locating the wind mast.**
- **Defining a suitable measurement sector after the mapping of terrain and obstacles in the predominant wind direction.**
- **Establishing proper flow distortion correction factors in terrains of complex nature.**
- **Selection and Installation of test Equipment.**
- **Data Acquisition and analysis.**
- **Data Reporting.**
- **Uncertainty Calculations.**

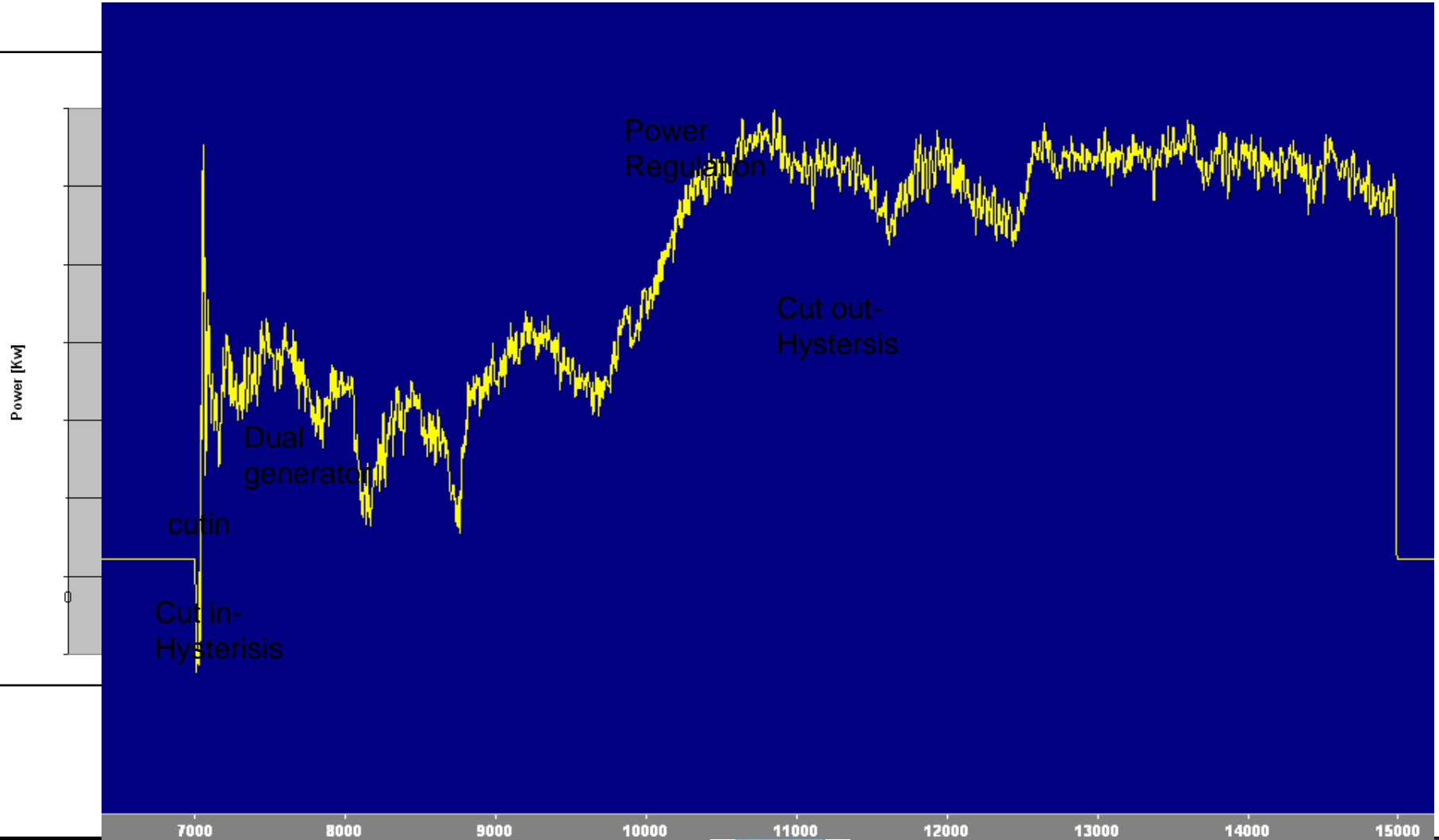


$$P = \frac{1}{2} \rho_{air} C_p A_r v_w^3 = \frac{1}{2} \rho_{air} C_p(\lambda, \theta) \pi r^2 v_w^3$$

$$C_p = \frac{1}{2} \left[1 + \left[\frac{V_2}{V_1} \right] - \left[\frac{V_2}{V_1} \right]^2 - \left[\frac{V_2}{V_1} \right]^3 \right]$$

0.1	0.5445
0.2	0.576
0.3	0.5915
0.4	0.588
0.5	0.5625
0.6	0.512
0.7	0.4335
0.8	0.324
0.9	0.1805





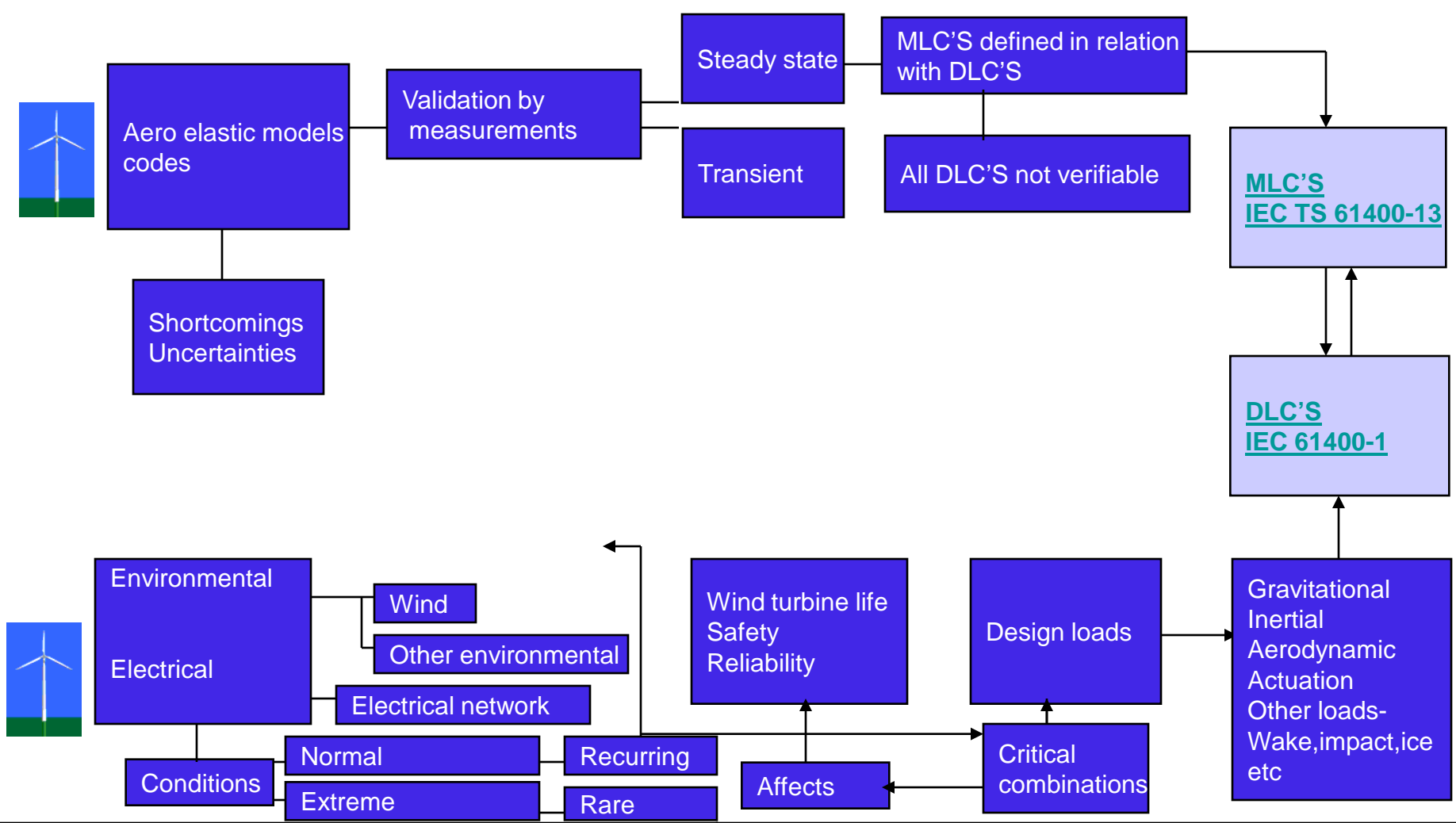


Table 2 – Design load cases

Design situation	DL C	Wind condition	Other conditions	Type of analysis	Partial safety factors
1) Power production	1.1	NTM $V_{in} < V_{hub} < V_{out}$	For extrapolation of extreme events	U	N
	1.2	NTM $V_{in} < V_{hub} < V_{out}$		F	*
	1.3	ETM $V_{in} < V_{hub} < V_{out}$		U	N
	1.4	EOC $V_{hub} = V_T - 2 \text{ m/s}$, $V_T + 2 \text{ m/s}$		U	N
	1.5	EWS $V_{in} < V_{hub} < V_{out}$		U	N
2) Power production plus occurrence of fault	2.1	NTM $V_{in} < V_{hub} < V_{out}$	Control system fault or loss of electrical network	U	N
	2.2	NTM $V_{in} < V_{hub} < V_{out}$	Protection system or preceding internal electrical fault	U	A
	2.3	EOG $V_{hub} = V_T \pm 2 \text{ m/s}$ and V_{out}	External or internal electrical fault including loss of electrical network	U	A
	2.4	NTM $V_{in} < V_{hub} < V_{out}$	Control, protection, or electrical system faults including loss of electrical network	F	*
3) Start up	3.1	NWP $V_{in} < V_{hub} < V_{out}$		F	*
	3.2	EOG $V_{hub} = V_{in}$, $V_T \pm 2 \text{ m/s}$ and V_{out}		U	N
	3.3	EOC $V_{hub} = V_{in}$, $V_T \pm 2 \text{ m/s}$ and V_{out}		U	N
4) Normal shut down	4.1	NWP $V_{in} < V_{hub} < V_{out}$		F	*
	4.2	EOG $V_{hub} = V_T \pm 2 \text{ m/s}$ and V_{out}		U	N
5) Emergency shut down	5.1	NTM $V_{hub} = V_T \pm 2 \text{ m/s}$ and V_{out}		U	N
6) Parked (standing still or idling)	6.1	EWM 50-year recurrence period		U	N
	6.2	EWM 50-year recurrence period	Loss of electrical network connection	U	A
	6.3	EWM 1-year recurrence period	Extreme yaw misalignment	U	N
	6.4	NTM $V_{hub} < 0,7 V_{ref}$		F	*
7) Parked and fault conditions	7.1	EWM 1-year recurrence period		U	A
8) Transport, assembly, maintenance and repair	8.1	NTM V_{max} to be stated by the manufacturer		U	T
	8.2	EWM 1-year recurrence period		U	A



Table 2 – Measurement of transient load cases related to the DLCs defined in IEC 61400-1

MLC	Measurement load case MLC	DLC	Target wind speed
2.1	Start-up	3.1	v_{in} and $> v_r + 2$ m/s
2.2	Normal shut-down	4.1	v_{in} , v_r and $> v_r + 2$ m/s
2.3	Emergency shut-down	5.1	v_{in} and $> v_r + 2$ m/s
2.4	Grid failure	1.5	v_r and $> v_r + 2$ m/s
2.5	Overspeed activation of the protection system	5.1	$> v_r + 2$ m/s
Ideally the measurements should be taken at v_{out} . As this is impractical, the measurements are taken at wind speeds higher than $v_r + 2$ m/s.			

Table 1 – MLCs during steady-state operation related to the DLCs defined in IEC 61400-1

MLC number	Measurement load case MLC	DLC number (IEC 61400-1)	Wind condition at DLC	Remarks
1.1	Power production	1.2	$v_{in} < v_{hub} < v_{out}^*$	In this mode of operation, the wind turbine is running and connected to the grid
1.2	Power production plus occurrence of fault	2.3	$v_{in} < v_{hub} < v_{out}^*$	Any fault in the control or protection system, which does not cause an immediate shut-down of the turbine
1.3	Parked, idling	6.2	$v_{in} < v_{hub} < 0,75 v_{e1}^*$	When the wind turbine is parked, the rotor may either be stopped or idling

* Has to be divided further into wind speed bins and turbulence bins.



Loads

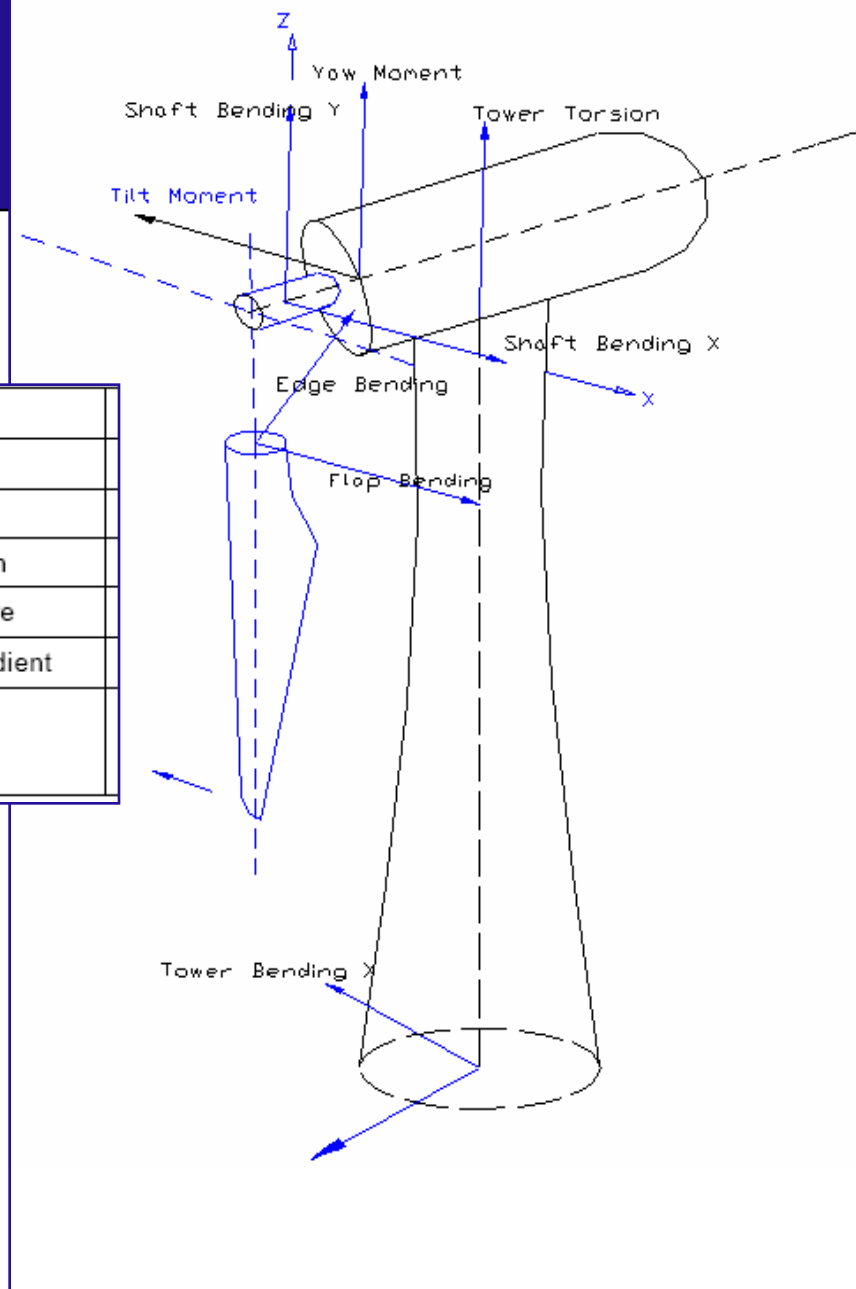
Load quantities
Blade root loads
Rotor loads
Tower loads

Meteorological parameters

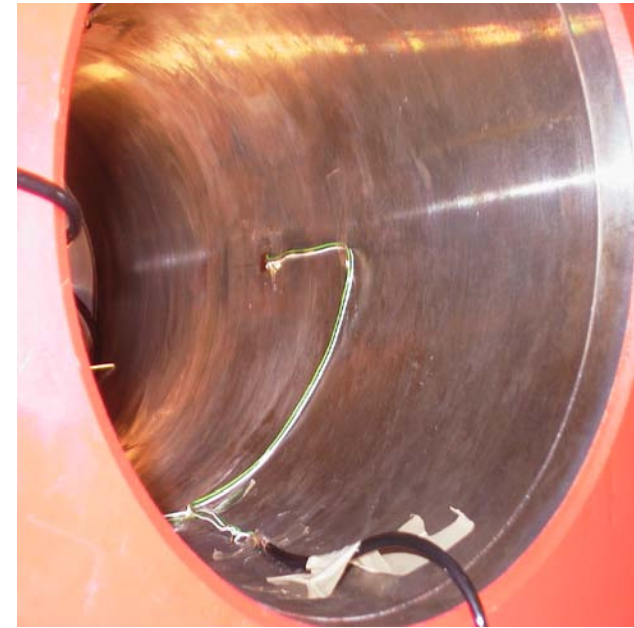
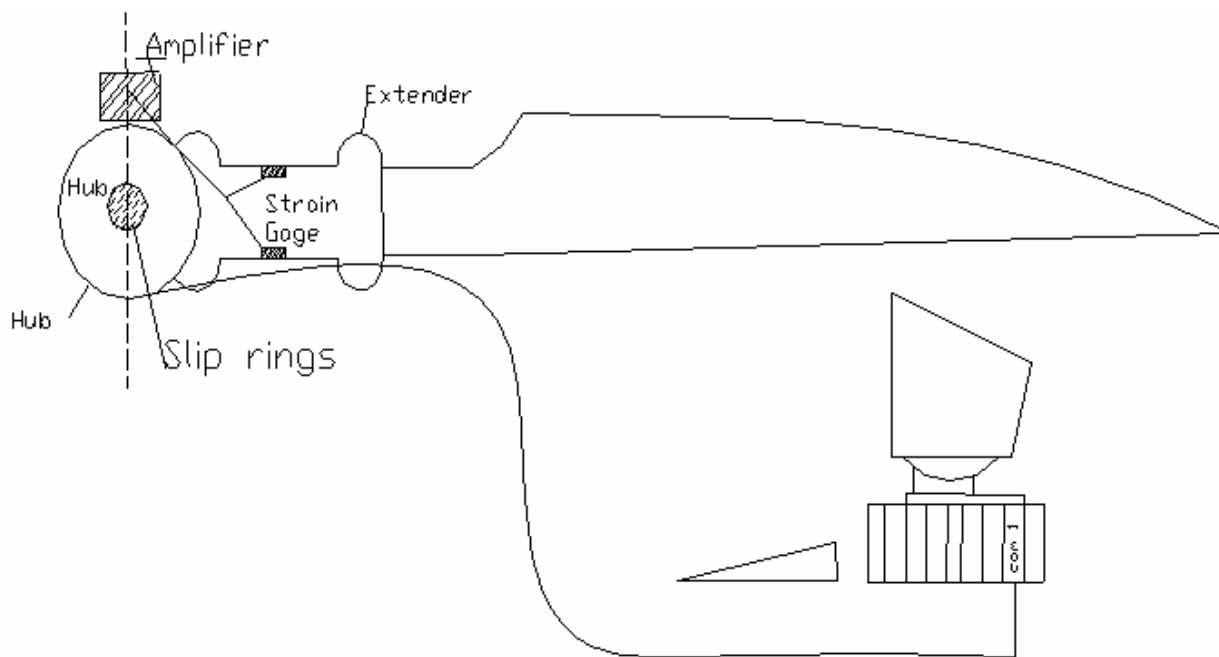
Quantity
Wind speed
Wind shear
Wind direction
Air temperature
Temperature gradient
Air density

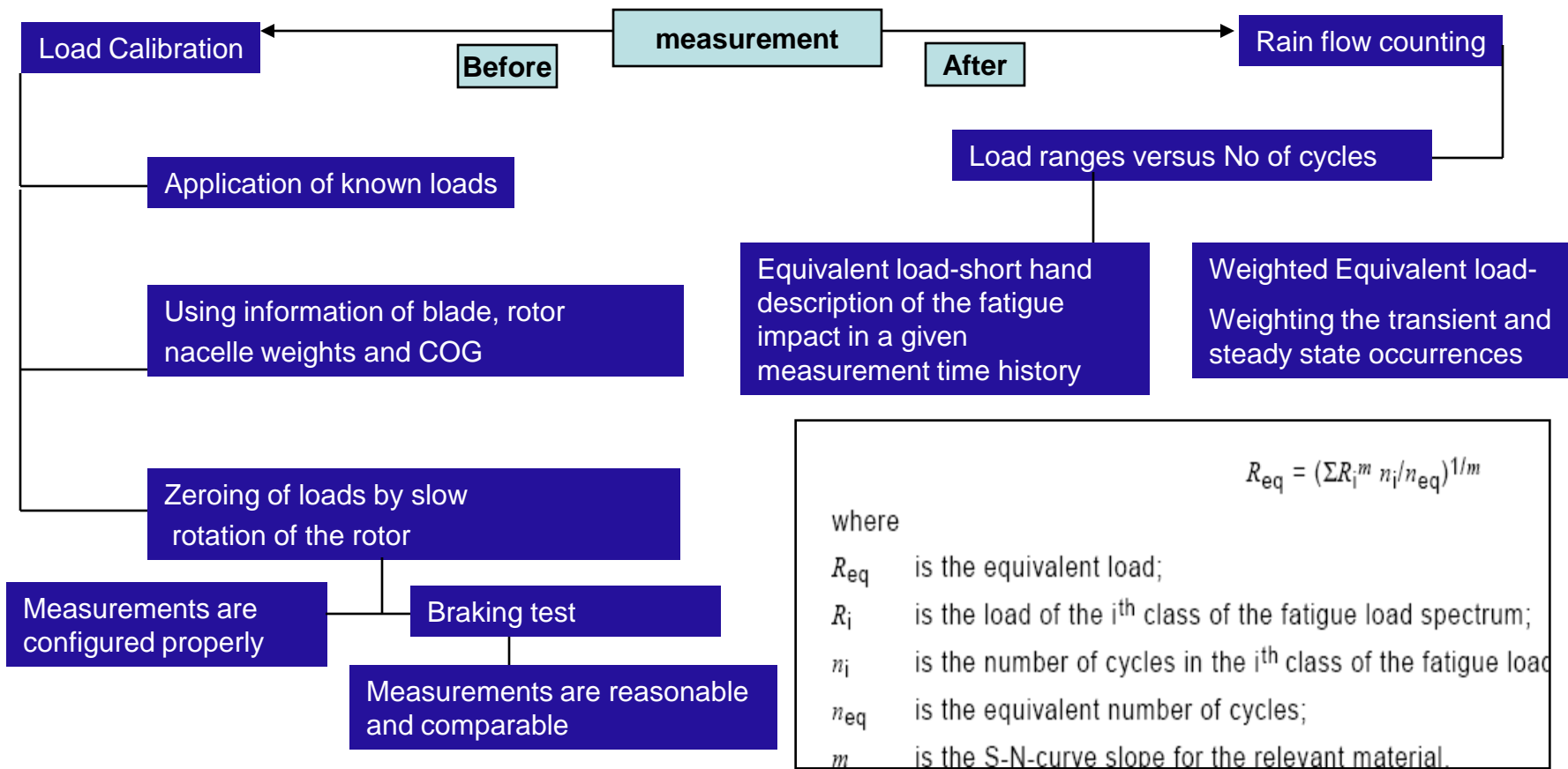
Other parameters

Quantity
Electrical power
Rotor speed
Pitch angle
Yaw position
Rotor azimuth
Grid connection
Brake status
Wind turbine status

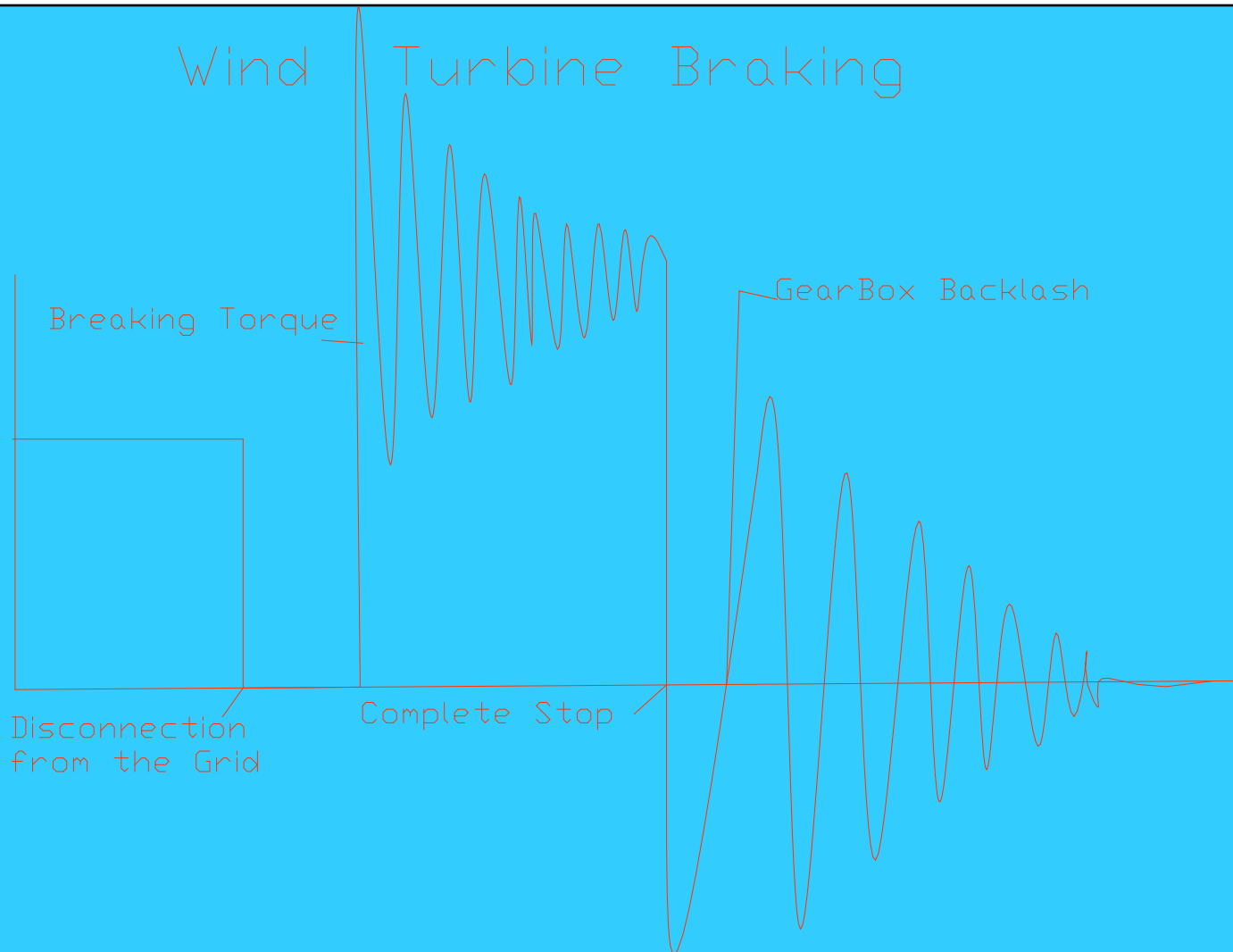


- Selection of places in the wind turbine to measure loads
- Strain gaging and instrumentation
- Calibration
- Measurement and Analysis of data





Wind Turbine Braking



The yaw efficiency test indicates the capability of the wind turbine to follow the wind

Difference between the wind direction and the yaw position

Affects of higher yaw error

Reduction in Electrical power

Increase in mechanical loads

Design considerations-Requirements for test

DLC 6.1-yaw misalignment of up to $\pm 15^\circ$ using the steady extreme wind model or a mean yaw misalignment of $\pm 8^\circ$ using the turbulent extreme wind model

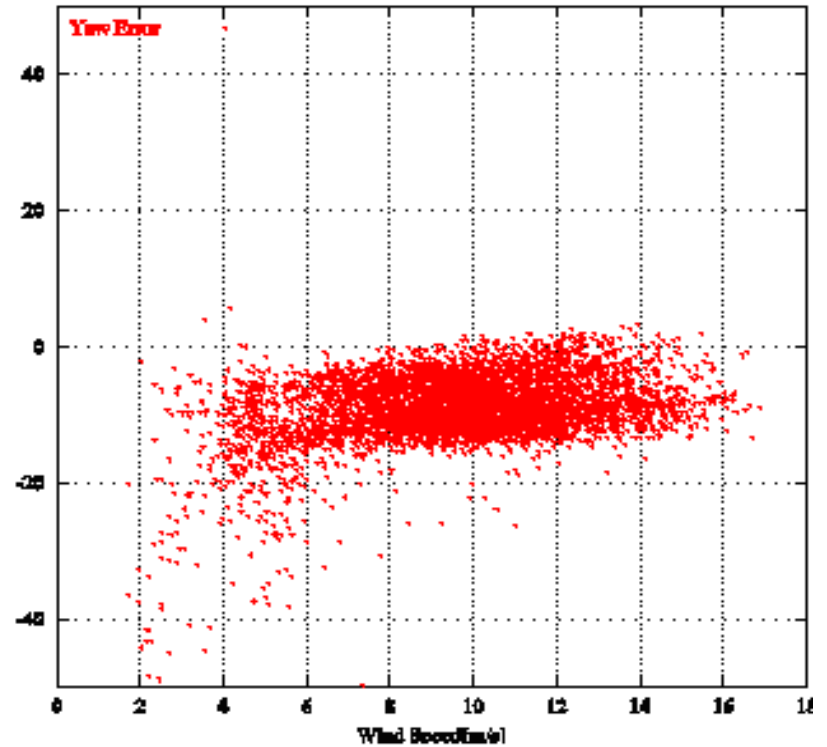
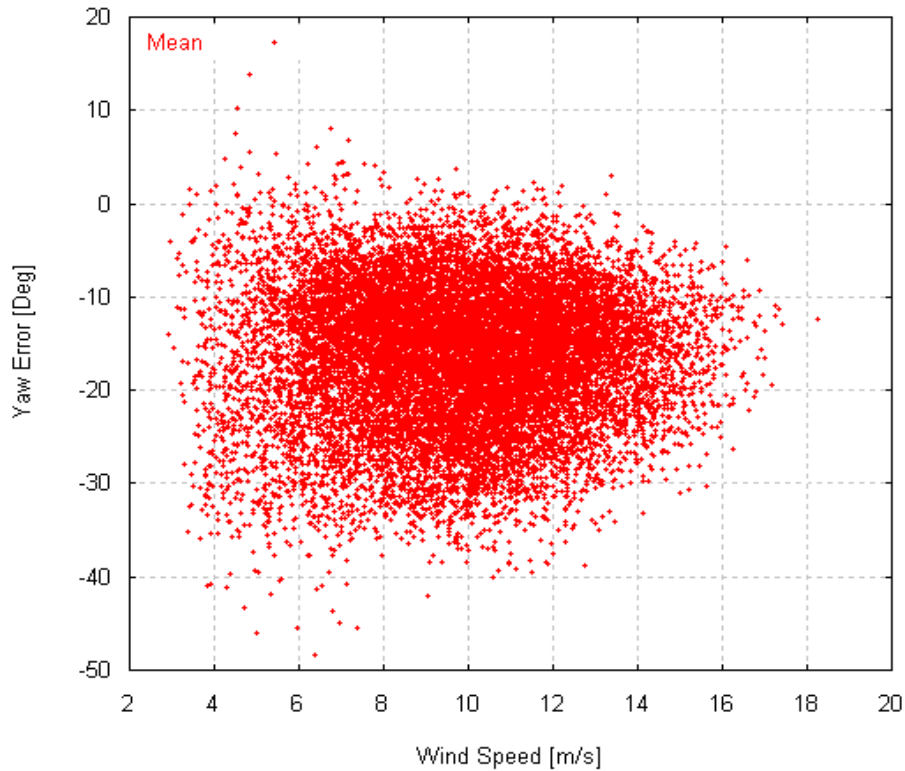
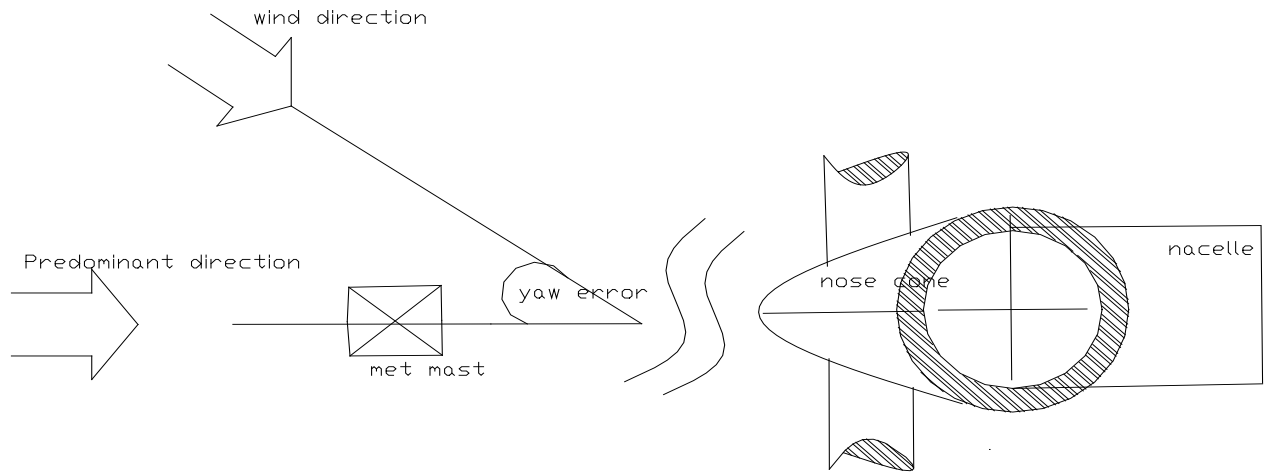
Measurement possible under operating conditions

DLC 6.2-effect of wind direction change of ± 180 shall be analysed

DLC 6.3- 6.1-yaw misalignment of up to $\pm 30^\circ$ using the steady extreme wind model or a mean yaw misalignment of $\pm 20^\circ$ using the turbulent extreme wind model

Measurement possible under operating conditions





Function Tests

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

Protection tests

Normal stop Test
Emergency stop Test
Grid failure without simulation of errors in braking system
Grid failure simulation of error in one independent braking system
Grid failure simulation of error in second independent braking system
Rotor Over speed
Generator over speed
Cut in current measurement



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	✓		✓			✓	✓	✓	✓		✓	✓
<u>Overspeed test</u>	✓		✓			✓	✓	✓	✓		✓	✓
<u>Cutin to grid test</u>	✓					✓	✓	✓	✓			
Yaw functionality	✓	✓	✓		✓			✓			✓	✓
Cable twist test	✓	✓	✓		✓			✓			✓	✓
Backwind operation	✓	✓	✓	✓	✓							
<u>Cutin measurement</u>								✓	✓	✓		

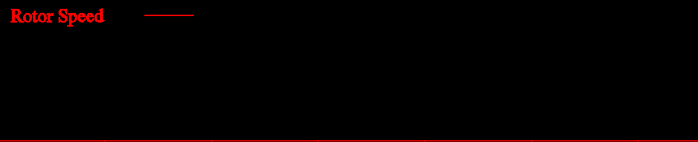
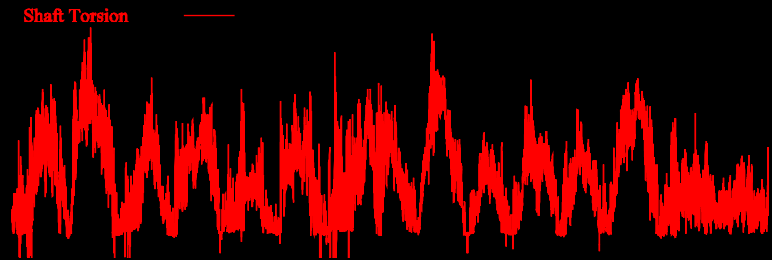
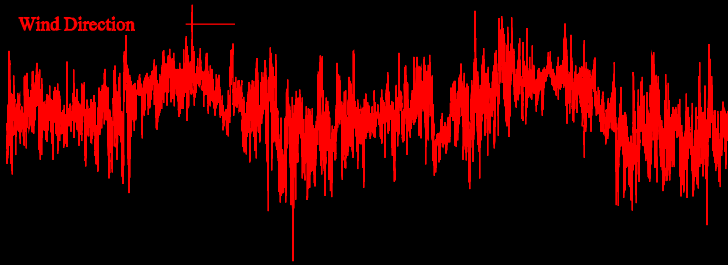
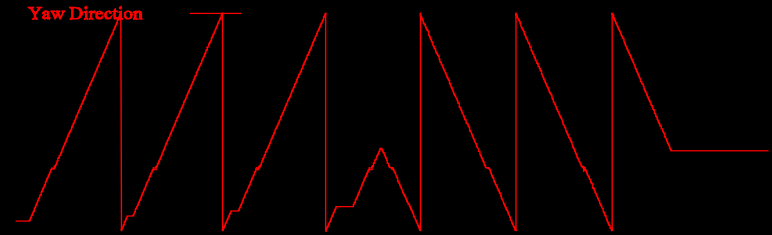
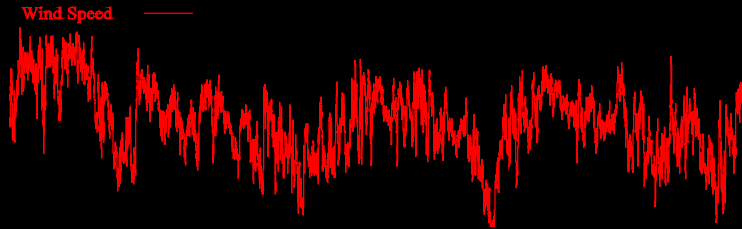
Table 5.2.1 Parameters measured for safety and function testing

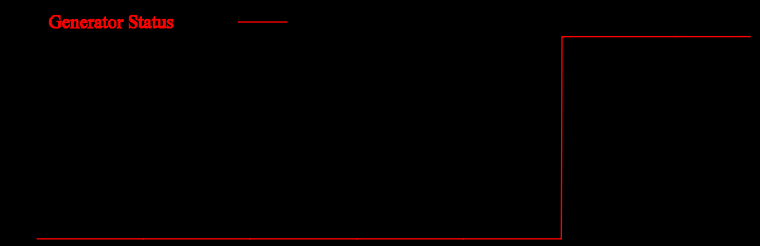
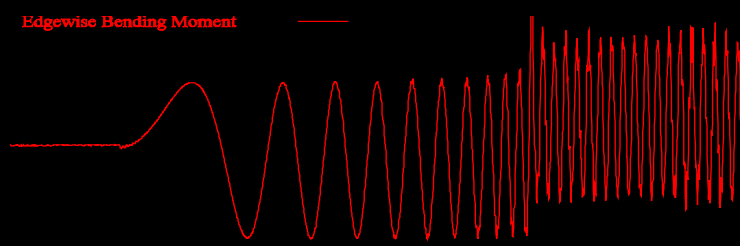
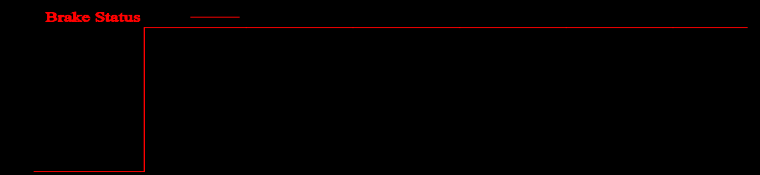
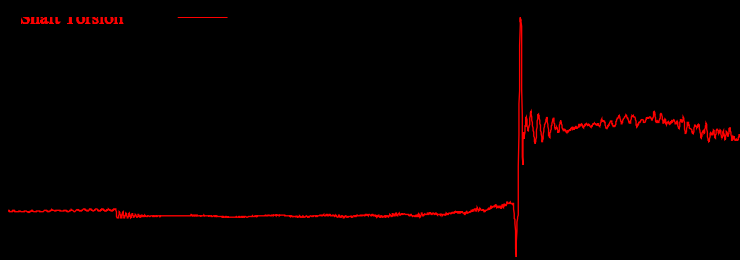
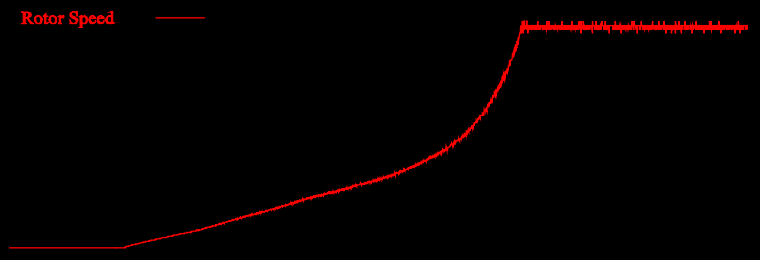
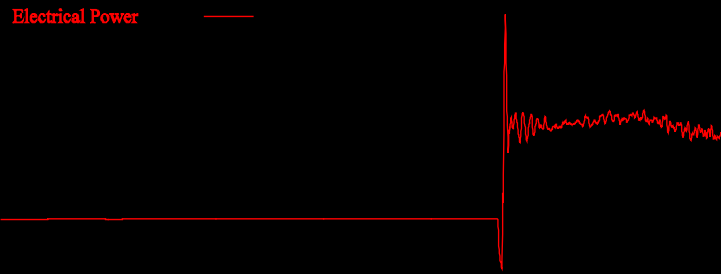
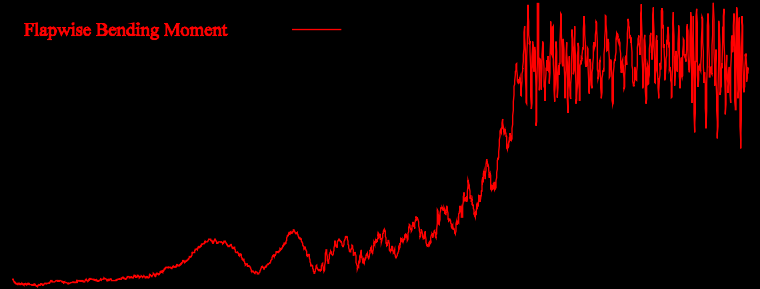
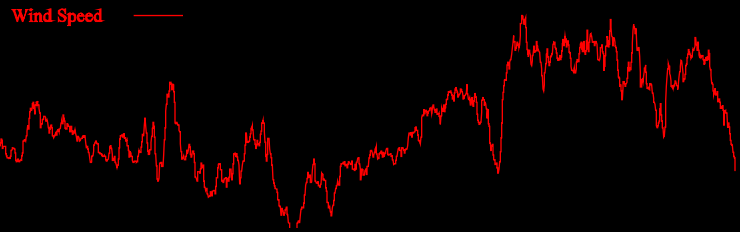
*WS – Wind speed, WD– Wind direction, RS– Rotor shaft, RP– Rotor position, YD-Yaw direction, EBM– Edge wise bending moment, FBM– Flap wise bending moment, ST – Shaft torsion, AP– Active power, TC– Transient current, GS – Generator status, BS– Brake status



Cable twist

Function Test





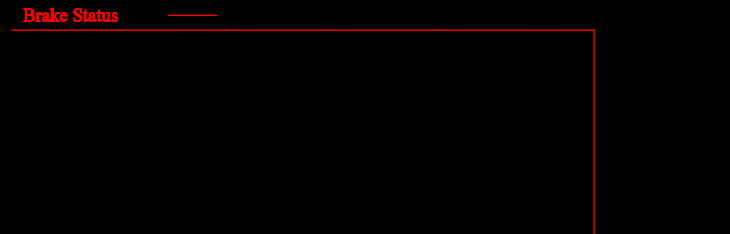
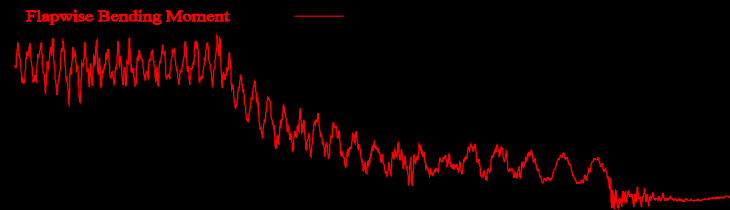
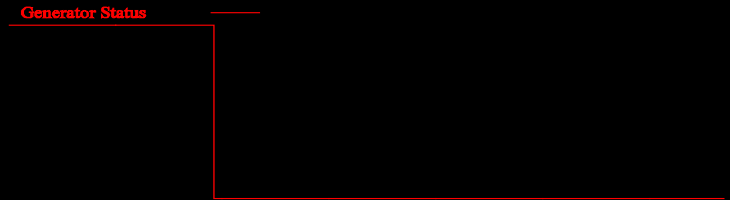
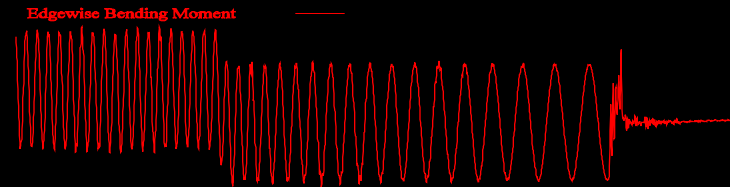
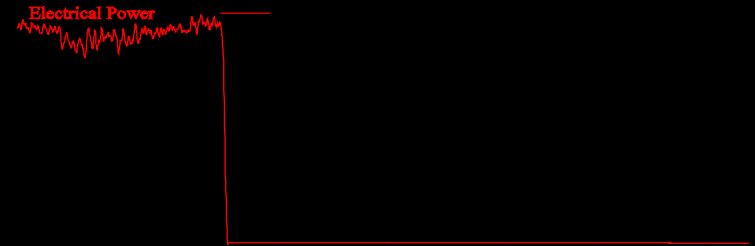
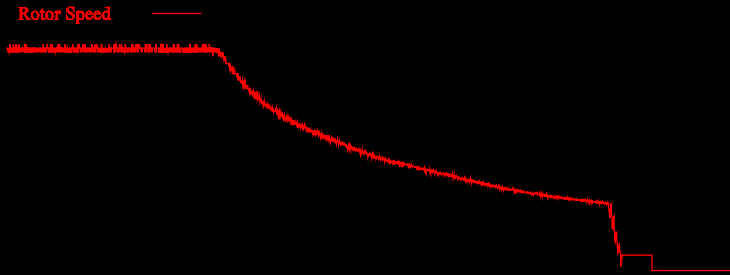
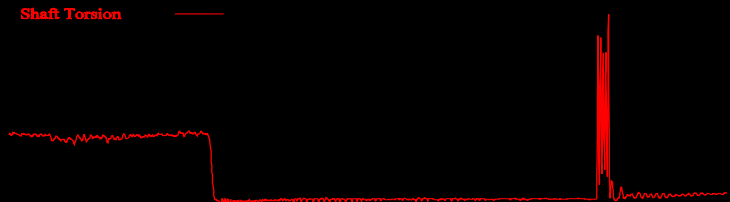
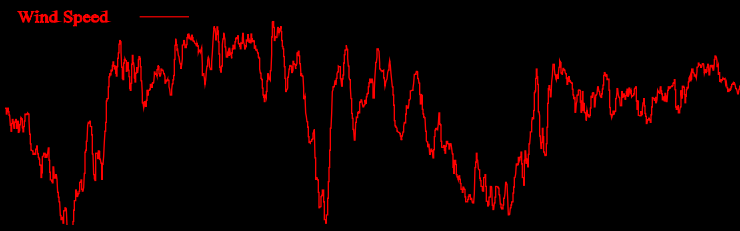
Normal Start

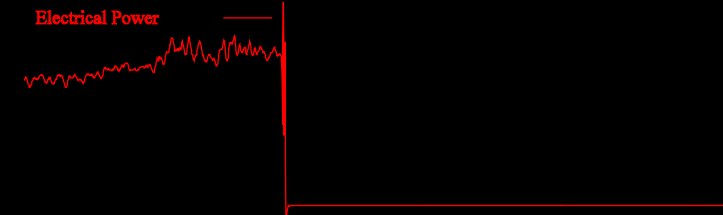
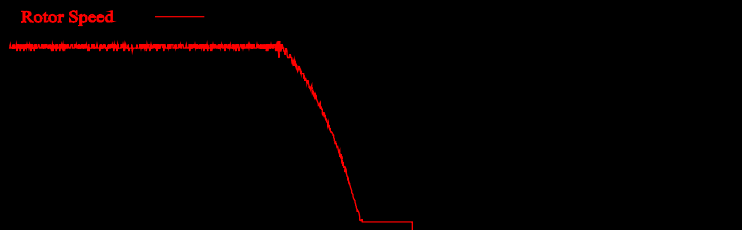
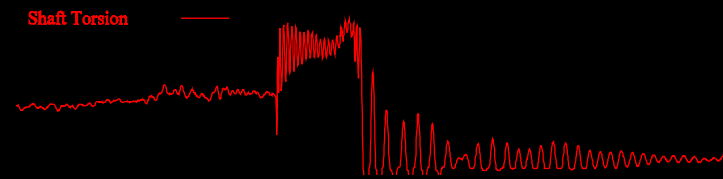
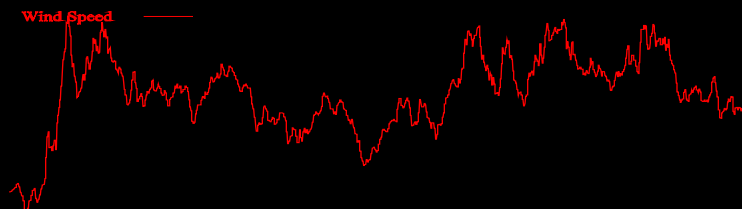
Protection



Normal Stop

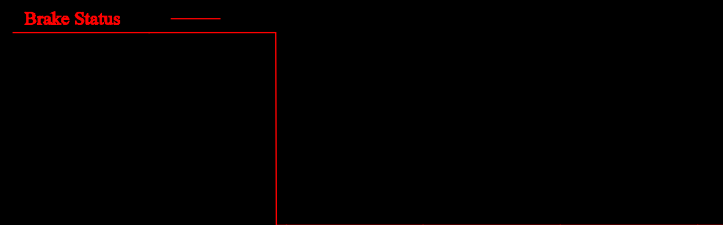
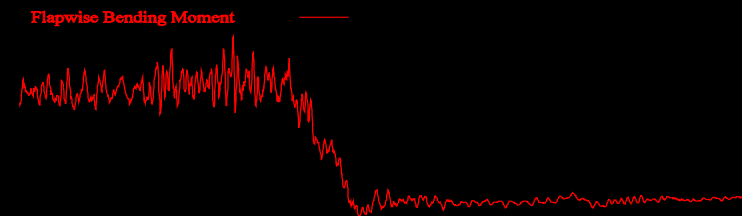
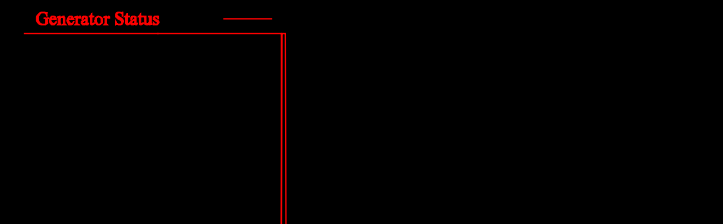
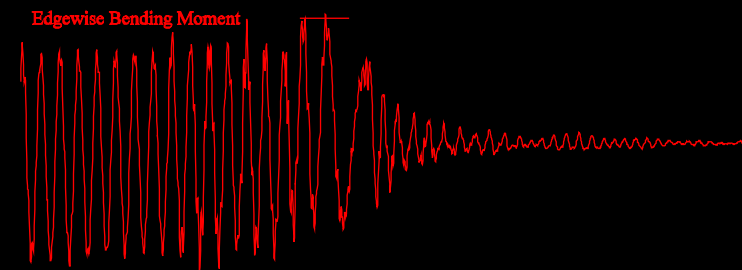
Protection





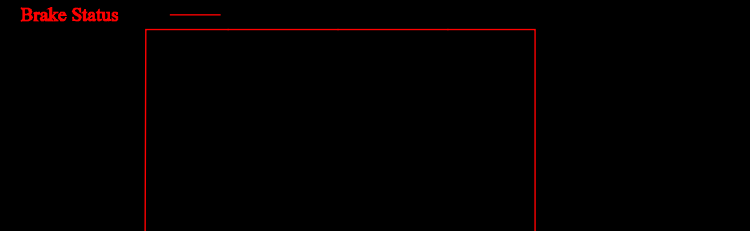
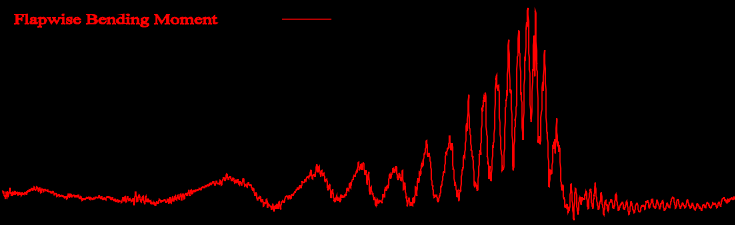
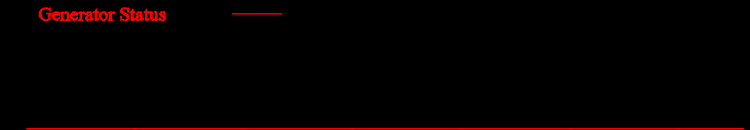
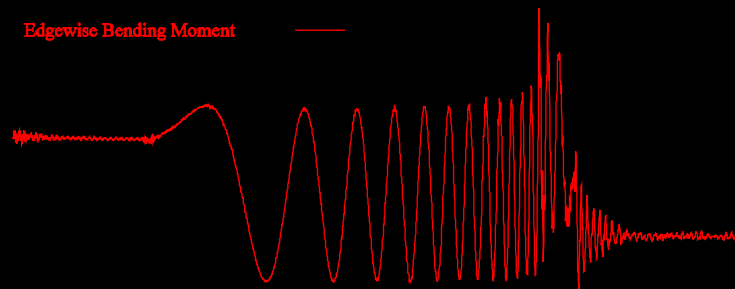
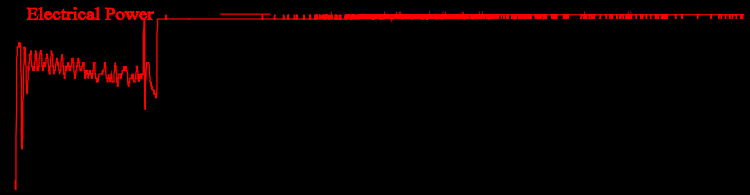
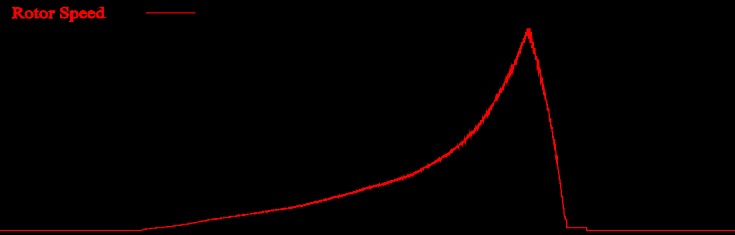
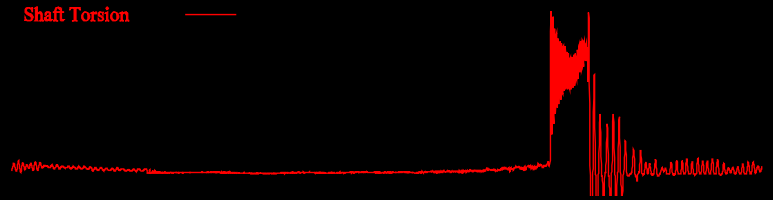
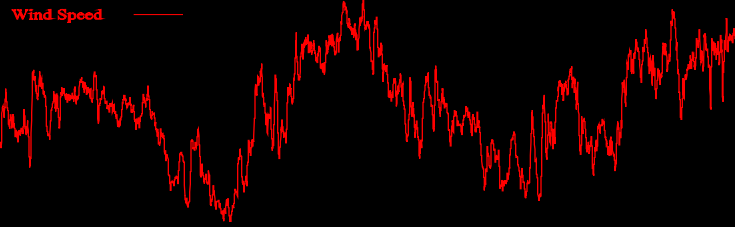
Emergency
Stop

Protection



Over Speed

Protection



Data Acquisition system

- -Transducers
- -Amplifiers
- -Filters
- -Multiplexers
- -Sample and hold circuits
- -AD Converter



➤ Instrumentation

- Accuracy
- Range
- Compatibility of sensors with Data Acquisition Equipment

➤ Installation

- Proper mounting Techniques
- Trained manpower



THANK YOU FOR THE PATIENT HEARING

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