HYDRO AND EOLIC PLANTS

ESF II project of the University of West Bohemia in Pilsen, reg. number: CZ.02.2.69/0.0/0.0/18_056/0013239



EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research,
Development and Education



Eolic power plant

Milan Bělík

Eolic power plants

- horizontal axis (HAWT)
  - n-blade propeller
  - wind wheel
  - wind mill
- vertical axis (VAWT)
  - Savonius
  - Darrieus

- onshore
- offshore



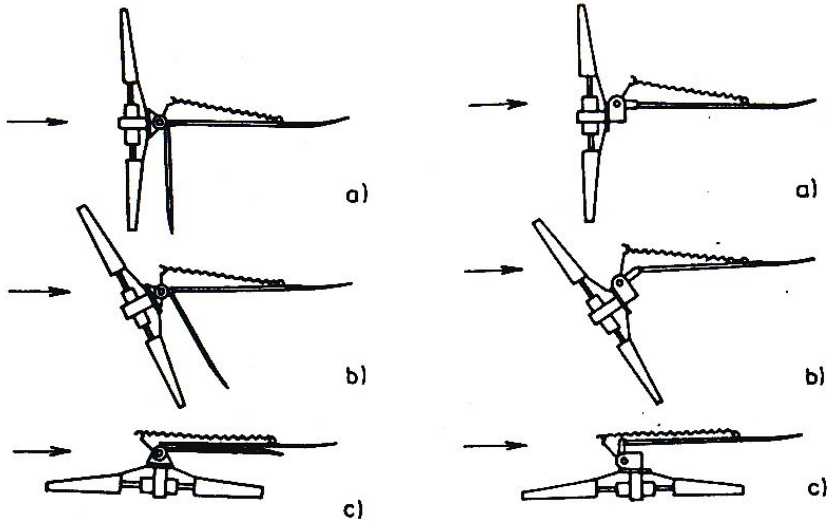




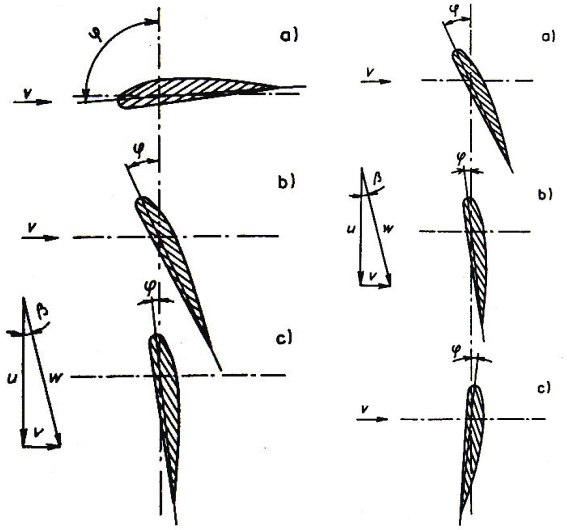


Regulation of wind engines

- fixed blades
  - stall



- variable angle
  - pitch



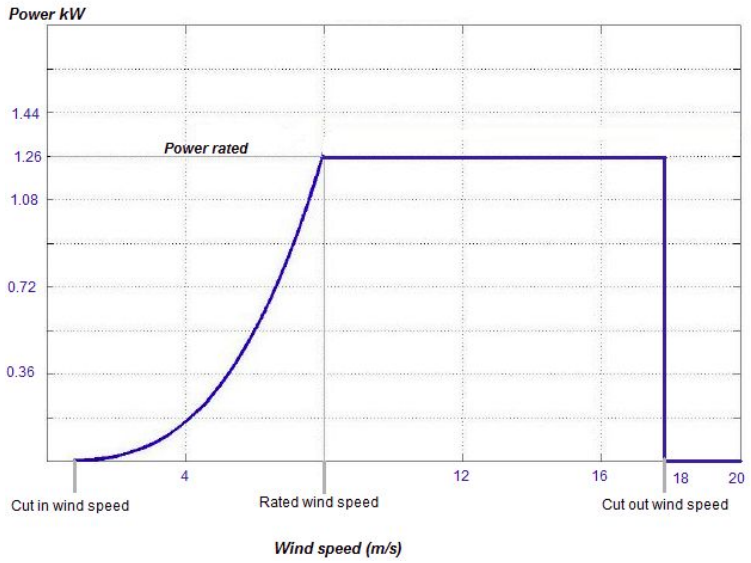


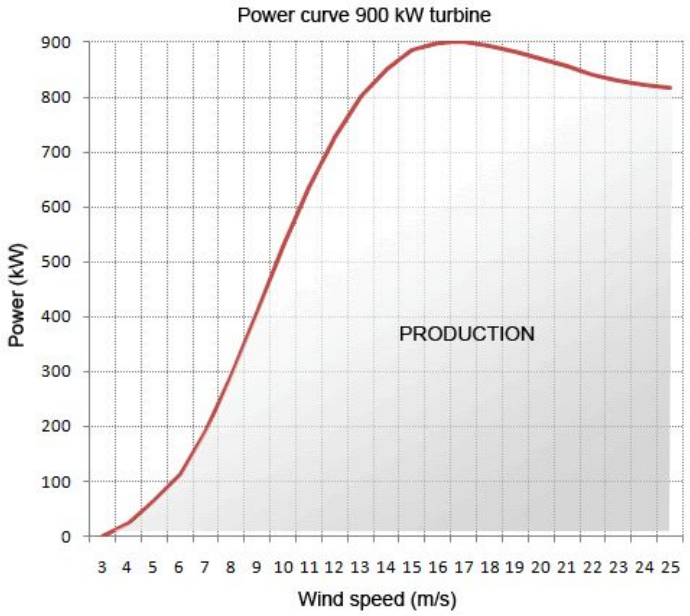




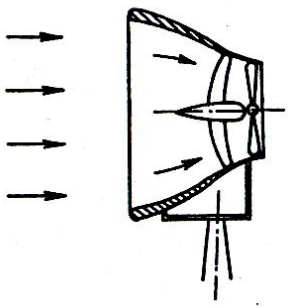


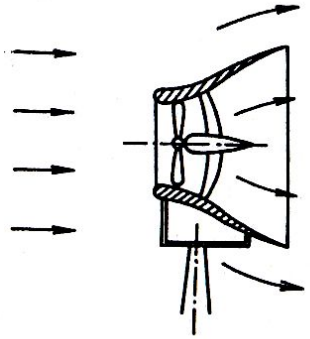
Regulation pitch / stall





Konfuzor & difuzor












Overhead Swivel Mount View

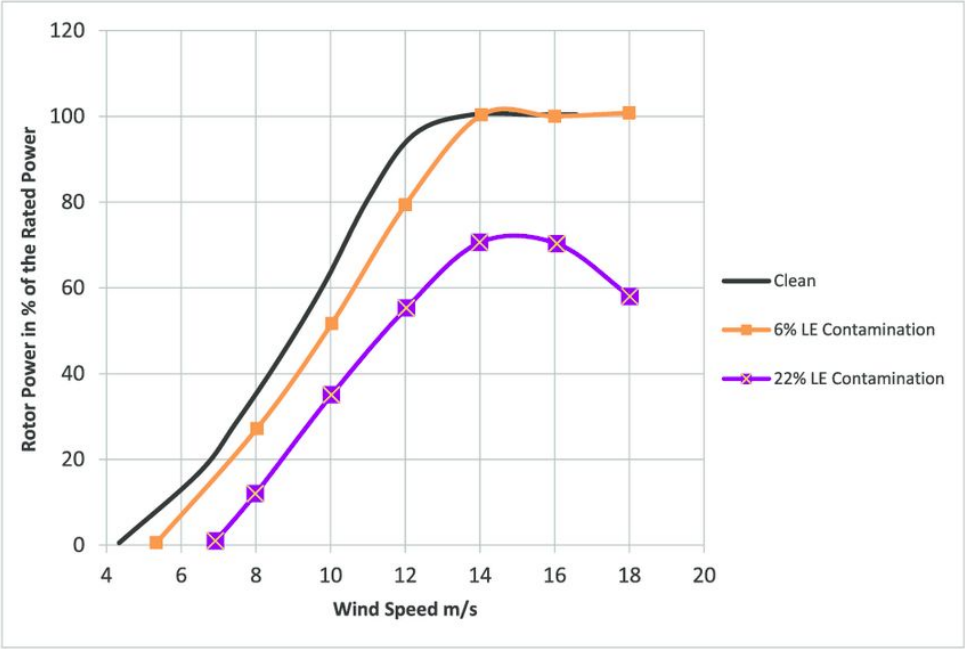


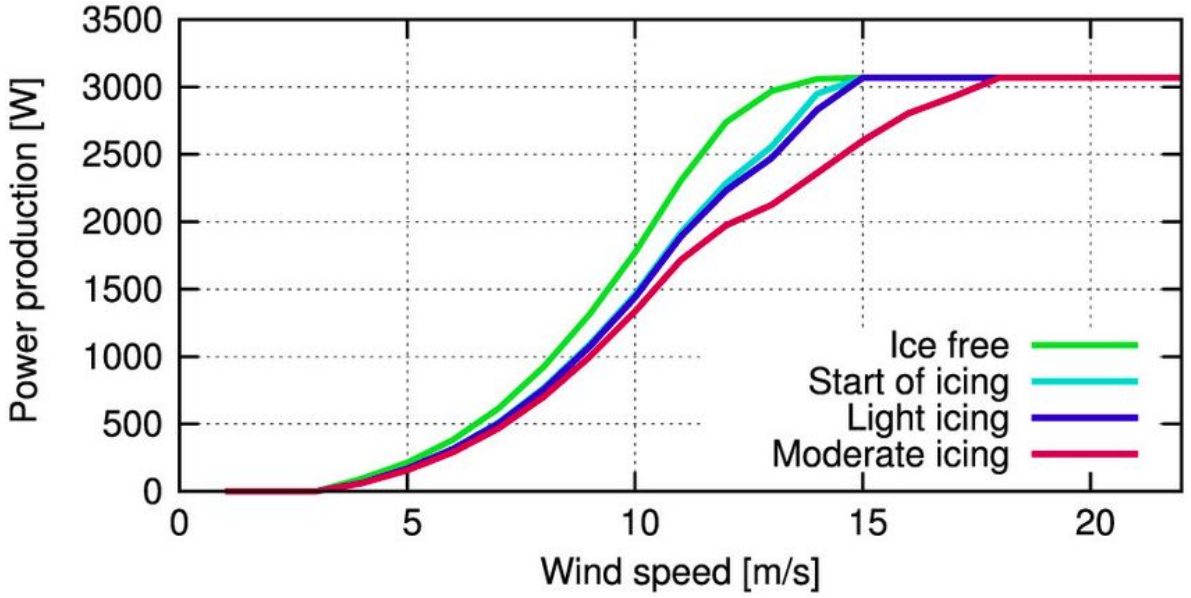






Power characteristics - looses



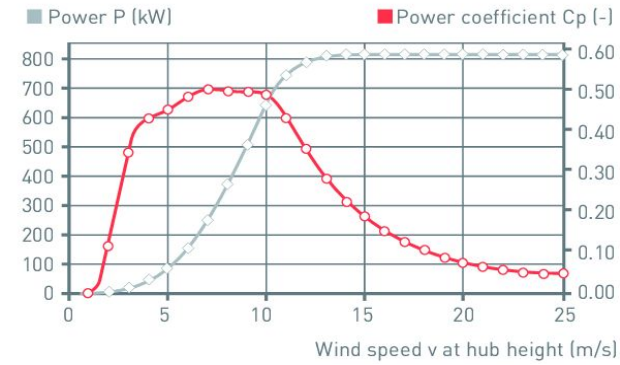


	GE 1.5 MW	GE 1.6 MW	GE 3.6 MW	GE 2.5 MW
Generator Rating	1.67 MVA	1.78 MVA	4 MVA	3 MVA
Pmax	1.5 MW	1.6 MW	3.6 MW	2.5 MW
Pmin	0.07 MW	0.075 MW	0.16 MW	0 MW
Qmax	0.726 MVAr*	0.775 MVAr*	2.08 MVAr	1.20 MVAr*
Qmin	-0.726 MVAr*	-0.775 MVAr*	-1.55 MVAr	-1.20 MVAr*
Terminal Voltage (60 Hz)	690 V**	690 V	4160 V	690 V
Terminal Voltage (50 Hz)	690 V	690 V	3300 V	690 V
Unit Transformer Rating	1.75 MVA	1.75 MVA	4 MVA	2.8 MVA
Unit Transformer Z	5.75%	5.75%	7%	6.0%
Unit Transformer X/R	7.5	7.5	7.5	7.5

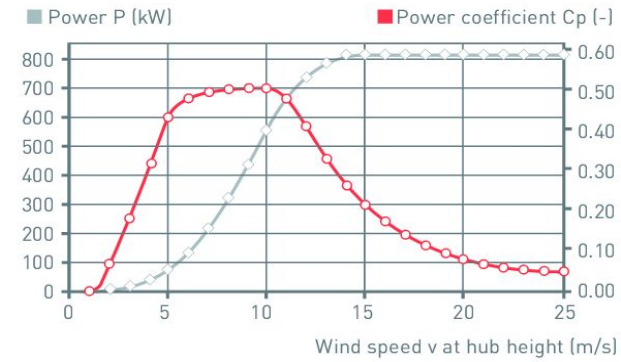
Type	AC 120 | AC 240	AC 502 | AC 752/NE	AC 1002 H
Generator	18-pole	16-pole	16-pole
Power output	120 W | 240 W	500 W | 750 W	1000 W
System voltage	12/24 V	12/24 V | 24/48 V	230V
Rated output at	9 m/s	9 m/s	9 m/s
Cut-in wind speed	3 m/s	3 m/s	3 m/s
Critical wind speed	40 m/s	40 m/s	40 m/s
Rotational speed	700 rpm	600 rpm	600 rpm
Number of rotor blades	5 | 3	3	3
Material of rotor blades	GRP	GRP	GRP
Diameter of rotor blades	120 cm | 165 cm	240 cm	240 cm
Swept area of rotor blades	1.13 m^2 | 2.14 m^2	4.5 m^2	4.5 m^2
Azimuth control	Wind vane	Wind vane	Wind vane
Azimuth bearing	Dual ball bearing	Dual ball bearing	Dual ball bearing
Power transmission	Slip rings	Cable 3 x 2.5 mm	Cable 3 x 2.5 mm
Storm safety system	Helicopter position	Eclipse control	Eclipse control
Weight	17 kg | 19 kg	41 kg | 43 kg	45 kg
Mast mounting	Flange 130 mm	Flange 130 mm	Flange 130 mm

WEC	Rated power	Rotor diameter	Swept area	Hub height	Rotational speed	Cut-out wind speed	Wind zone (DIBt)	Wind class (IEC)
ENERCON E-44	900 kW	44 m	1,521 m²	45 / 55 m	variable, 16 - 34.5 rpm	28 - 34 m/s	-	IEC/EN IA
ENERCON E-48	800 kW	48 m	1,810 m²	50 / 60 / 65 / 76 m	variable, 16 - 31.5 rpm	28 - 34 m/s	WZ III	IEC/EN IIA
ENERCON E-53	800 kW	52.9 m	2,198 m²	50 / 60 / 73 m	variable, 11 - 29.5 rpm	28 - 34 m/s	WZ II exp	IEC/NVN Class S
ENERCON E-70	2,300 kW	71 m	3,959 m²	57 / 64 / 75 / 85 / 98 / 114 m	variable, 6 - 21 rpm	28 - 34 m/s	WZ III	IEC/EN IA and IEC/EN IIA
ENERCON E-82 E2	2,000 kW	82 m	5,281 m²	78 / 84 / 85 / 98 / 108 / 138 m	variable, 6 - 18 rpm	28 - 34 m/s	WZ III	IEC/EN IIA
ENERCON E-82 E2	2,300 kW	82 m	5,281 m²	78 / 84 / 85 / 98 / 108 / 138 m	variable, 6 - 18 rpm	28 - 34 m/s	WZ III	IEC/EN IIA
ENERCON E-82 E4	2,350 kW	82 m	5,281 m²	59 / 69 / 78 / 84 m	variable, 6 - 18 rpm	28 - 34 m/s	-	IEC/EN IA and IEC/EN IIA
ENERCON E-82 E4	3,000 kW	82 m	5,281 m²	69 / 78 / 84 m	variable, 6 - 18 rpm	28 - 34 m/s	-	IEC/EN IA and IEC/EN IIA
ENERCON E-92	2,350 kW	92 m	6,648 m²	78 / 84 / 85 / 98 / 104 / 108 / 138 m	variable, 5 - 16 rpm	28 - 34 m/s	WZ III	IEC/EN IIA
ENERCON E-101	3,050 kW	101 m	8,012 m²	99 / 124 / 135 / 149 m	variable, 4 - 14.5 rpm	28 - 34 m/s	WZ III	IEC/EN IIA
ENERCON E-101 E2	3,500 kW	101 m	8,012 m²	74 m	variable, 4 - 14.5 rpm	28 - 34 m/s	WZ IV	IEC/EN IA
ENERCON E-115	3,000 kW	115.7 m	10,515.5 m²	92 / 122 / 135 / 149 m	variable, 4 - 12.8 rpm	28 - 34 m/s	WZ III	IEC/EN IIA
ENERCON E-126 EP4	4,200 kW	127 m	12,668 m²	135 m	variable, 3 - 11.6 rpm	28 - 34 m/s	WZ III	IEC/EN IIA
ENERCON E-126	7,580 kW	127 m	12,668 m²	135 m	variable, 5 - 12.1 rpm	28 - 34 m/s	WZ III	IEC/EN IA

Technical specifications E-53 — 800 kW



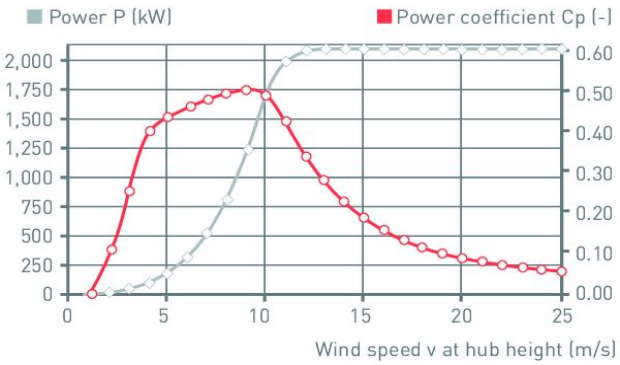
Technical specifications E-48 — 800 kW



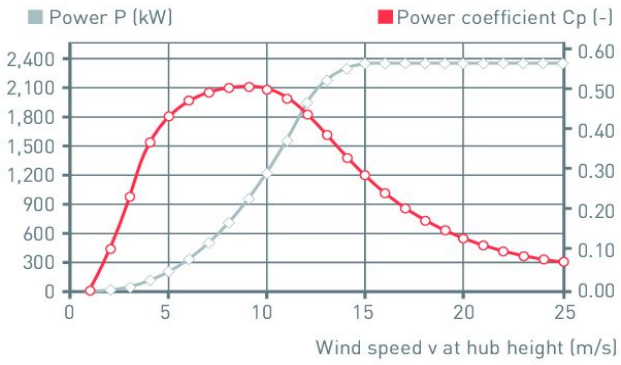
Technical specifications E-101 E2 — 3,500 kW



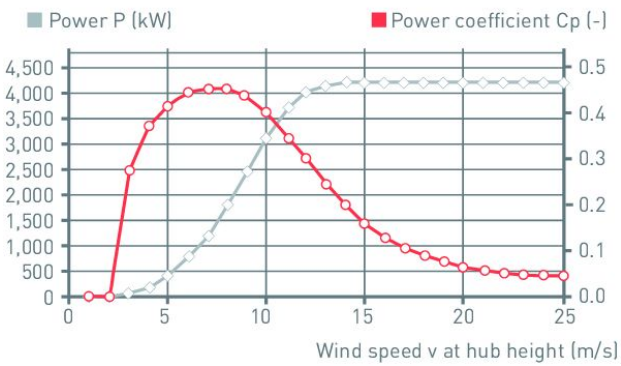
Technical specifications E-82 E2 — 2,000 kW



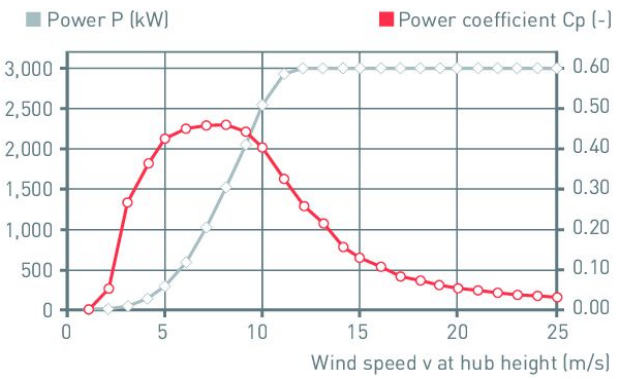
Technical specifications E-70 E4 — 2,300 kW



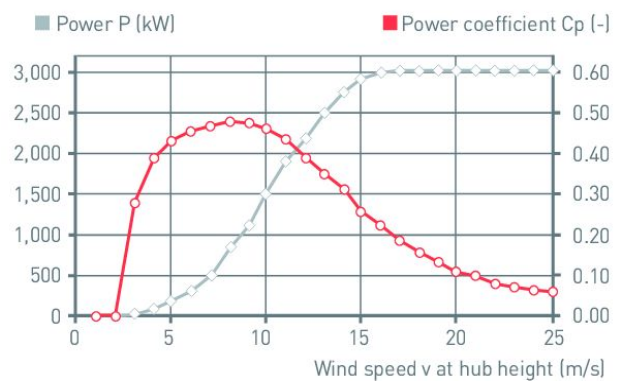
Technical specifications E-126 EP4 — 4,200 kW



Technical specifications E-115 — 3,000 kW



Technical specifications E-82 E4 — 3,000 kW

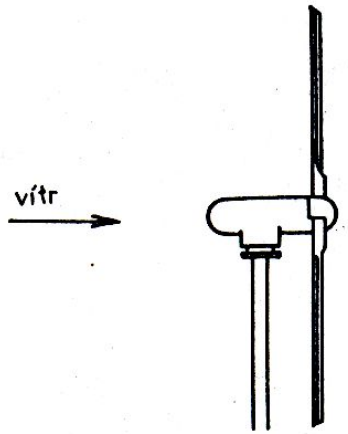


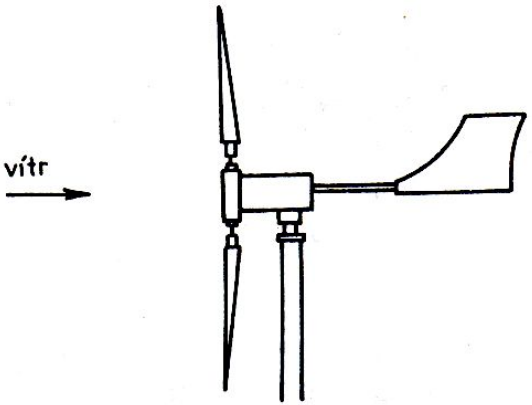
Technical specifications E-126 — 7,580 kW

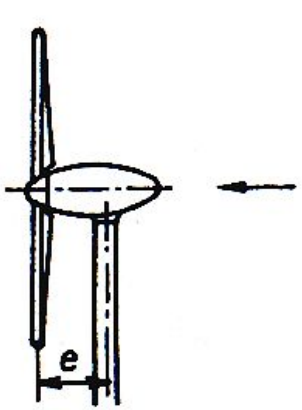


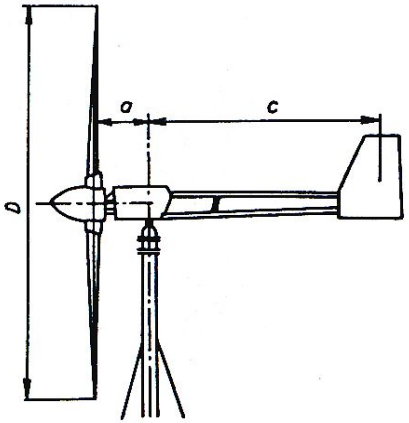
Gondola positioning

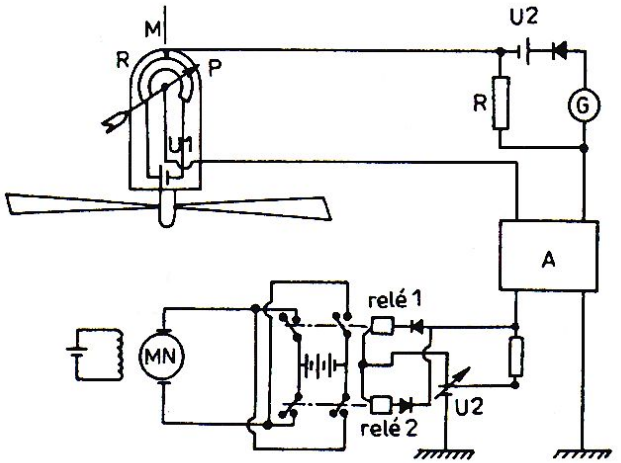
$$\Delta P = 1 - \cos^3 \delta$$





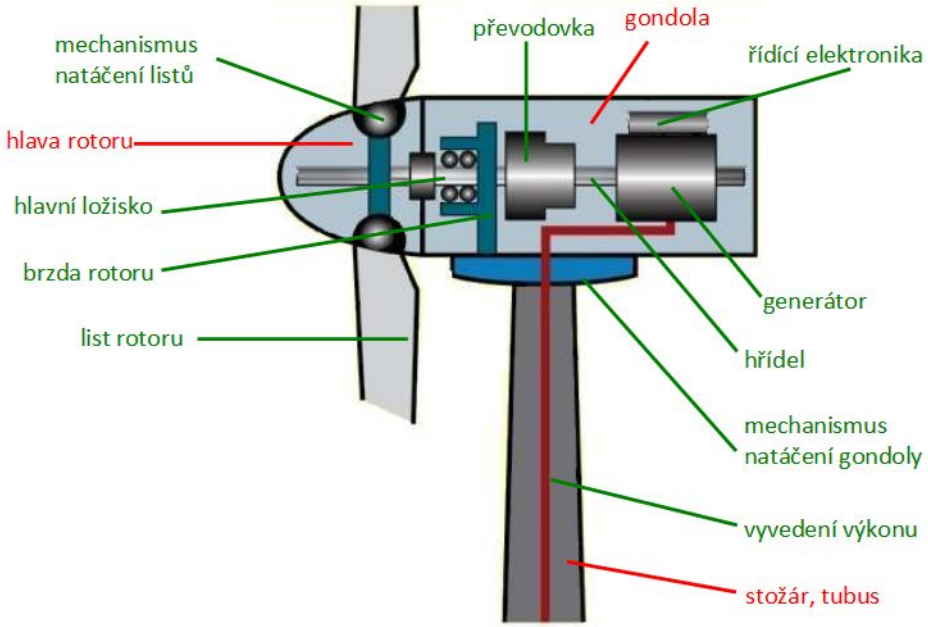


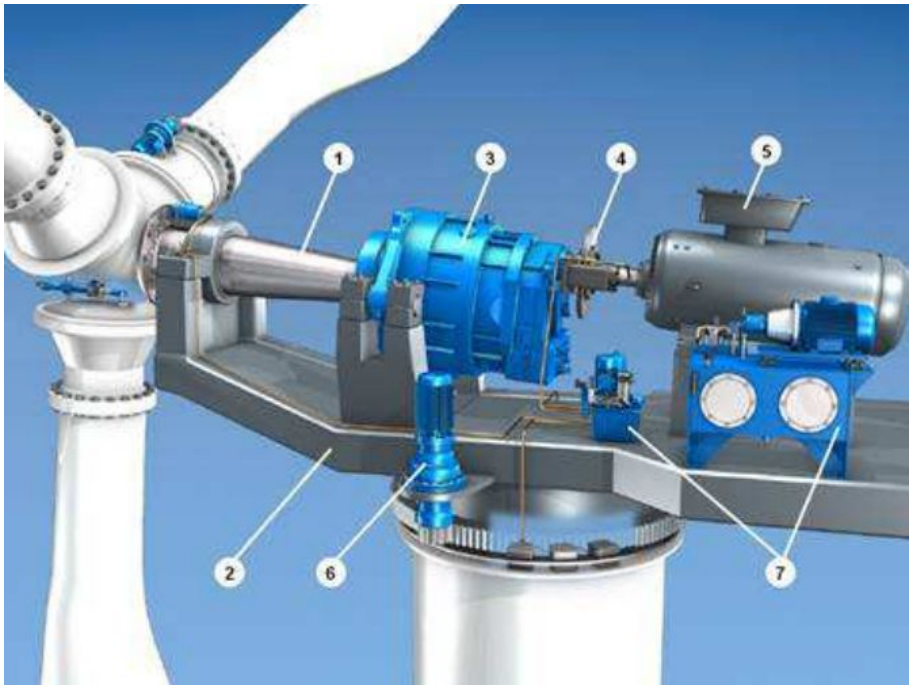


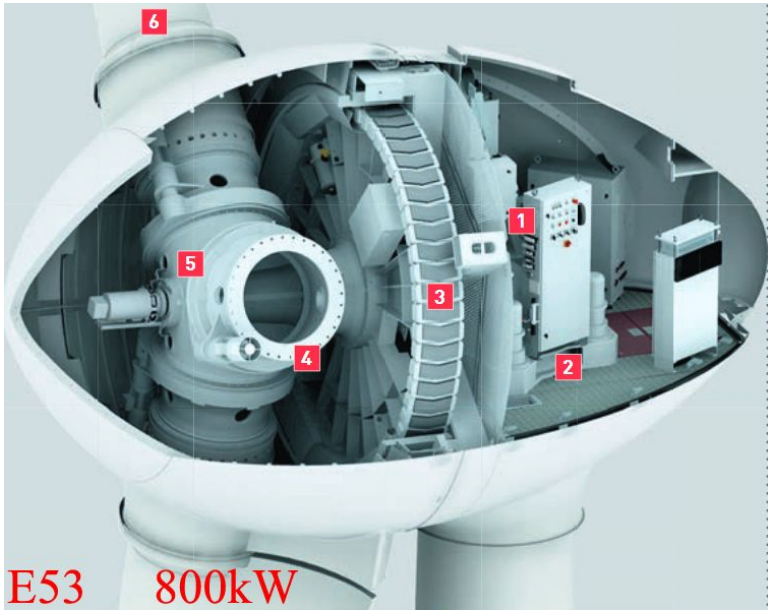


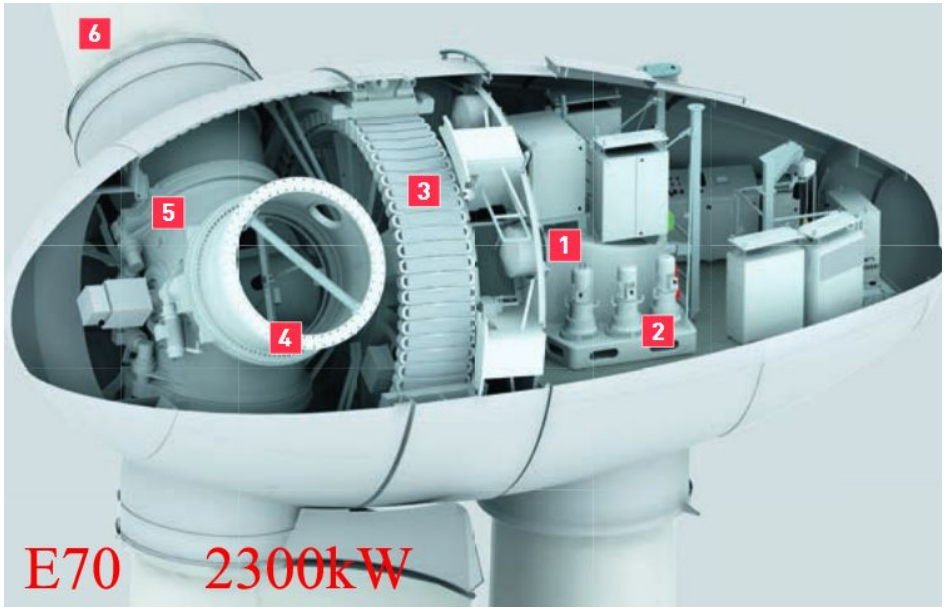
$$A_K = D^2 \frac{e}{c} k_K$$

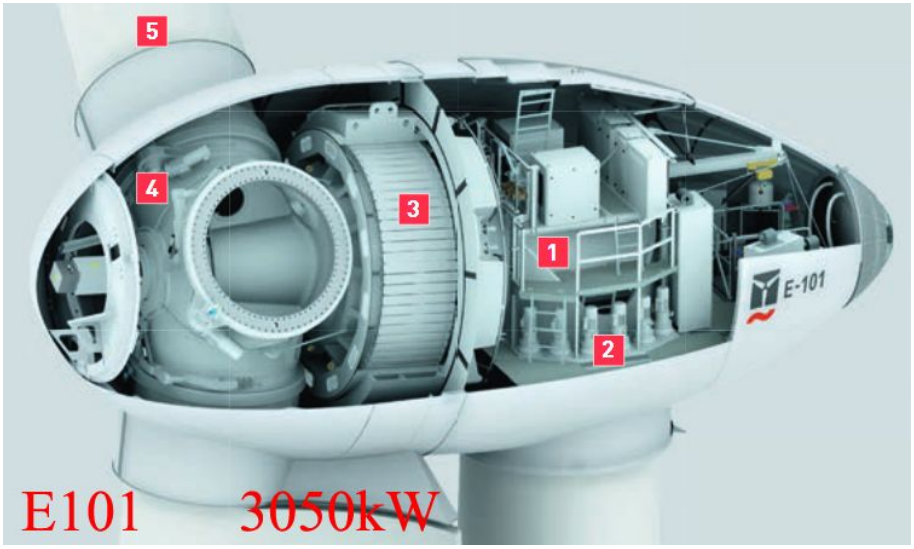
D je průměr vrtule
e - vzdálenost od osy natáčení k rovině vrtule
c - vzdálenost od osy natáčení k těžišti kormidla $c = (2 \text{ až } 5)e$
k_K - empirický součinitel (u rychloběžných motorů $k_K = 0{,}13$ a u pomaloběžných $k_K = 0{,}32$)

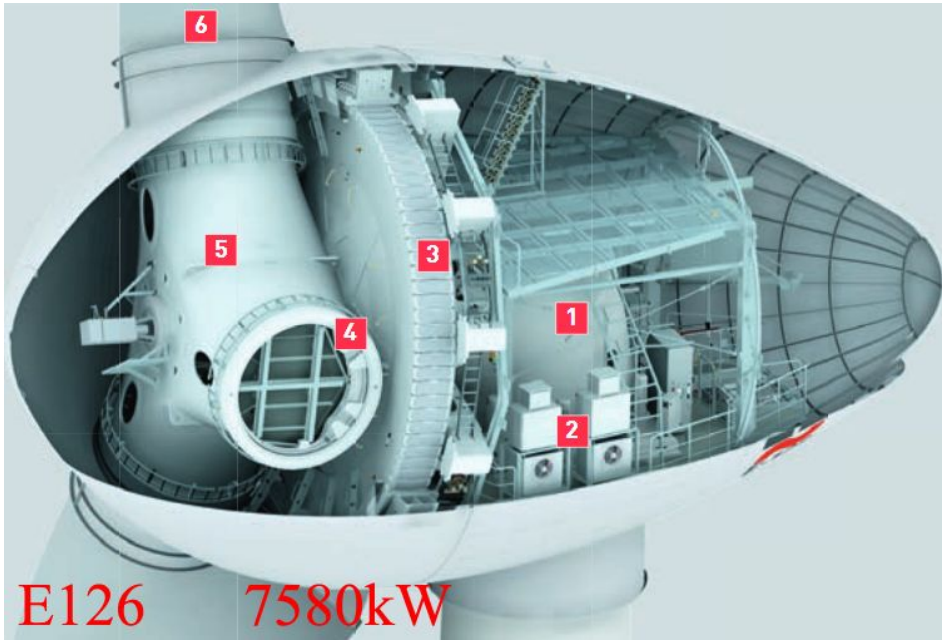

mechanismus
natáčení listů
převodovka
gondola
řídící elektronika
hlava rotoru
hlavní ložisko
brzda rotoru
list rotoru
generátor
hřídel
mechanismus
natáčení gondoly
vyvedení výkonu
stožár, tubus


1
3
4
5
2
6
7


6
5
1
3
4
2
E53 800kW

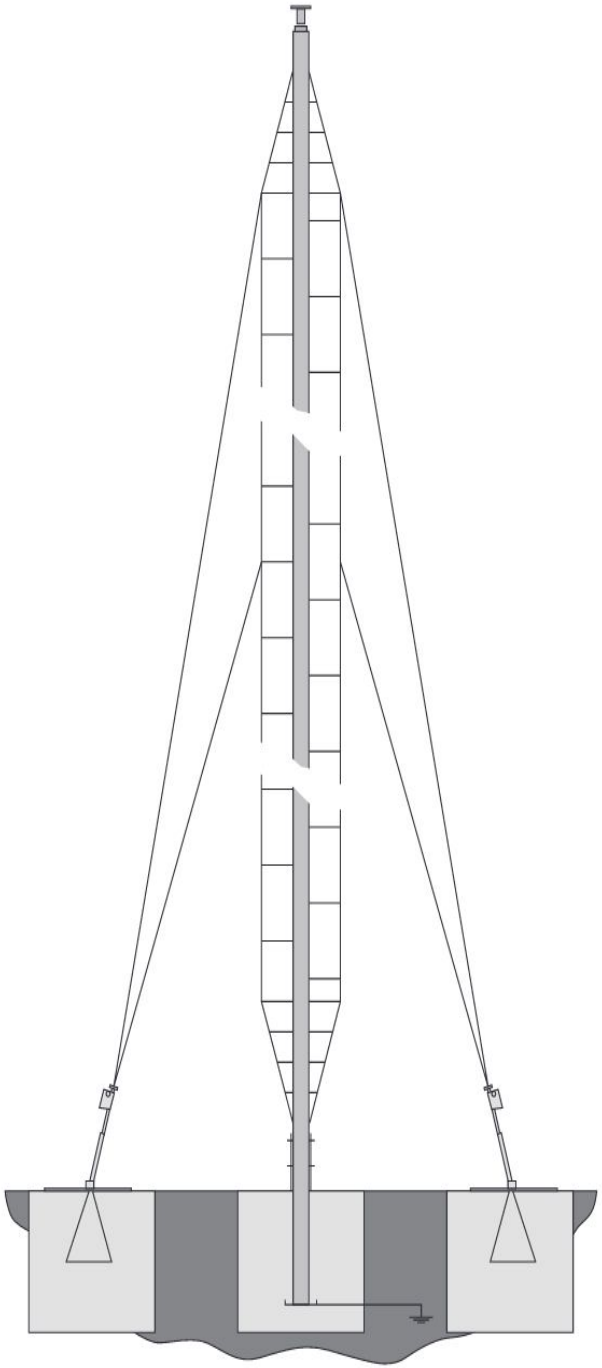

6
5
3
1
4
2
E70 2300kW

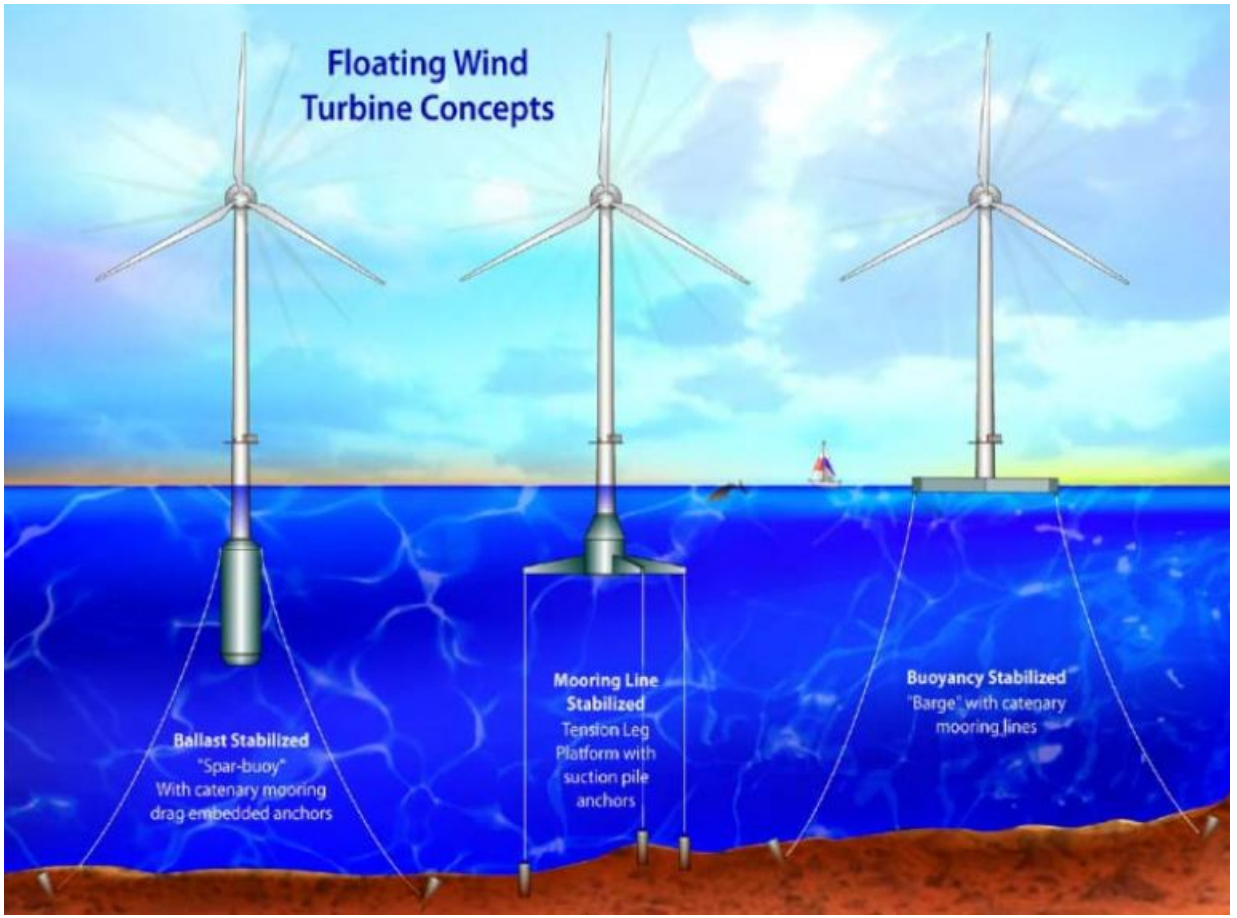

5
4
3
1
2
E-101
E101 3050kW


6
5
3
1
4
2
E126 7580kW





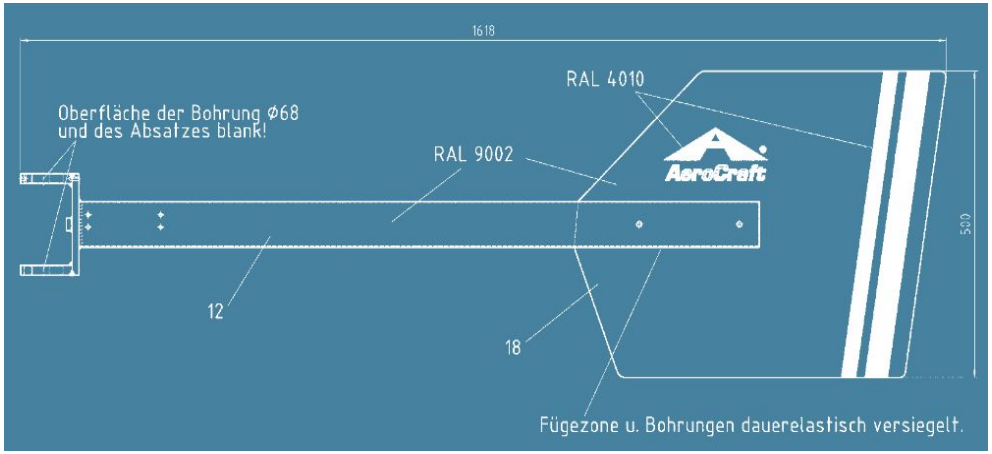



Floating Wind
Turbine Concepts
Ballast Stabilized
"Spar-buoy"
With catenary mooring
drag embedded anchors
Mooring Line
Stabilized
Tension Leg
Platform with
suction pile
anchors
Buoyancy Stabilized
"Barge" with category
mooring lines

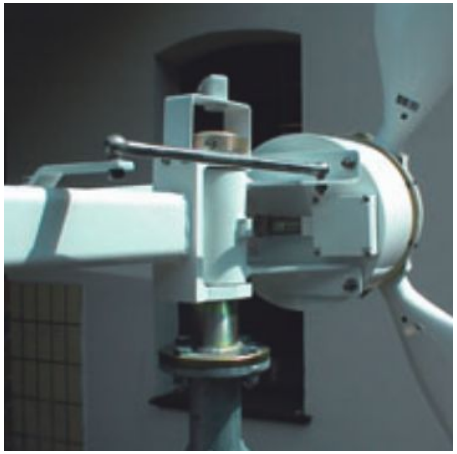


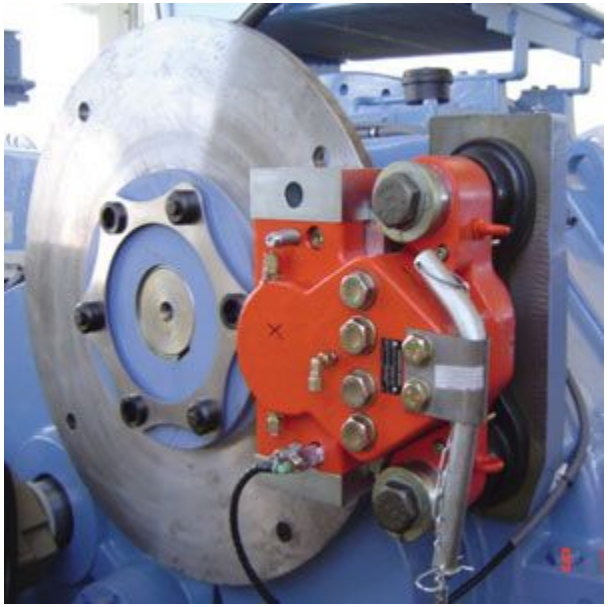

WINDTOWER®

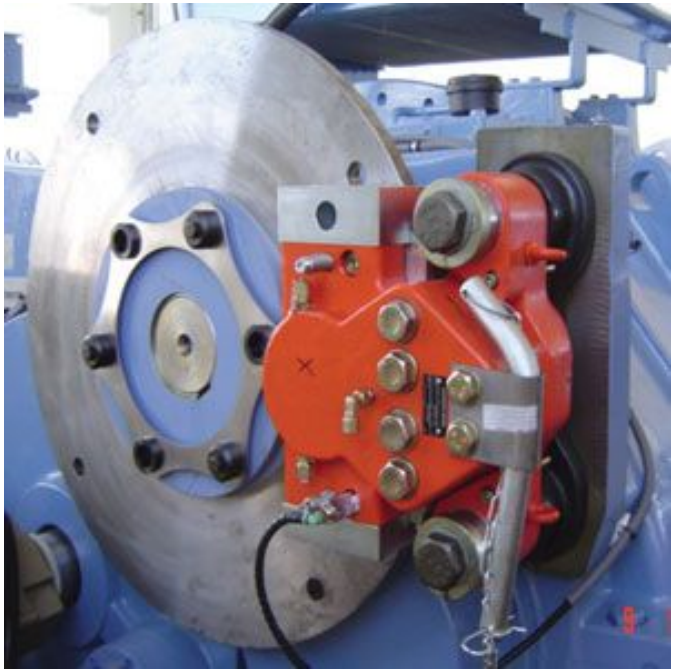



1618
RAL 4010
Oberfläche der Bohrung Ø68
und des Absatzes blank!
RAL 9002
AeroCraft
530
12
18
Fügezone u. Bohrungen dauerelastisch versiegelt.

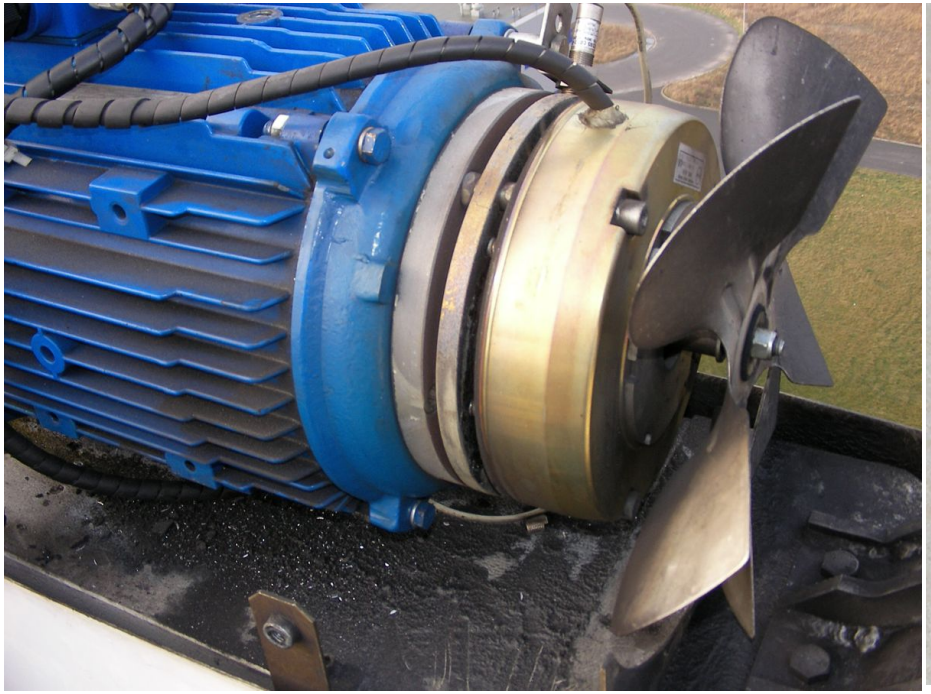














Icing

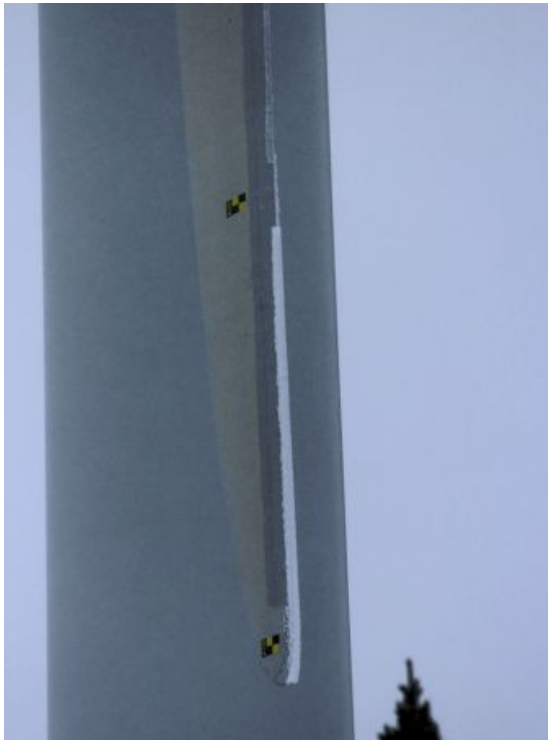




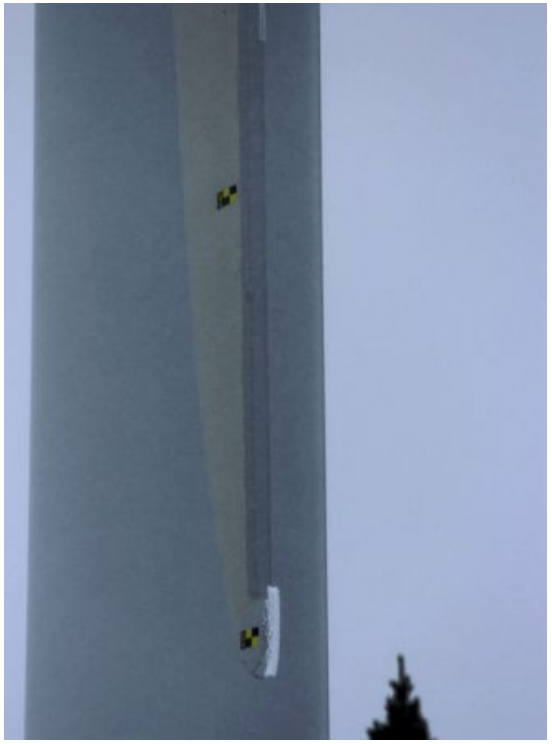












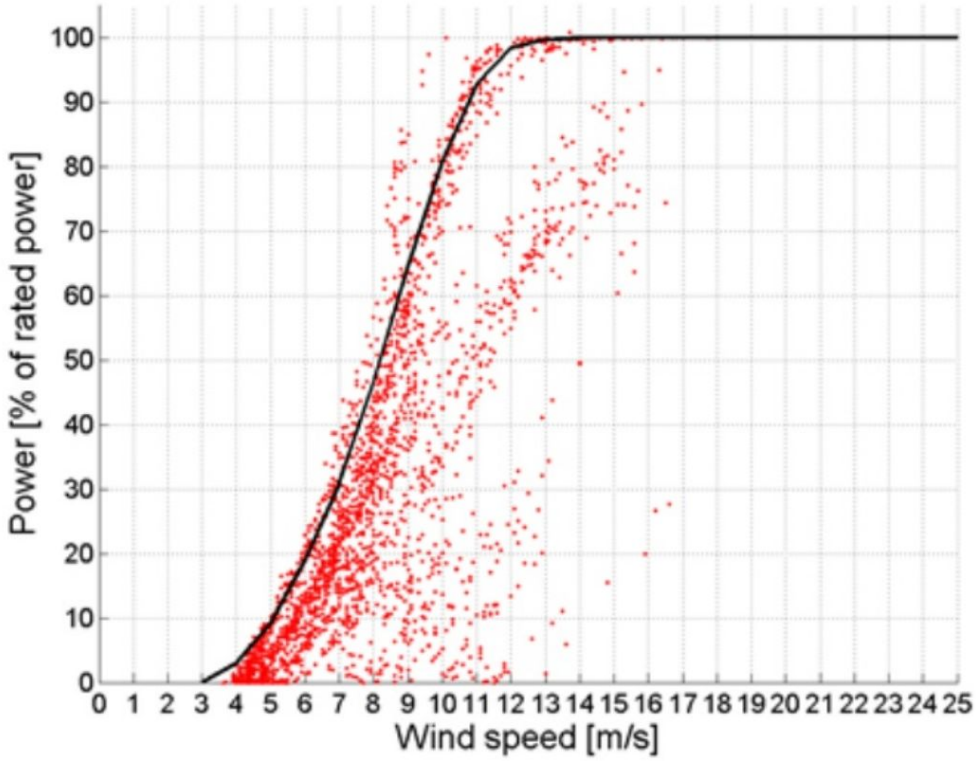


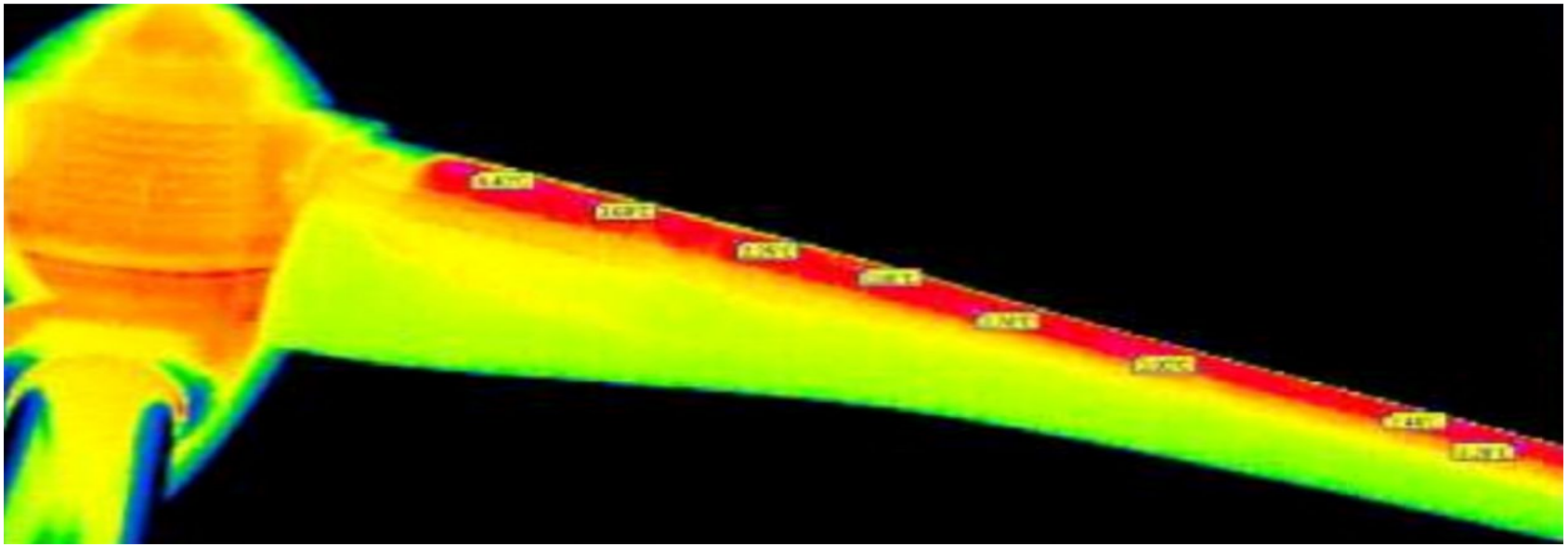


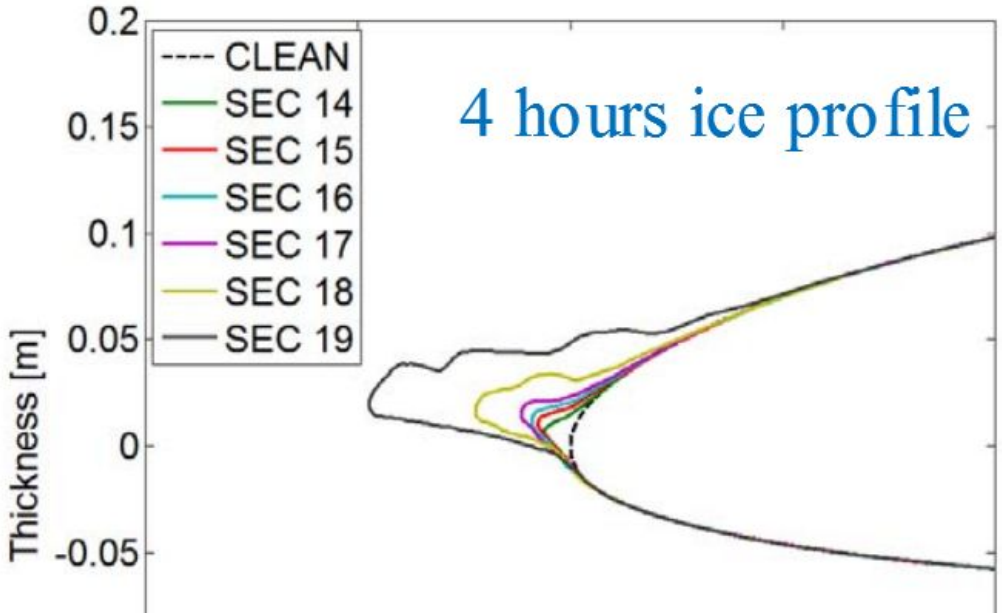

FARADOR

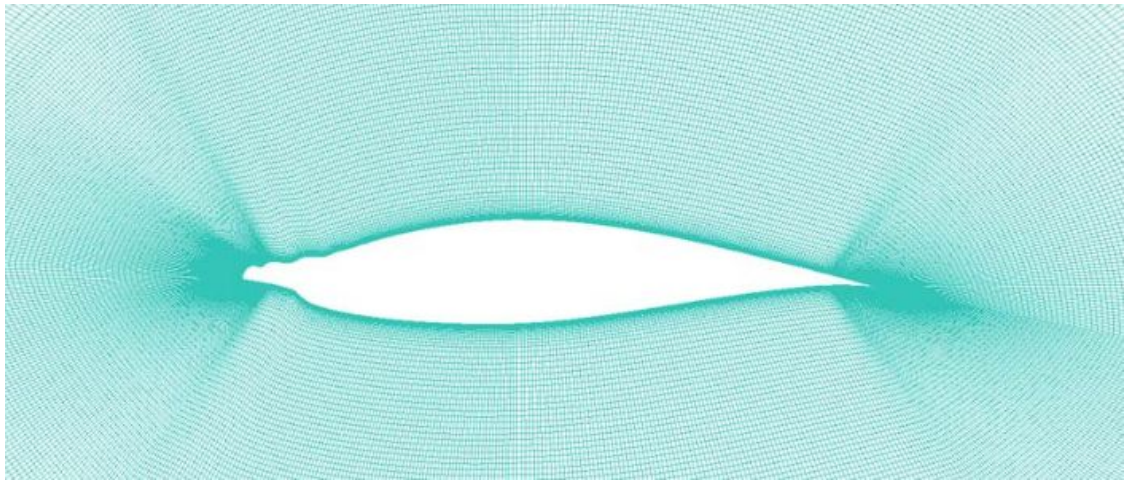


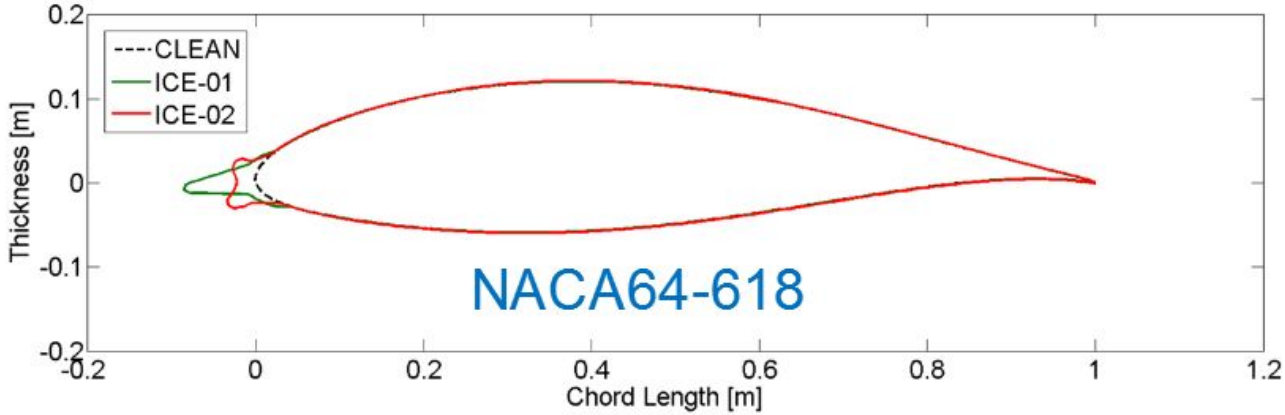

PROVOZ
VĚTRNÝCH
ELEKTRÁREN
PŘI PRŮCHODU
DBEJTE ZVÝŠENÉ
OPATRNOSTI
POZOR
PADAJÍCÍ
NÁMRAZA

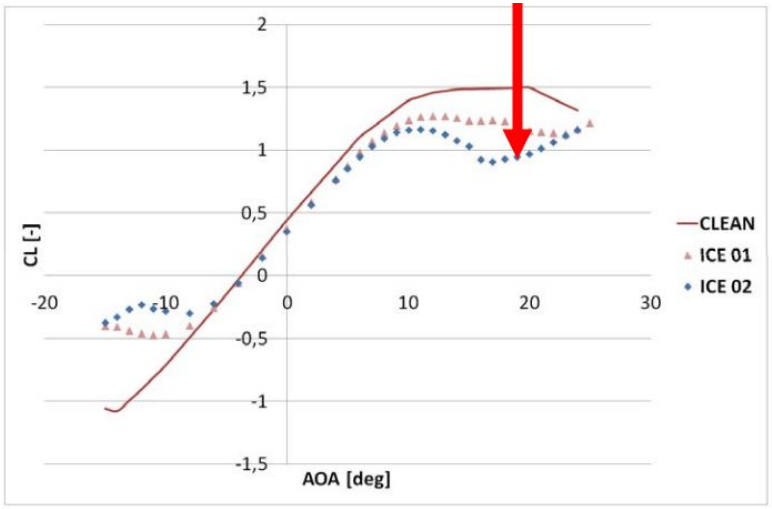

Power [% of rated power]
Wind speed [m/s]
0 10 20 30 40 50 60 70 80 90 100
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25



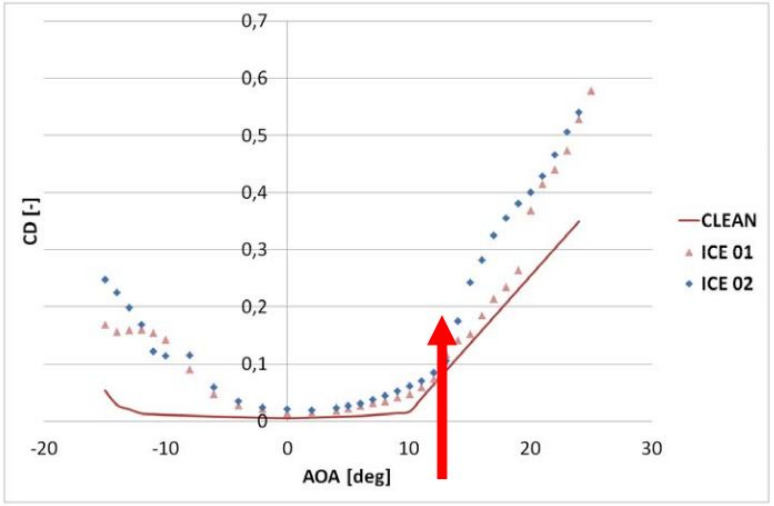

4 hours ice profile
CLEAN
SEC 14
SEC 15
SEC 16
SEC 17
SEC 18
SEC 19
Thickness [m]
0.2
0.15
0.1
0.05
0
-0.05





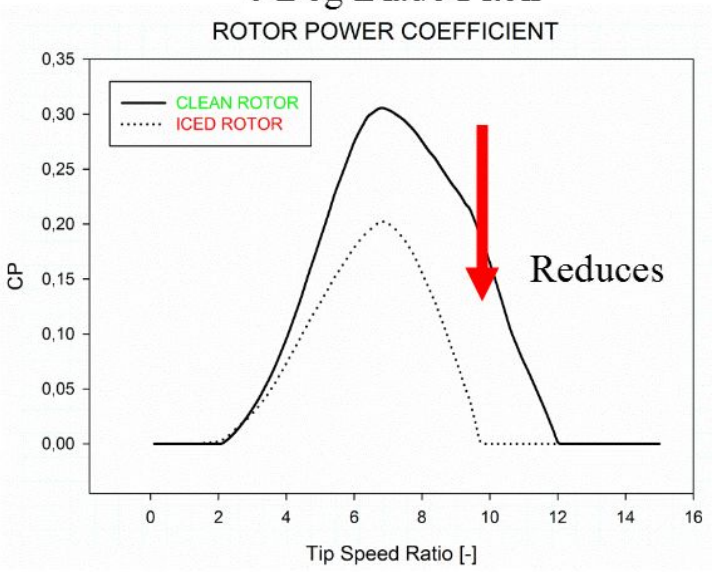


CL: Lift Coefficients

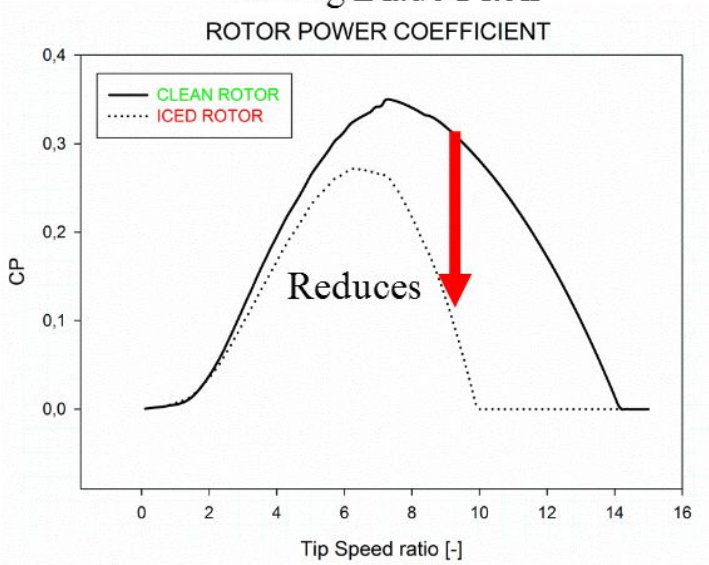


CD : Drag Coefficients

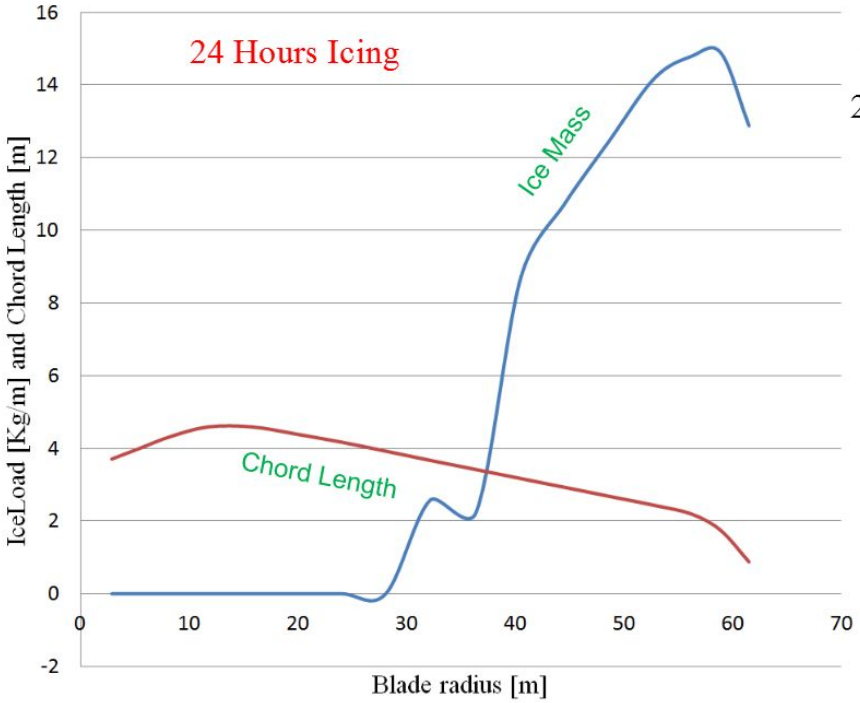
0 Deg Blade Pitch



10 Deg Blade Pitch



Distribution of Ice along the blade



Total Ice Mass = 486 Kg
2.8 % of total mass of blade

ICE LOAD [Kg/m]
CHORD LENGTH [m]




BUSS











Altamont Pass

Santa Clara



Diablo Range Mnts.
San Joaquin Valley
I-580 – „Silicon Valley“
average wind speed: 9 m/s

established 1980s - 4900 turbines (567 MW)
small = high speed turbines
1300 raptors/year
4700 birds/year











San Gorgonio Pass

San Bernardino



San Bernardino Mnts.
San Jacinto Mnts.
I-10 - Los Angeles
Average wind speed: 9 m/s

Shell Wind Energy Inc.
1980 - 1300 turbines (61,5 MW)
research: bird kills



today 4000 turbines (359 MW)
893 GWh/year




Whitewater





Cap Chat Wind Farm

Cap Chat, QC
coast of St. Lawrence gulf



project 57 MW
supposed production 195 GWh/year
Hydro Quebec Ltd.
finished:
76 x NEG-Micon NM750/48
2003 - 76 x 750 kW

largest north of CA








HALTE SANTÉ
CAPUCINS



Lingan Wind Turbine Project

North Sydney, NS
Coast of Cabot Strait



project 17 MW (9 turbines)
supposed production 42 GWh/year
Cape Breton Power Ltd.

finished:
7 x Enercon E70s

06/2006 - 2 x 2 MW
12/2006 - 3 x 2 MW
06/2007 - 2 x 2 MW







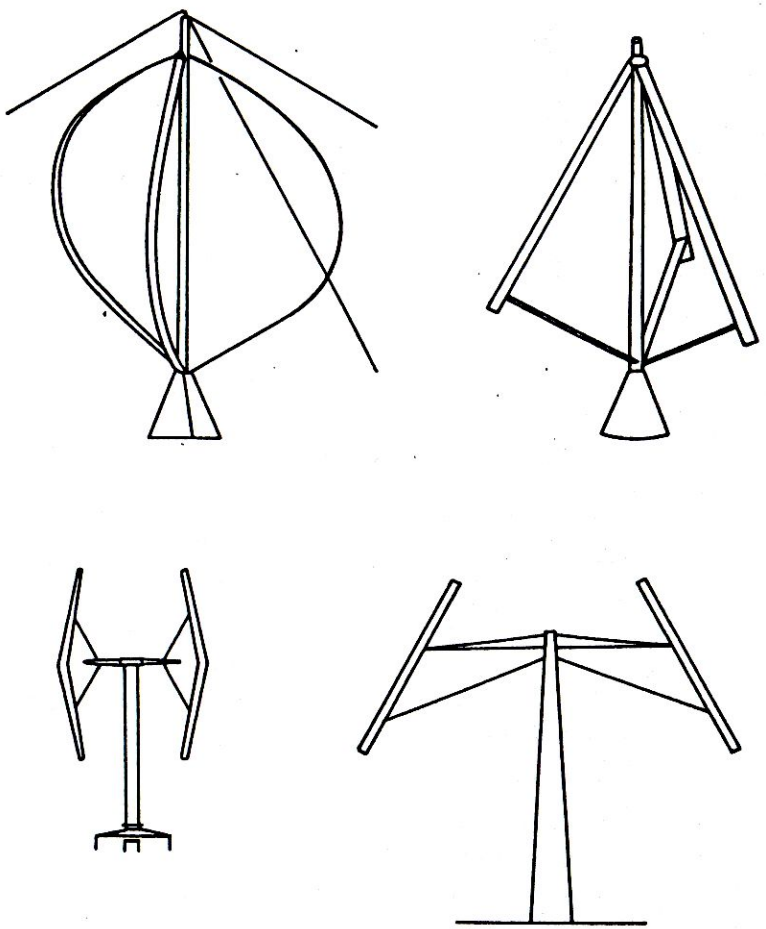


Enercon E70s

- power 2 MW
- rotor 90 metres, windward
- number of blades 3
- height 105 metrů
- area 6.362 m2
- rpm 8,2 – 14,9 rpm
- start up wind speed 4 m/s
- nominal wind speed 15 m/s
- drop-out wind speed 25 m/s
- restart wind speed 23 – 20 m/s
- generator 2 MW, asynchronous
- voltage 690 VAC, freq. 50/60 Hz
- planetary gear box
- material of blades: polyester/epoxid resin
- Blade length 44 m
- conic tower, tubed, steel, 5 parts
- diameter bottom / top 4,15 / 2,3 m
- basement plate: armored concrete 15,35 x 15,35 x 2 m
- weght 335,3 t (tower 231 t, machine room 68 t, rotor 36,3 t)
- costs cca 70 mil Kč
- ČR - Dukovany



Rotor Darrieus





EOLE VAWT

Cap Chat, QC
coast of St. Lawrence gulf

project 4,2 MW
Supposed production 15 GWh/rok
Axor Ltd.



finished:
1987 - 4,2 MW





EOLE 4,2 MW

vertical axis - type Darrieus
auxiliary start
height 110m
diameter 60m
basement 10m
rigging cables
DC generator
DC/AC inverter

1. multi MW
1. without gearbox
1. variable speed
1. with invereter







