

ESF II projekt Západočeské univerzity v Plzni

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EVROPSKÁ UNIE
Evropské strukturální a investiční fondy
Operační program Výzkum, vývoj a vzdělávání



MINISTERSTVO ŠKOLSTVÍ,
MLÁDEŽE A TĚLOVÝCHOVY

VODNÍ A VĚTRNÉ ELEKTRÁRNY



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Větrné elektrárny

Milan Bělík

Větrné elektrárny

- vodorovná osa (HAWT)

- n-listá vrtule
- větrné kolo
- větrný mlýn

- svislá osa (VAWT)

- Savonius
- Darrieus

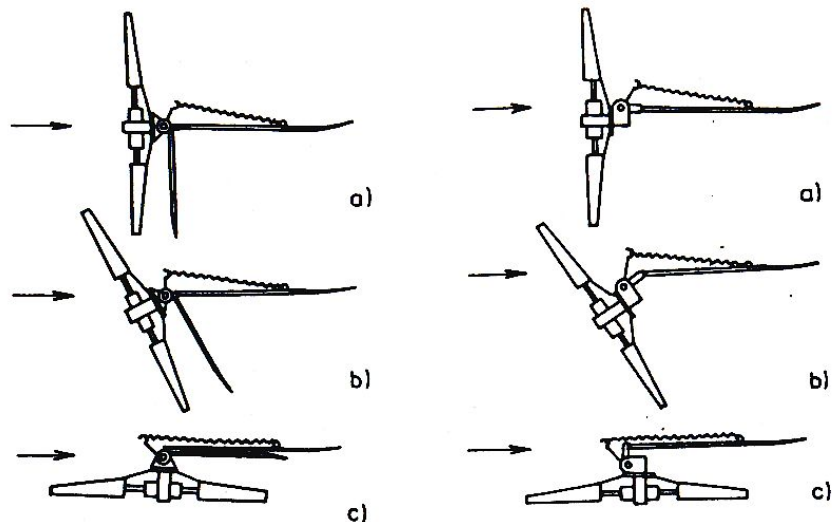
- onshore
- offshore



Regulace větrných motorů

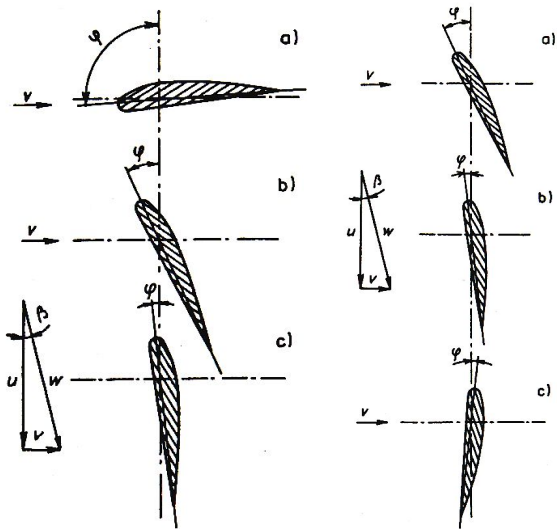
- s pevnými lopatkami

- s boční deskou
- s vyoseným kormidlem
- odtržením proudu (stall)



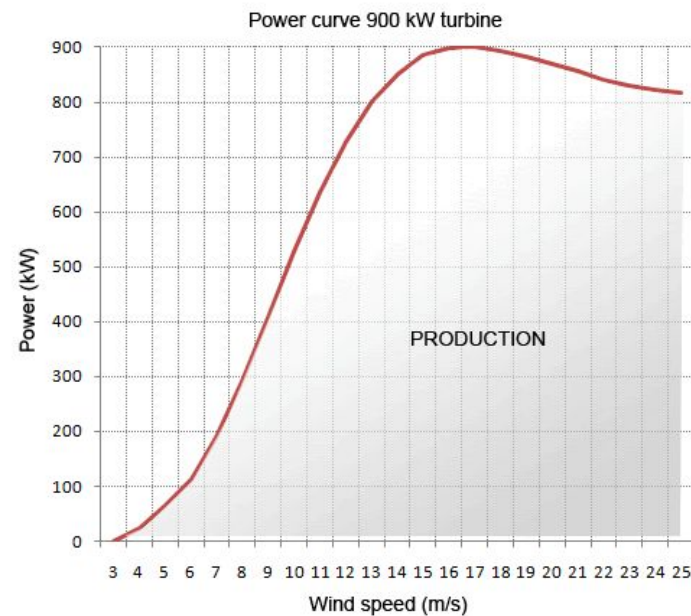
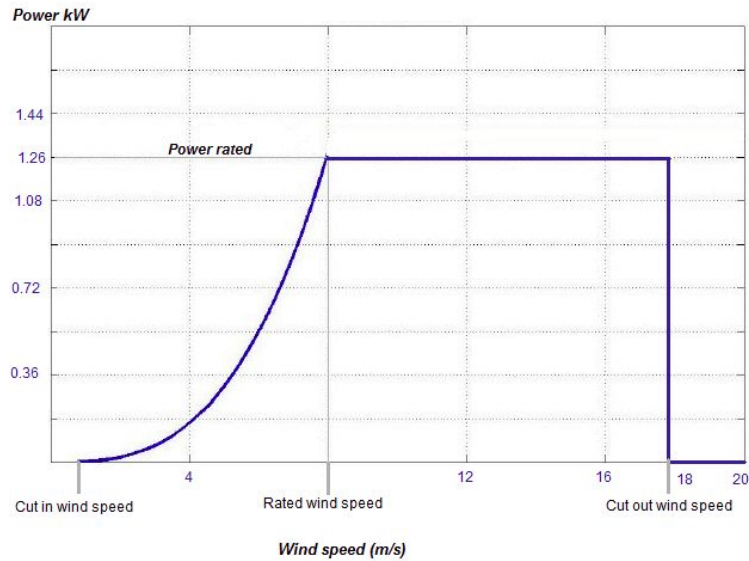
- s natáčivými lopatkami (pitch)

- do praporu
- na odtržení
- s aerodynamickou brzdou

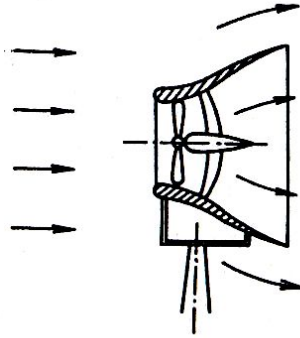
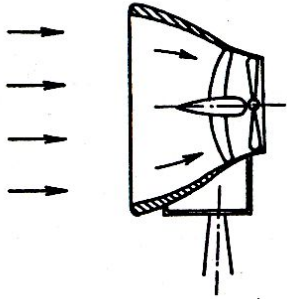




Regulace pitch / stall



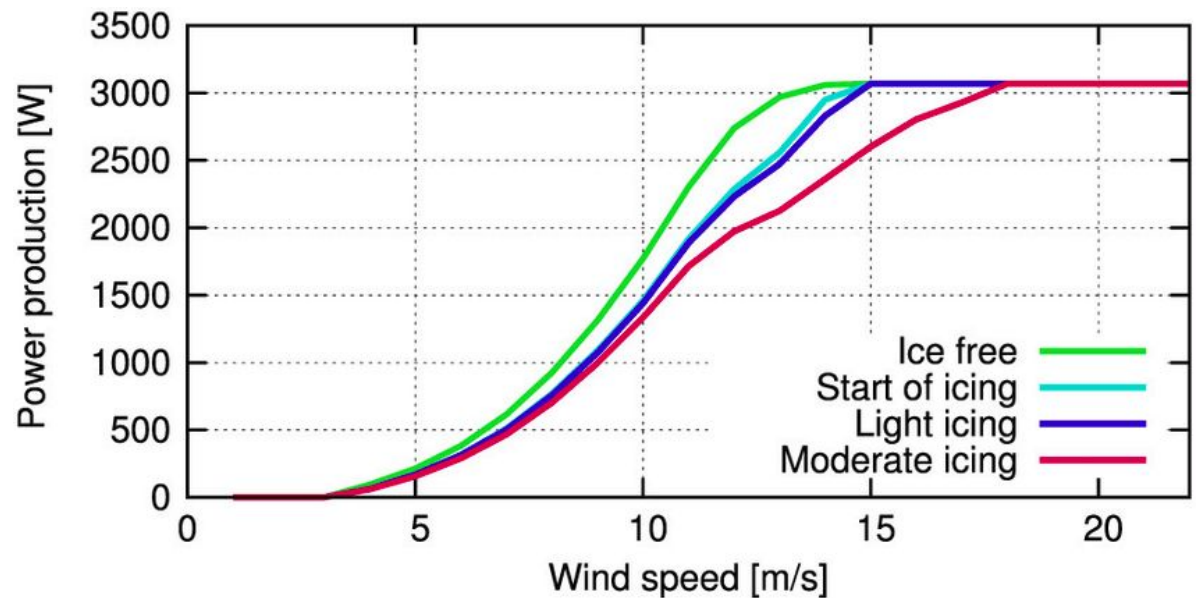
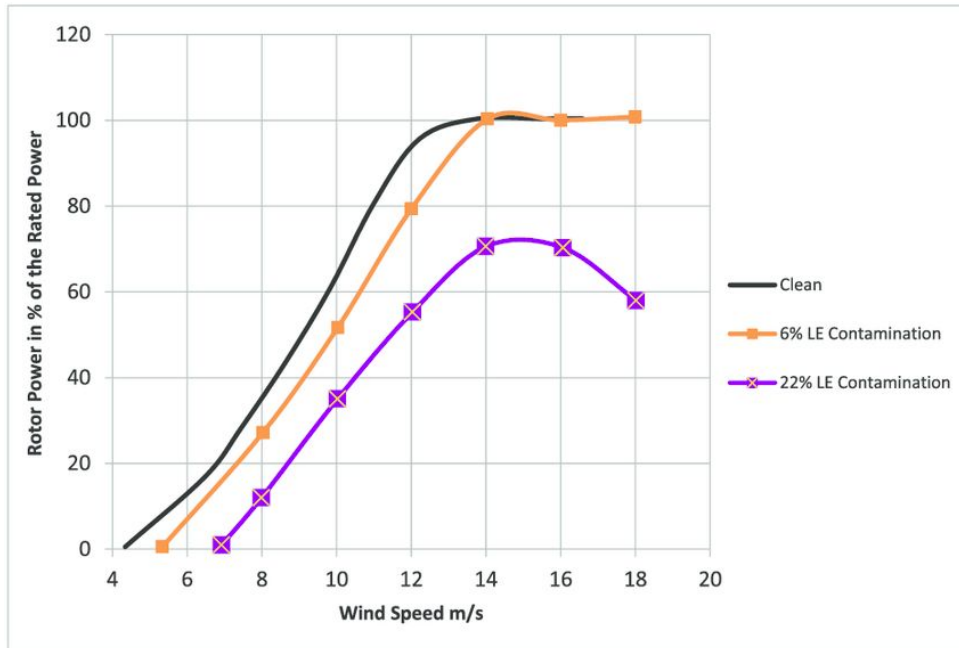
Konfuzor & difuzor







Výkonová charakteristika - ztráty

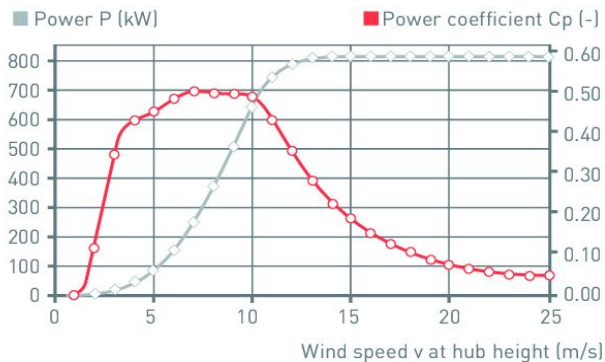


	GE 1.5 MW	GE 1.6 MW	GE 3.6 MW	GE 2.5 MW
Generator Rating	1.67 MVA	1.78 MVA	4 MVA	3 MVA
P _{max}	1.5 MW	1.6 MW	3.6 MW	2.5 MW
P _{min}	0.07 MW	0.075 MW	0.16 MW	0 MW
Q _{max}	0.726 MVar*	0.775 MVar*	2.08 MVar	1.20 MVar*
Q _{min}	-0.726 MVar*	-0.775 MVar*	-1.55 MVar	-1.20 MVar*
Terminal Voltage (60 Hz)	690 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

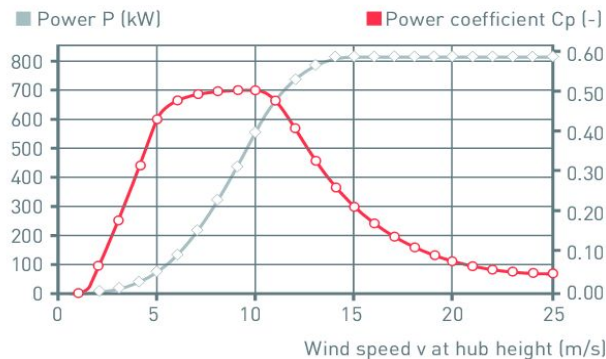
Type	AC 120 AC 240	AC 502 AC 752/NE	AC 1002 H
Generator	18-pole	16-pole	16-pole
Power output	120 W 240 W	500 W 750 W	1000 W
System voltage	12/24 V	12/24 V 24/48 V	230V
Rated output at	9 m/s	9 m/s	9 m/s
Cut-in wind speed	3 m/s	3 m/s	3 m/s
Critical wind speed	40 m/s	40 m/s	40 m/s
Rotational speed	700 rpm	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 m ²	45 / 55 m	variable, 16 - 34.5 rpm	28 - 34 m/s	-	IEC/EN IA
ENERCON E-48	800 kW	48 m	1,810 m ²	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 m ²	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 m ²	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 m ²	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 m ²	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 m ²	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 m ²	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 m ²	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 m ²	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 m ²	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 m ²	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 m ²	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 m ²	135 m	variable, 5 - 12.1 rpm	28 - 34 m/s	WZ III	IEC/EN IA

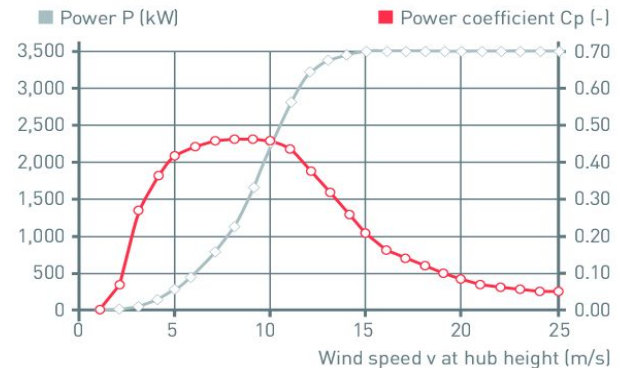
800 kW



800 kW



3,500 kW



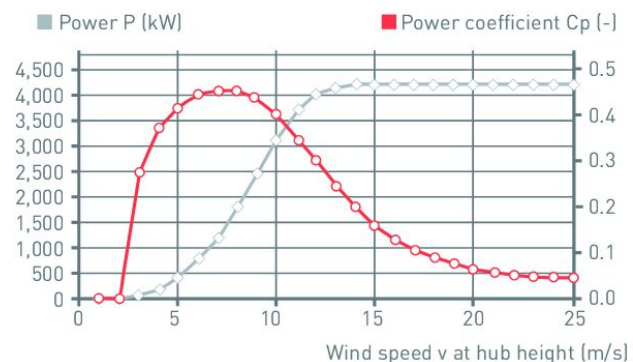
2,000 kW



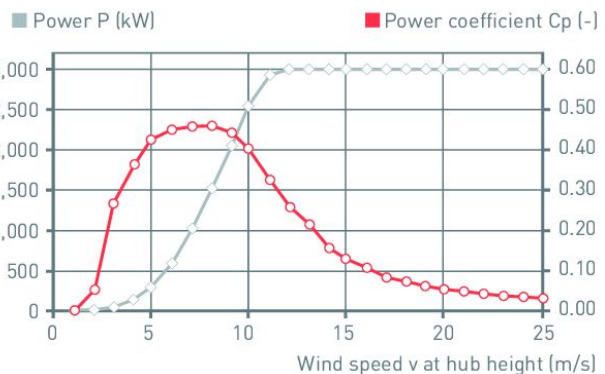
2,300 kW



4,200 kW



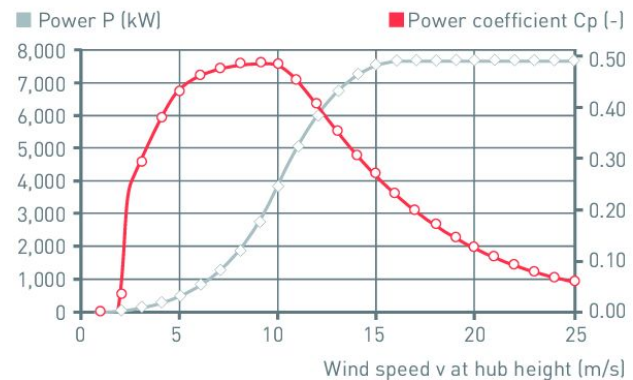
3,000 kW



3.000 kW

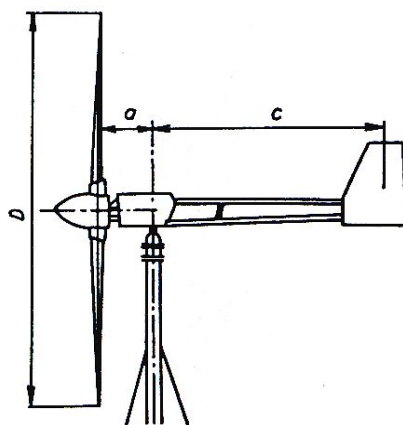
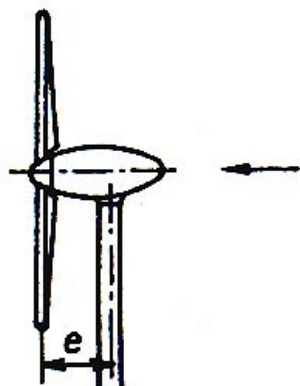
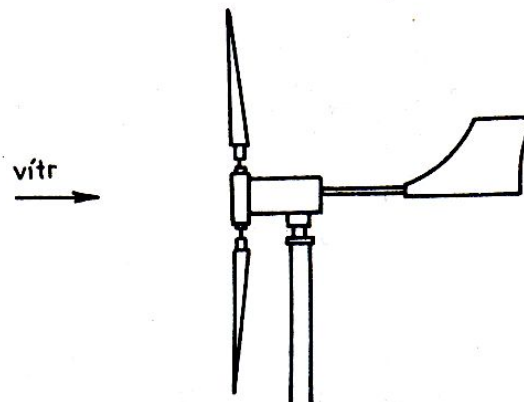
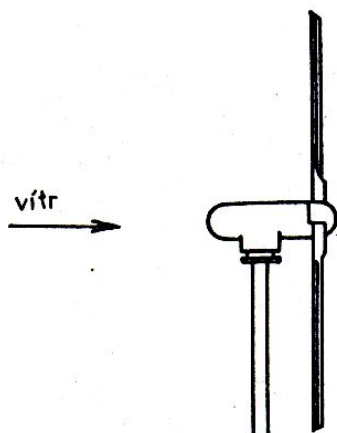


7,580 kW



Orientace gondoly

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



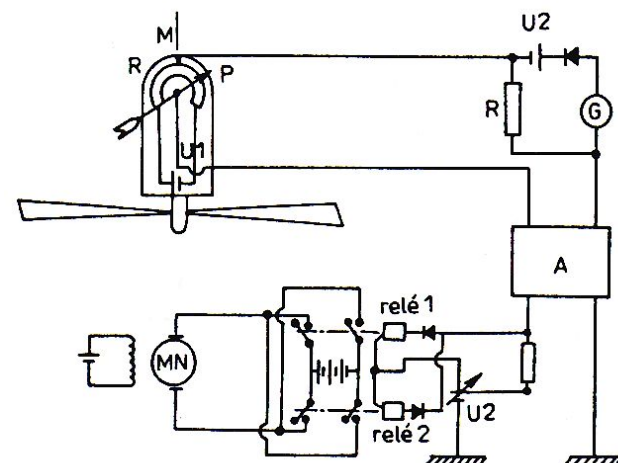
$$A_K = D^2 \frac{e}{c} k_K$$

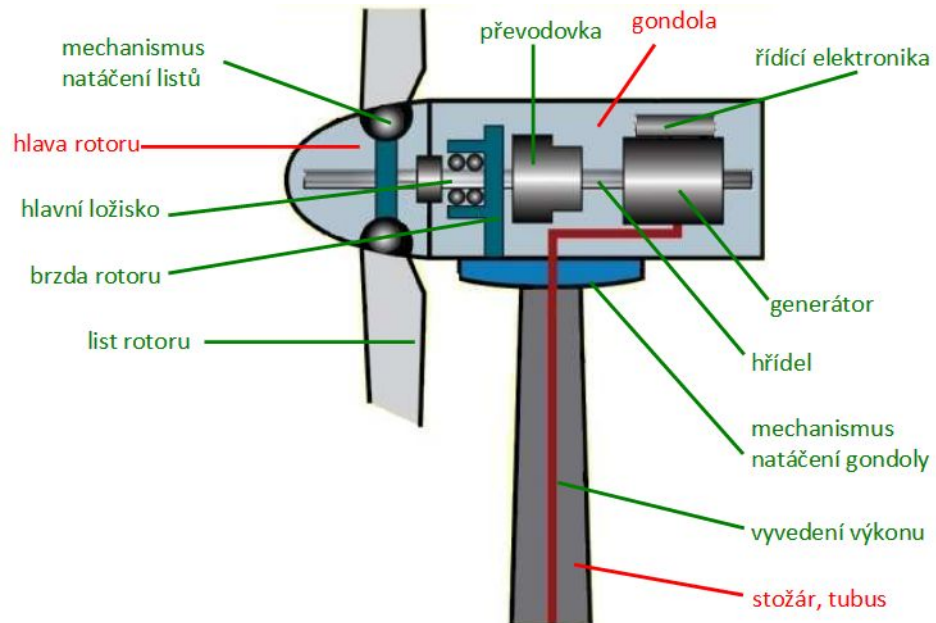
D je průměr vrtule

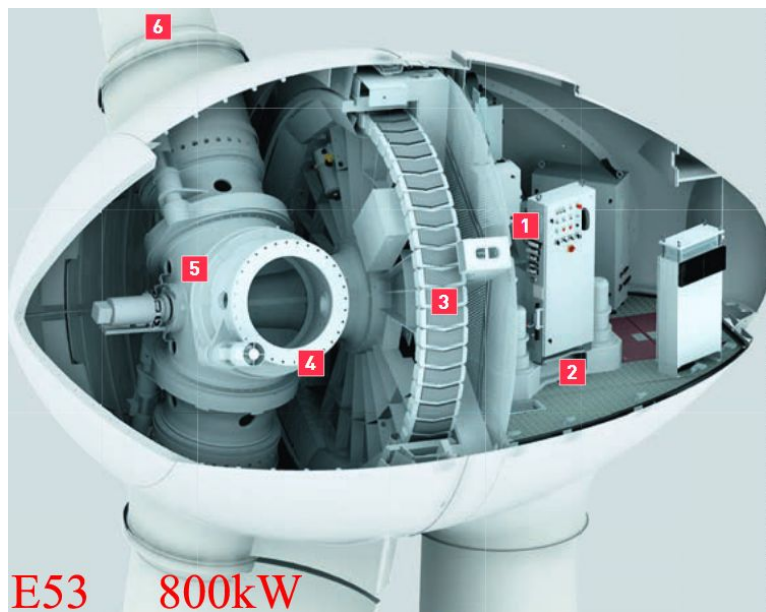
e - vzdálenost od osy natáčení k rovině vrtule

c - vzdálenost od osy natáčení k těžišti kormidla $c = (2 \text{ až } 5)e$

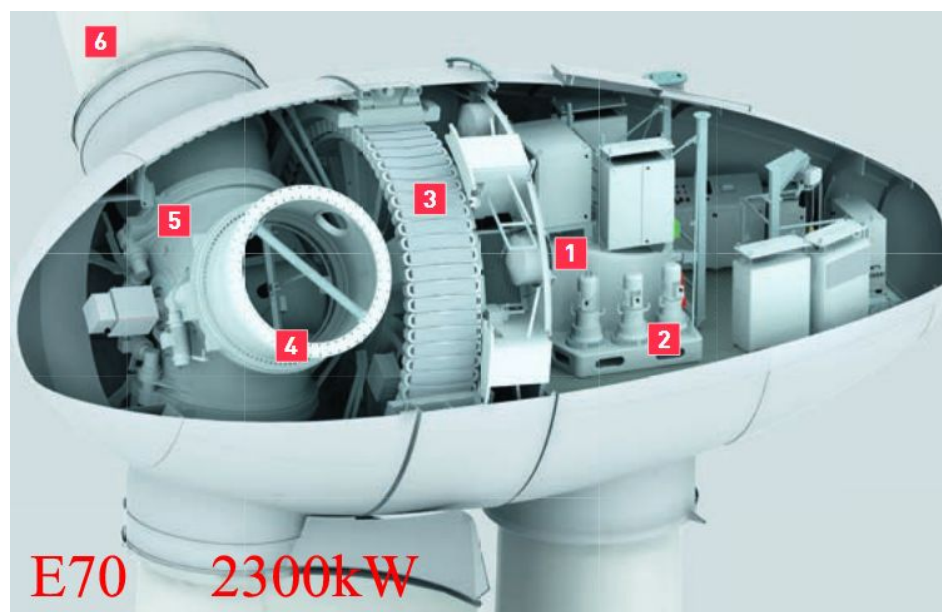
k_K - empirický součinitel (u rychloběžných motorů $k_K = 0,13$ a u pomaloběžných $k_K = 0,32$)



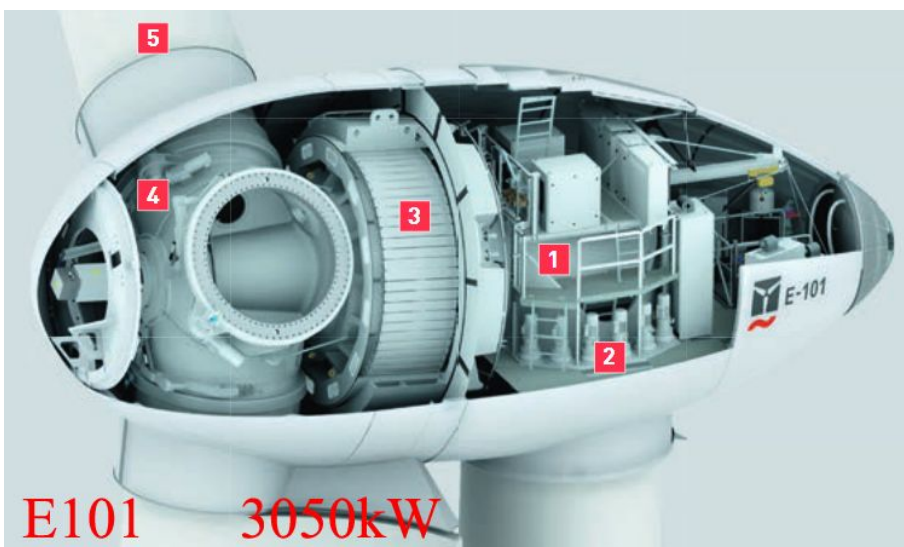




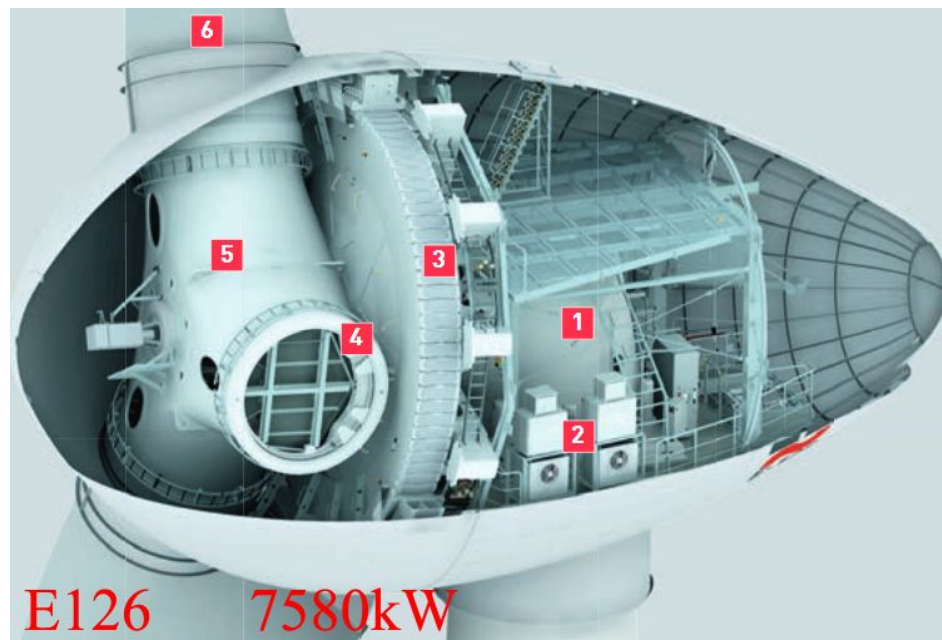
E53 800kW



E70 2300kW

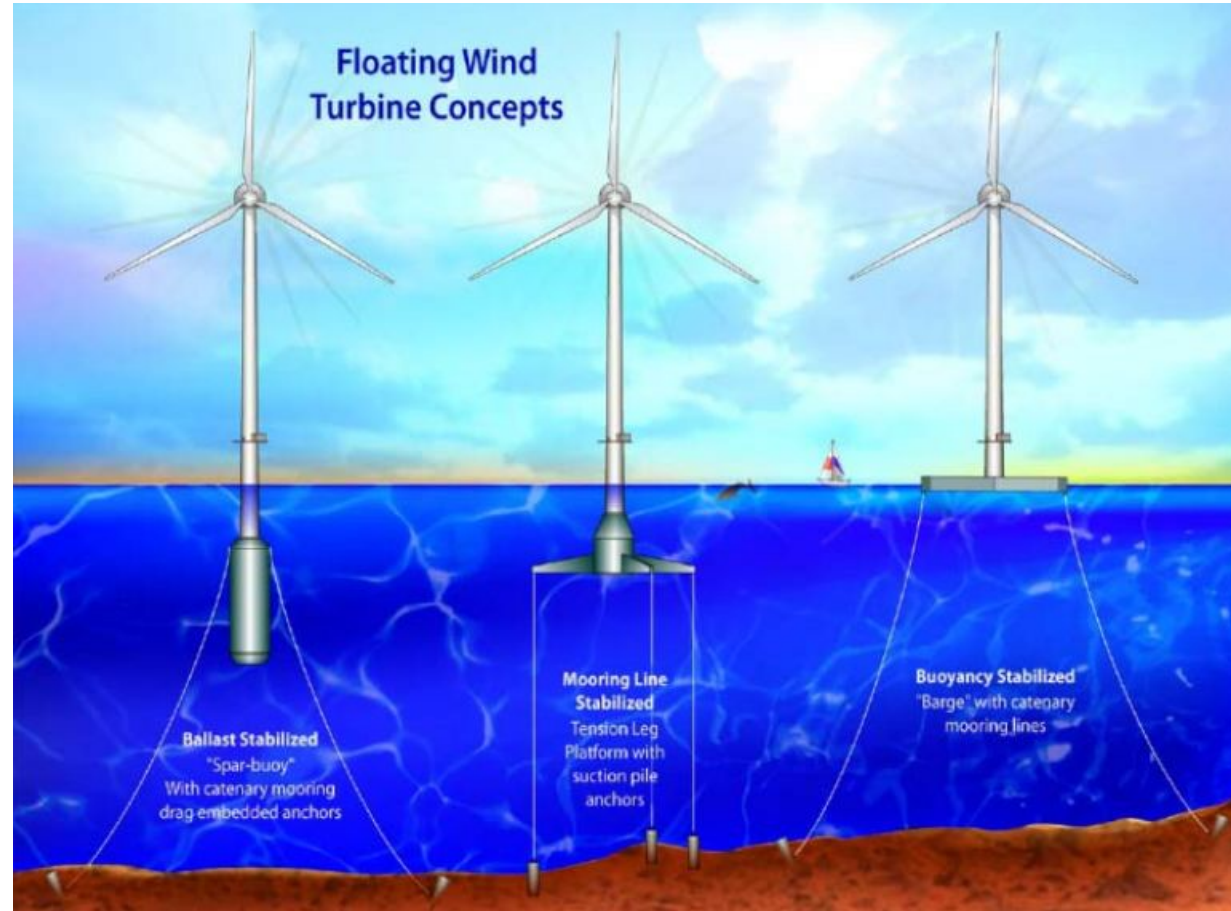
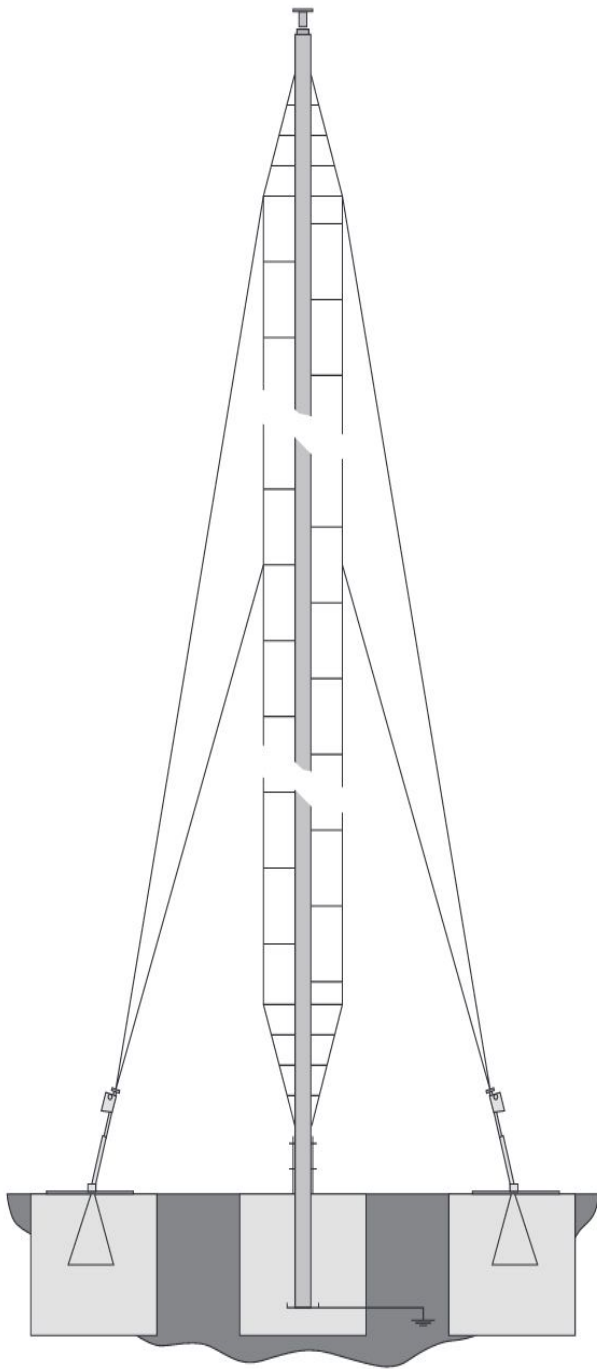


E101 3050kW

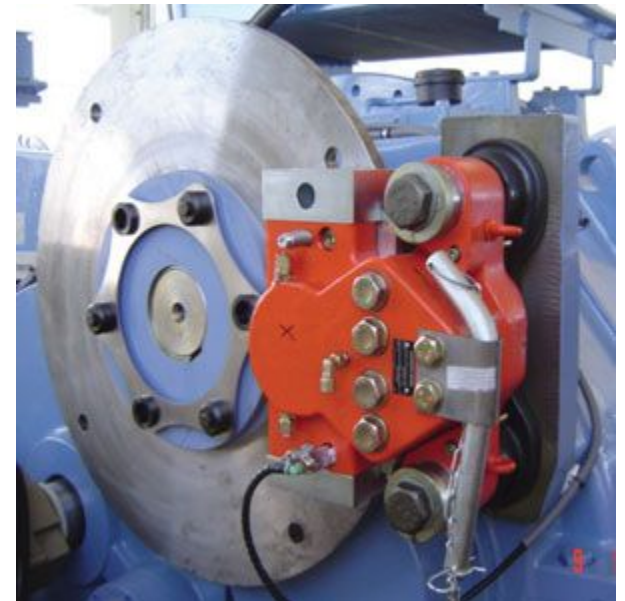
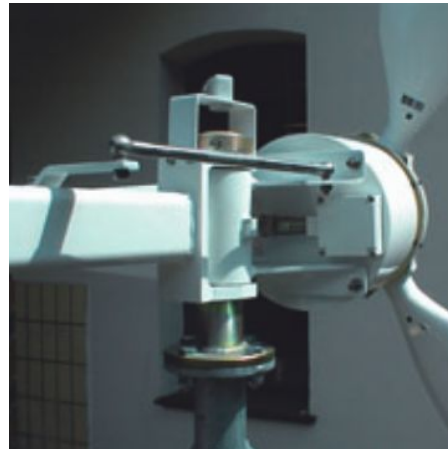
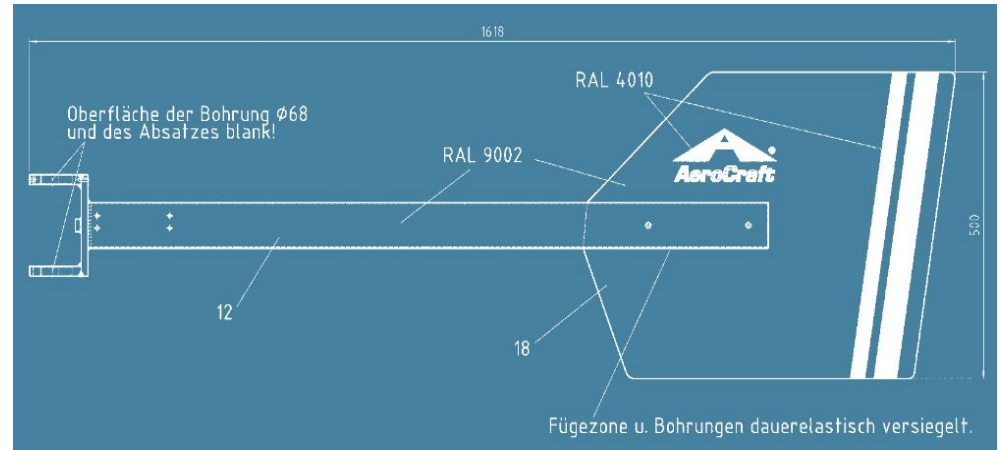


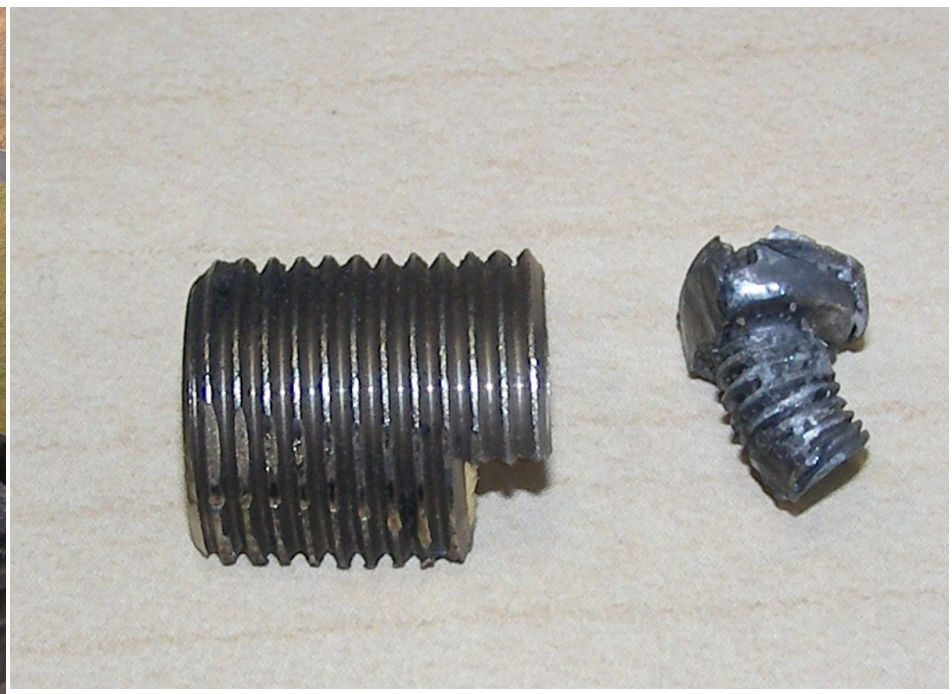
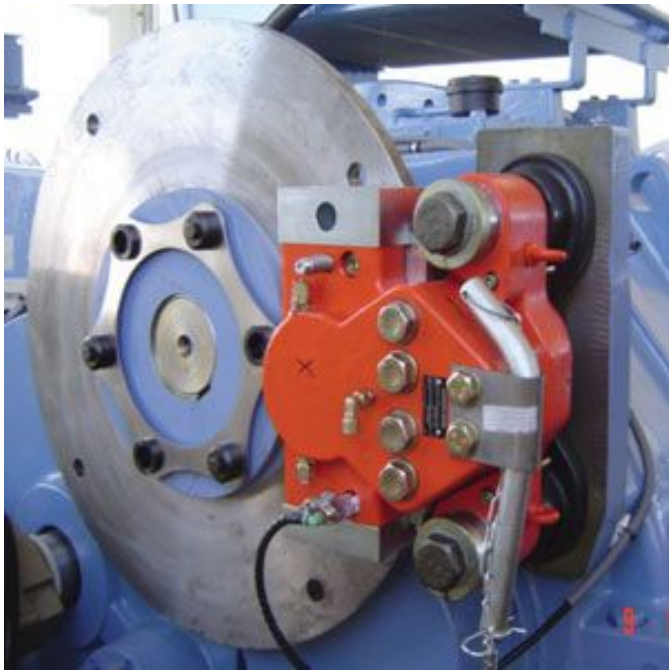
E126 7580kW





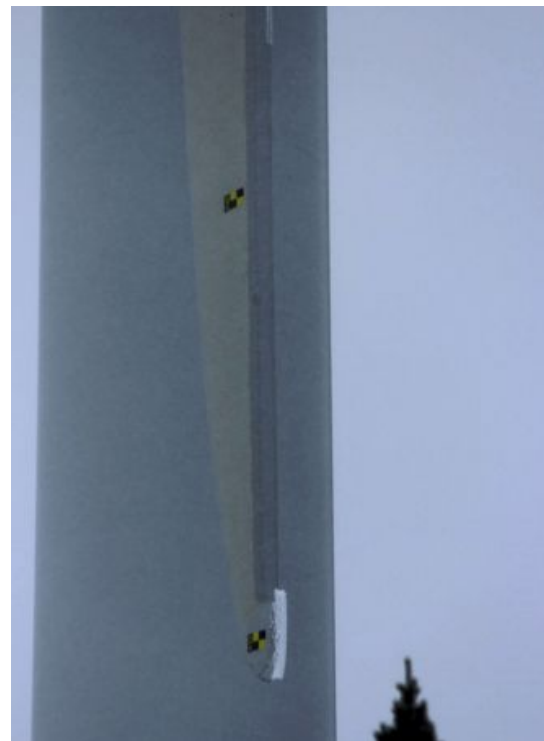






Icing







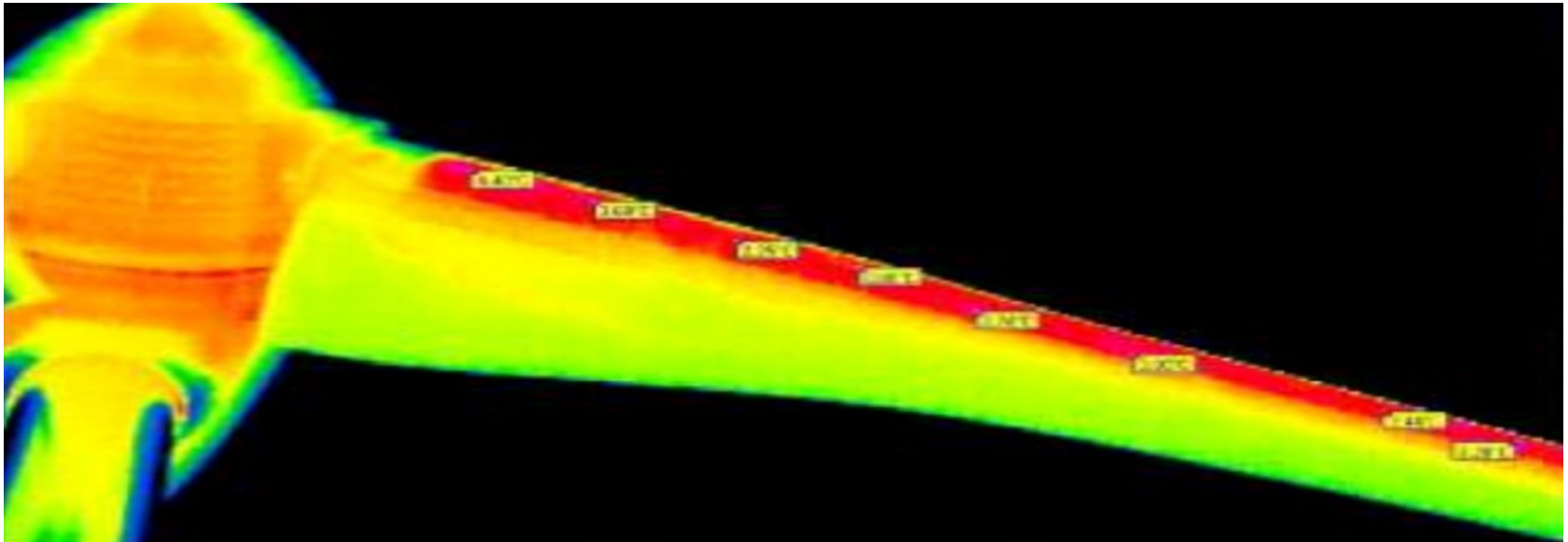
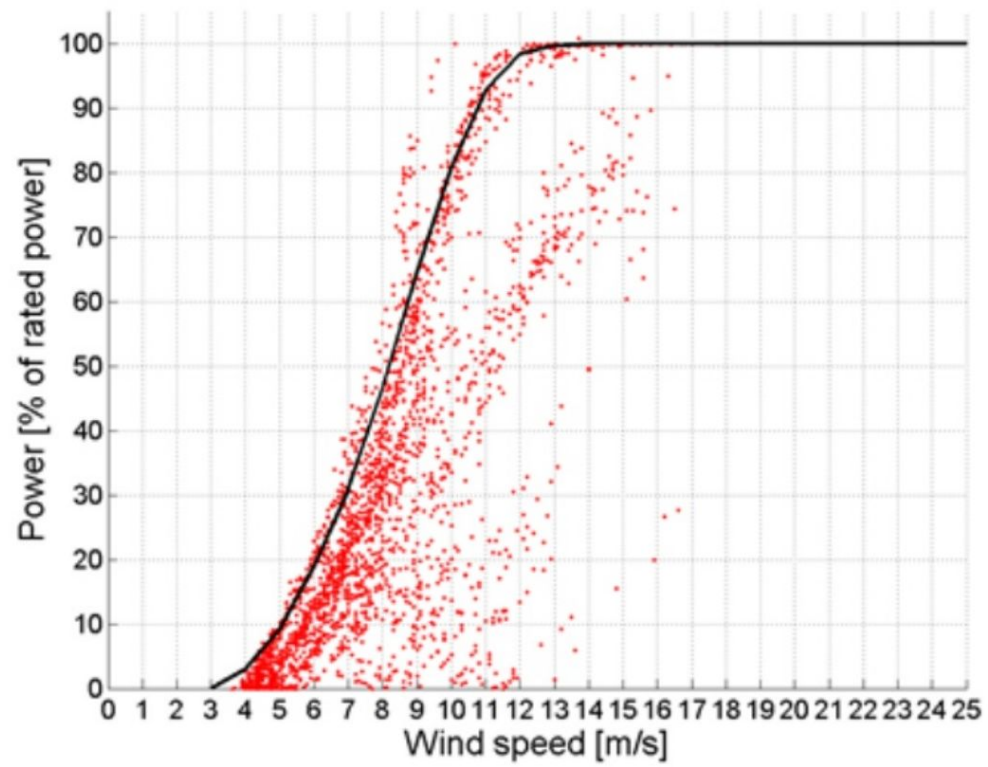
**PROVOZ
VĚTRNÝCH
ELEKTRÁREN**

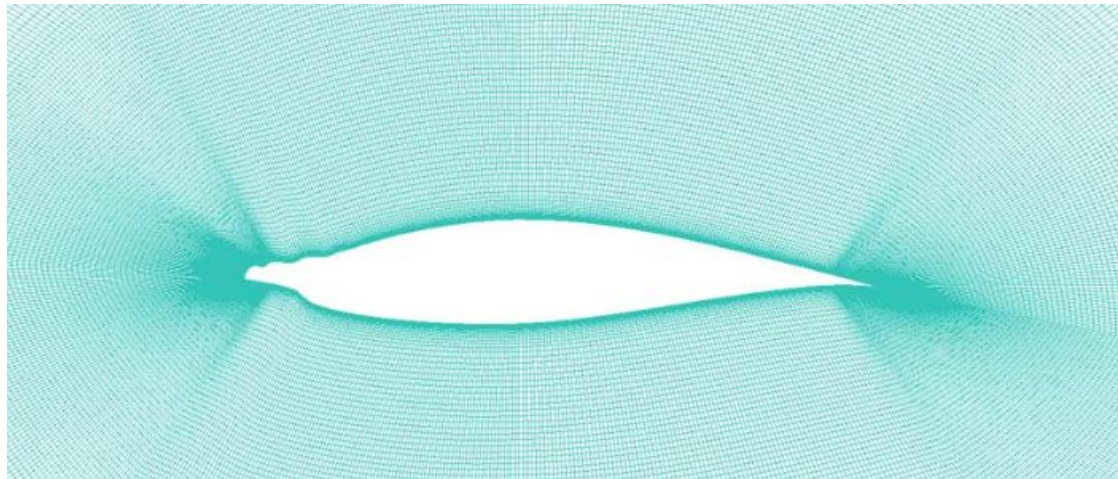
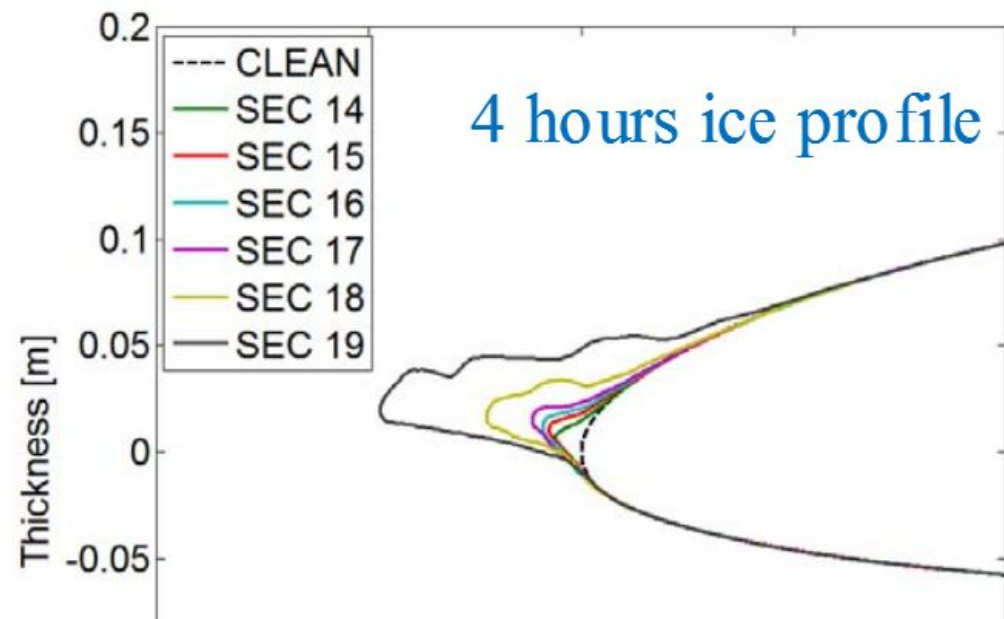
**PŘI PRŮCHODU
DBEJTE ZVÝŠENÉ
OPATRNOSTI**

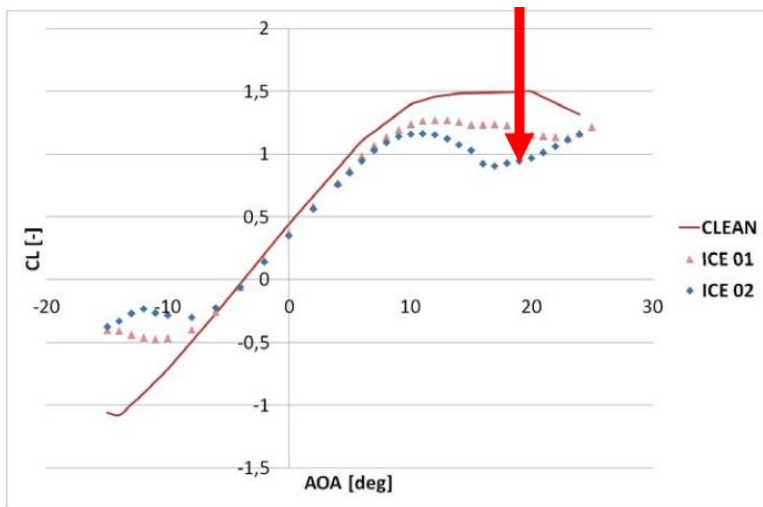
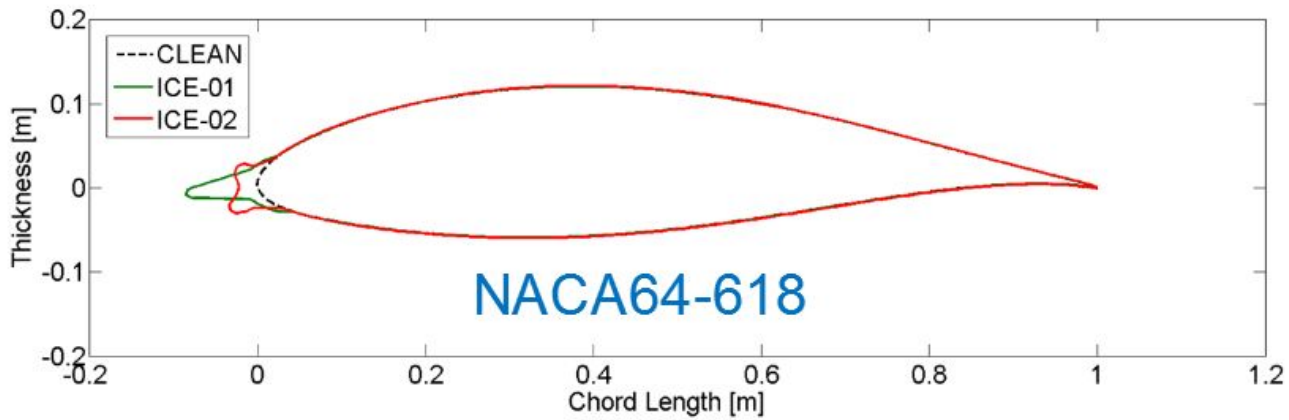
POZOR

PADAJÍCÍ
NÁMRAZA

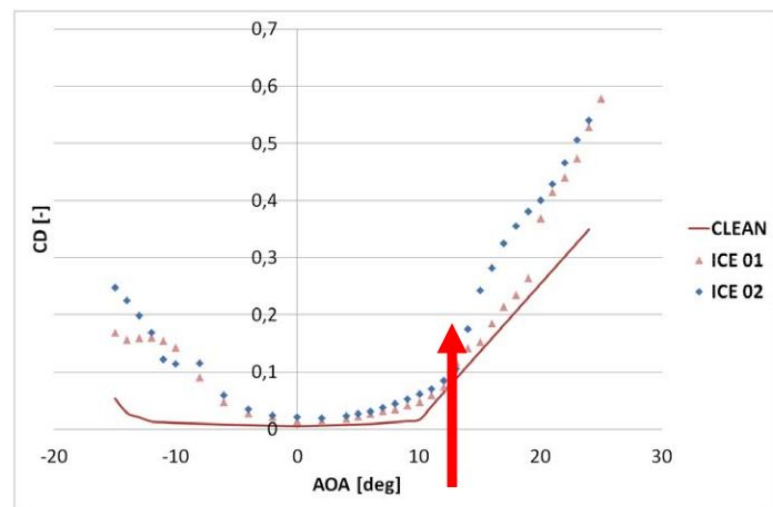








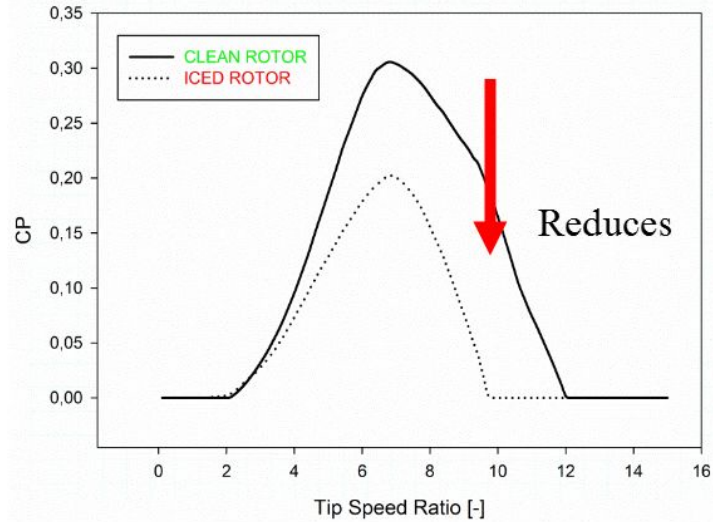
CL: Lift Coefficients



CD : Drag Coefficients

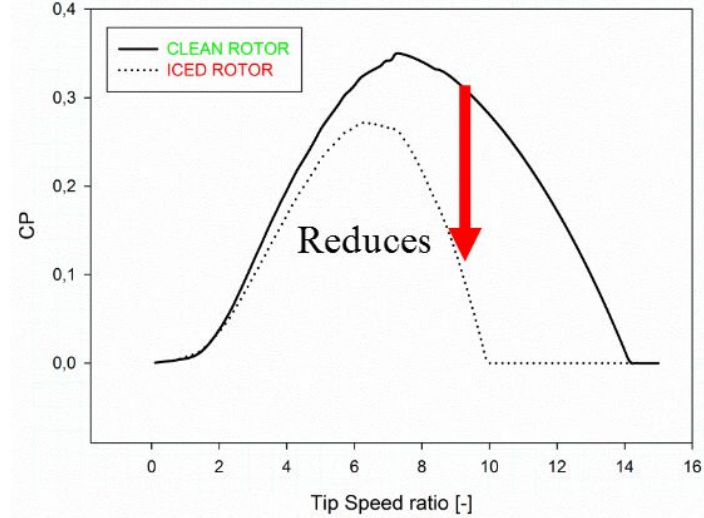
0 Deg Blade Pitch

ROTOR POWER COEFFICIENT

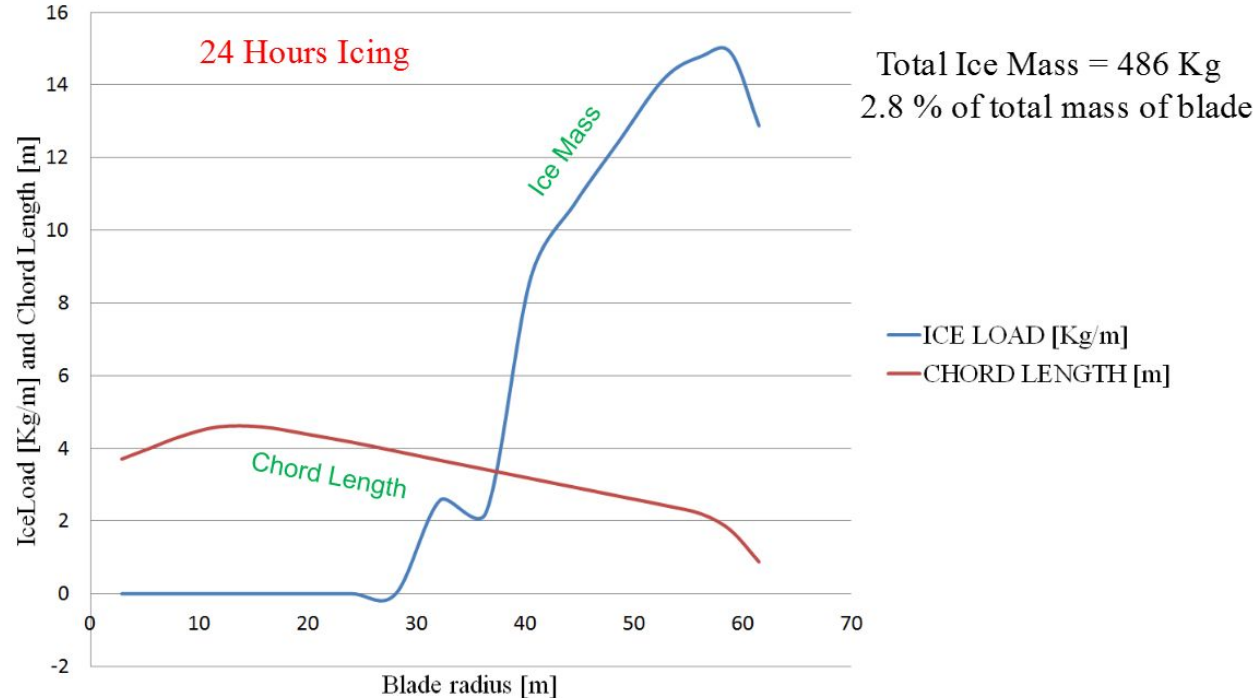


10 Deg Blade Pitch

ROTOR POWER COEFFICIENT



Distribution of Ice along the blade











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







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





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



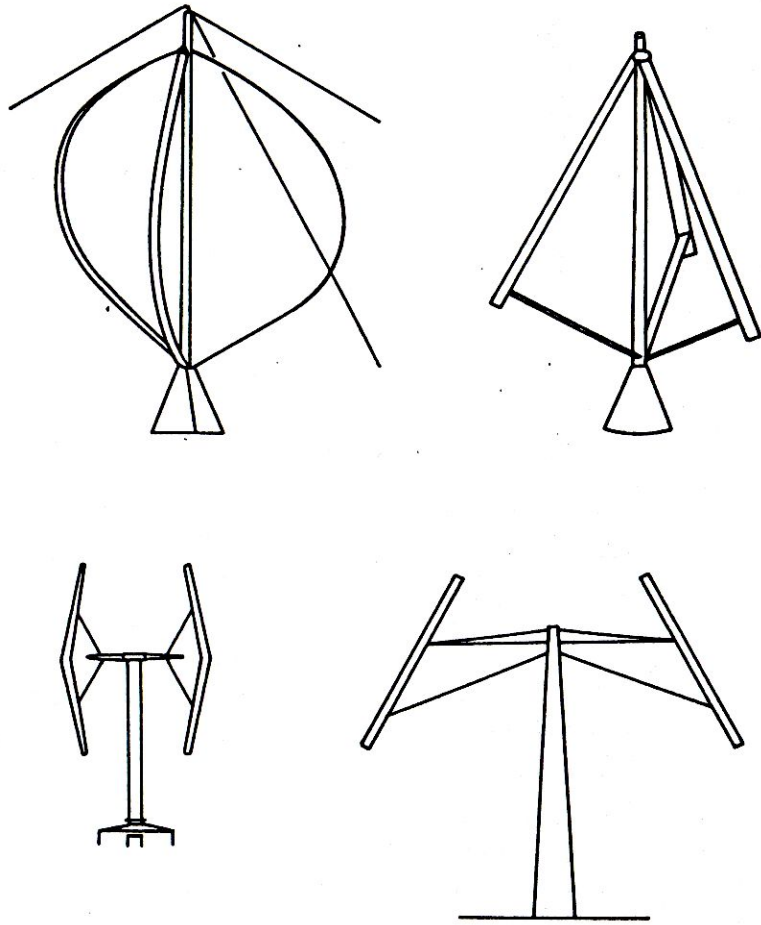


Enercon E70s

- 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
- weight 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 inverter**



