



College of Engineering  
Department of Mechanical Engineering

# ASSE 4311

## LEARNING OUTCOME ASSE. III/MEEN

### WIND TURBINE

**BY :**

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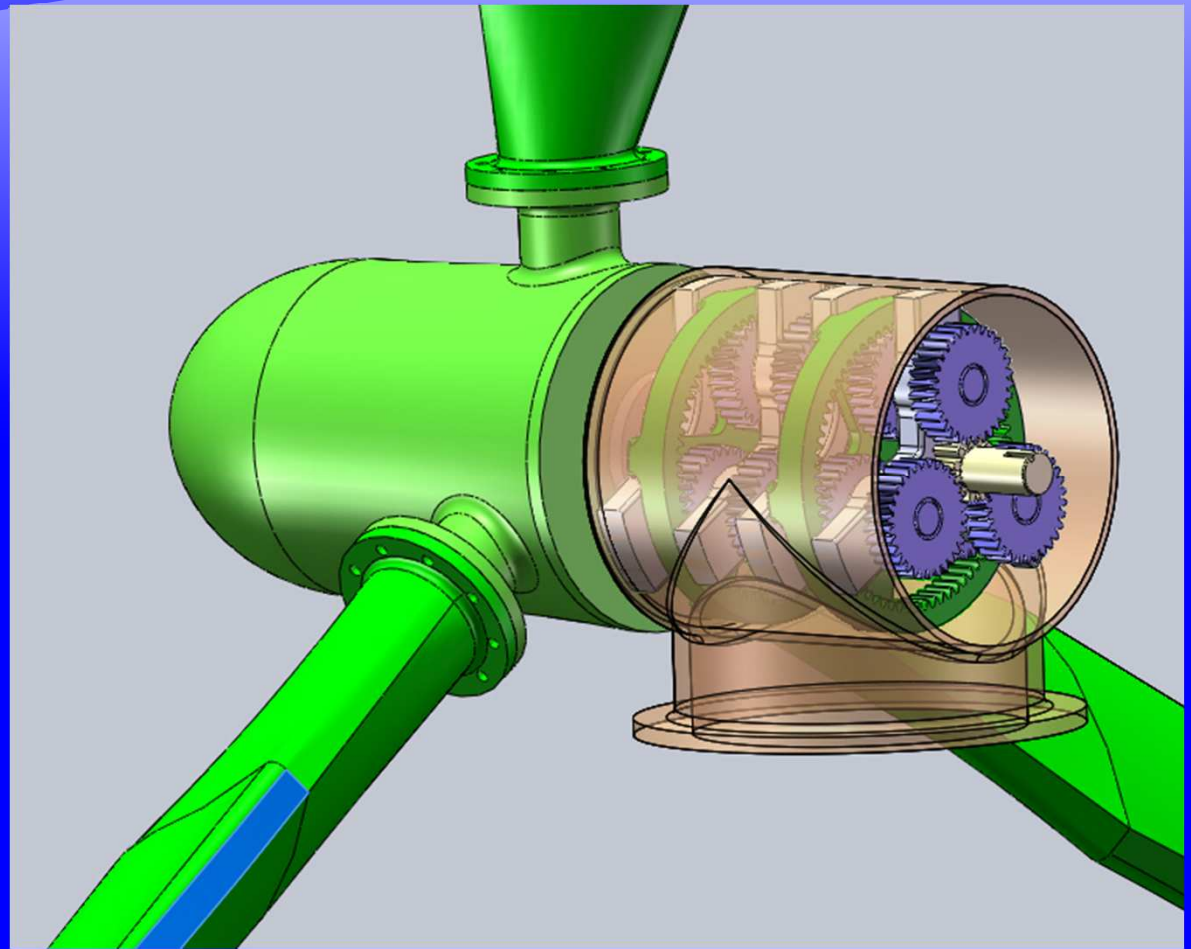
**INSTRUCTOR:**  
DR. EMAD AL-TANBOUR



# OUTLINE

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- 1- Project objective.
- 2- Introduction.
- 3- Gantt chart.
- 3- Theory.
4. 30 KW Wind turbine design.





# OBJECTIVE

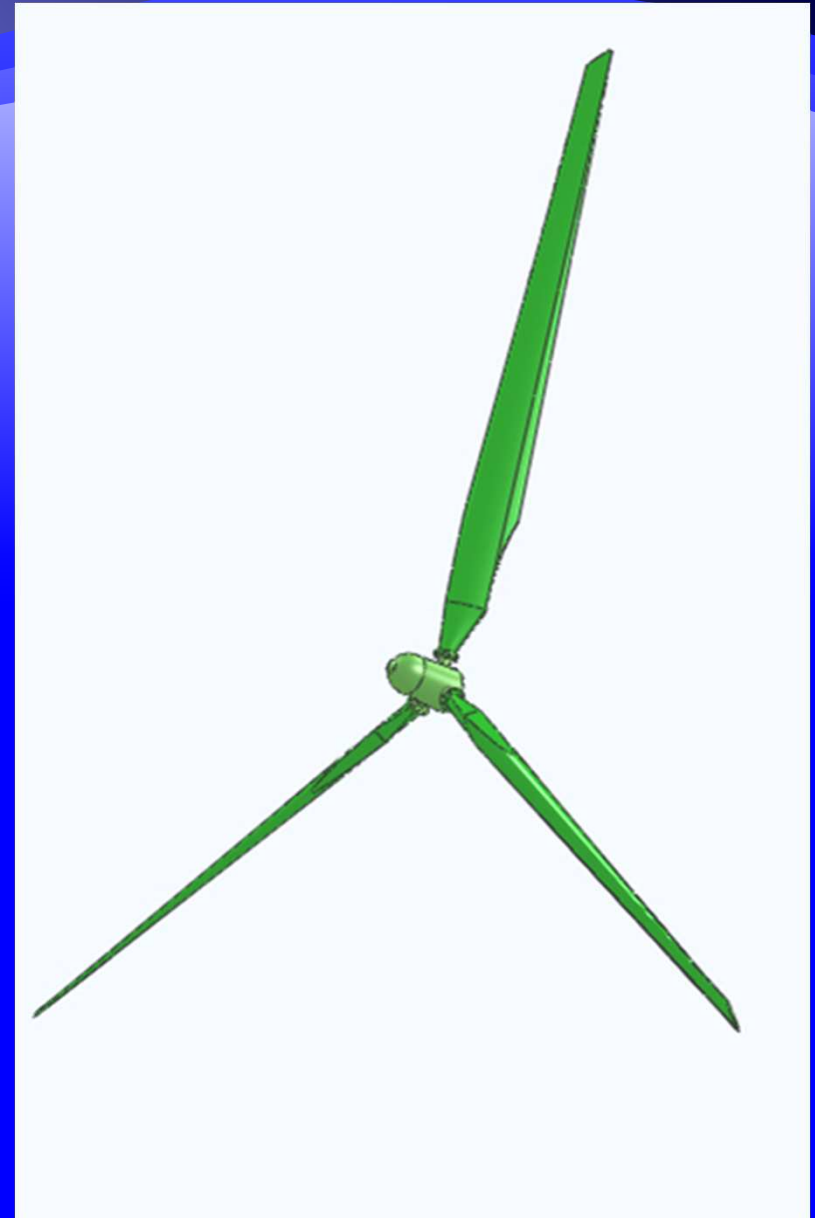
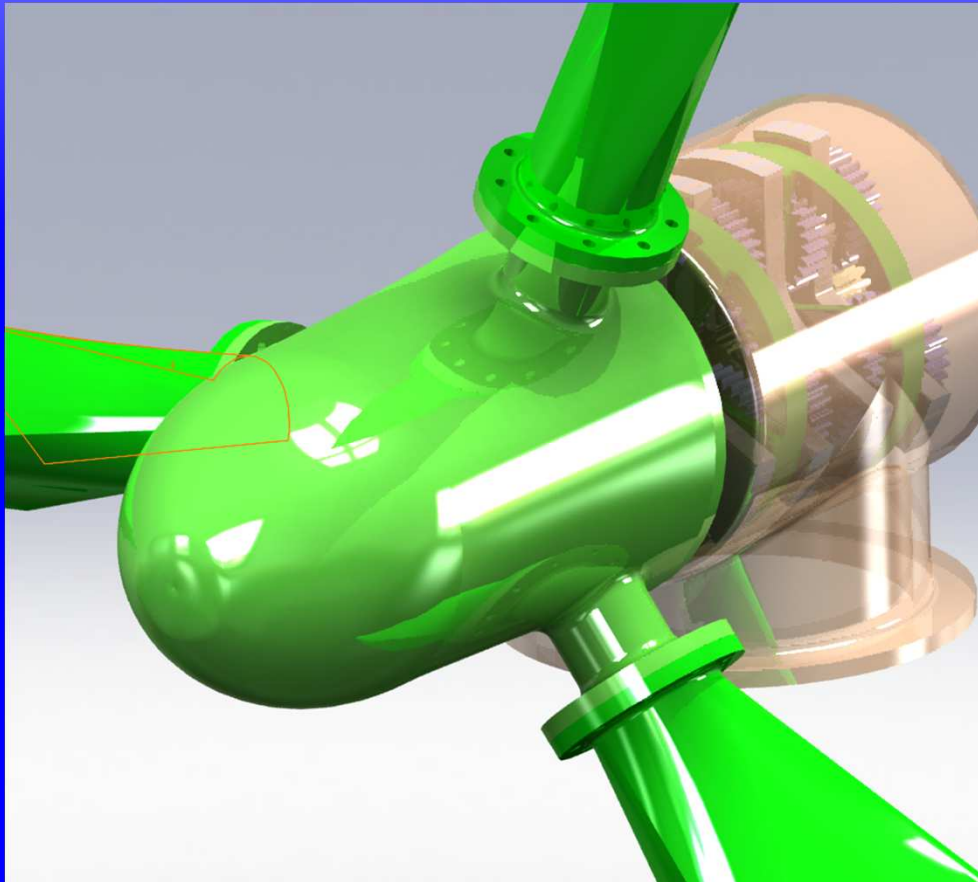
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The project design proposal is:

To design a 30 KW wind turbine  
horizontal axis type.

Rotor diameter: 11 m (estimated).

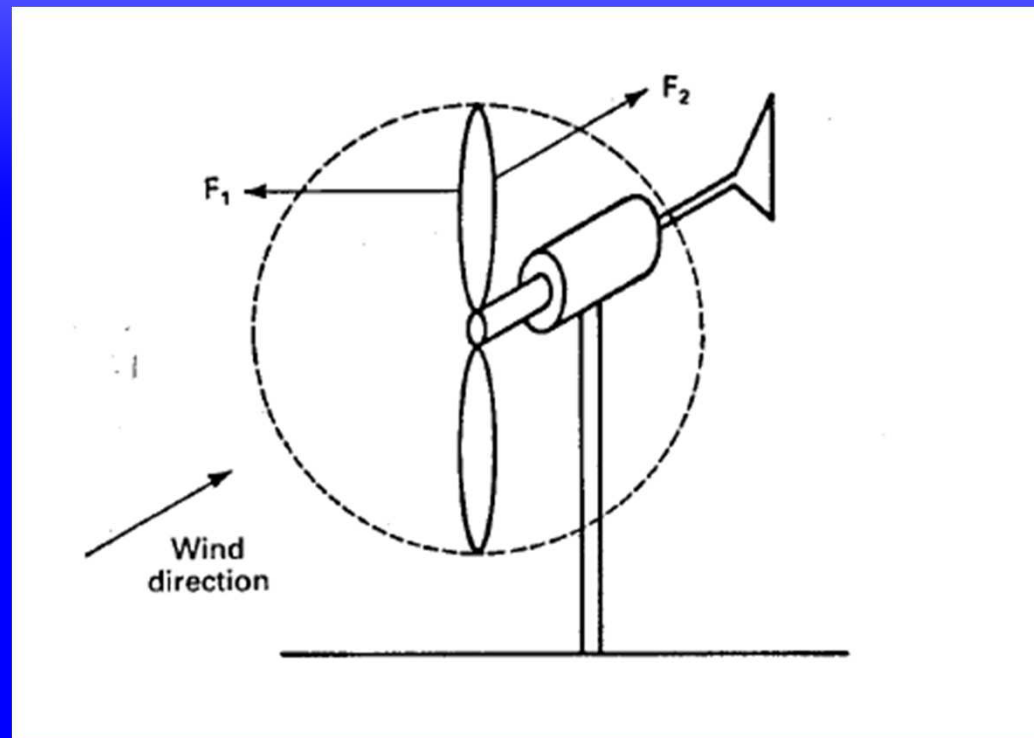
Tower height: 20 m (proposed).





# INTRODUCTION

A wind turbine is a device for extracting kinetic energy from the wind. By removing some of its kinetic energy the wind must slow down but only that mass of air which passes through the rotor disc is affected.





# GANTT CHART

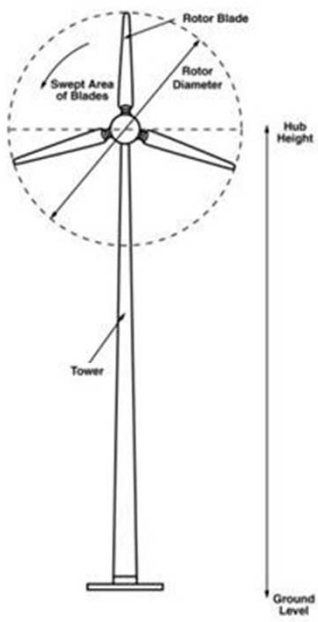
Highlight

Gantt chart senior project spring 2010 (Wind turbine)

Nr	Activity description	Man power	Week number (Spring 2010)																
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
1	Introduction by Dr. Emad of project & expectations		█																
2	Project selection (Wind turbine) & team forming			█															
3	Introduction of project/brainstorming/proposed WT rating				█														
4	Letriture and more brainstorming by team/sketch ideas					█													
5	Discuss with Dr. Emad the predesign calculations						█												
6	Edit calculations as needed, sketch using CAD							█											
7	Identify critical components of design (loading parts)								█										
8	Detailed engineering (strength calculation loading parts)									█									
9	Update conceptual design, update CAD assembly										█								
10	Fine tuning CAD design											█							
11	Simulate design using CAD (FEA, CFD).												█						
12	Detailing of design													█					
13	Final report														█				
14	Presentation															█			
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30 KW power output

- Turbine blades.
- Turbine shaft.
- Speed up gear box.
- Coupling



- Brainstorming:
- Wind speed survey in Saudi Arabia (7 m/s is chosen roughly for calculation purpose).
  - Generator output power 30 KW (proposal).
  - Torque calculation based on power output.
  - Gearbox input and output torque required by generator.
  - Gear box input and output speed required by generator.
  - Sizing of turbine output shaft based on torque and material selected.
  - Speed up gearbox detailed engineering (gear/bearing type).
  - Gearbox lubrication (bearings/gears).
  - Coupling type selection, interference fit calculation.
  - Tower hight (rule of thumb: higher is better in term of wind speed, but more bending stresses challenges).
  - Tower foundation engineering.



# THEORY

Power available in wind is derived from kinetic energy formula:

$$E = \frac{1}{2}mv^2$$

$$P = \frac{dE}{dt} = \frac{1}{2}v^2 \frac{dm}{dt}$$

Power is the rate of change in energy

$$\frac{dm}{dt} = \rho A \frac{dx}{dt}$$

$$\frac{dx}{dt} = v$$

$$\frac{dm}{dt} = \rho Av$$

$$P_w = \frac{1}{2}\rho Au^3$$

Where;

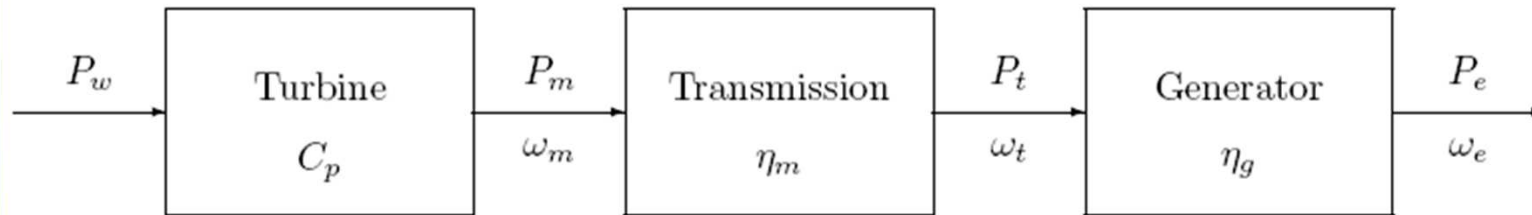
$\rho$  is air density=1.23 kg/m<sup>3</sup>

$u$  is wind speed (m/s).

$A$  is the swept area.



# THEORY (CONT.)



$$P_m = C_p \left( \frac{1}{2} \rho A u^3 \right) = C_p P_w$$

Power (mechanical)

$$P_t = \eta_m P_m$$

Power (transmitted)

$$P_e = \eta_g P_t$$

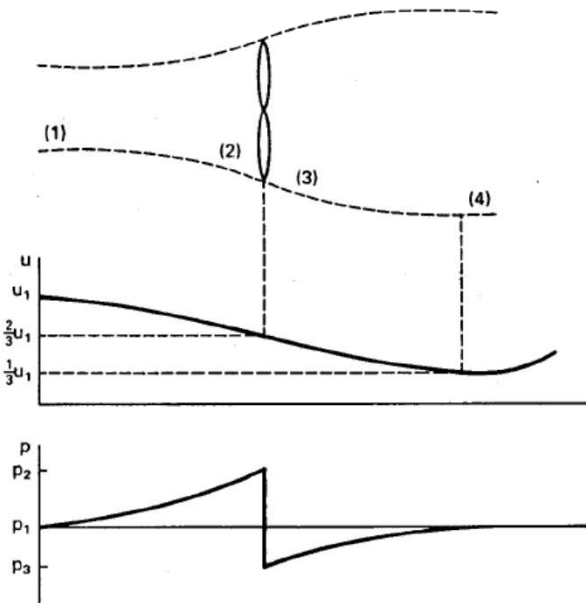
Power (generated)

$$P_e = C_p \eta_m \eta_g P_w$$

Rated power (generated)



# THEORY (CONT.)



$C_p$  is the performance coefficient = 0.59 max. A German physicist Albert Betz concluded in 1919 that no wind turbine can convert more than  $16/27$  (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor. To this day, this is known as the **Betz Limit** or **Betz' Law**. The **theoretical maximum power efficiency** of any design of wind turbine is 0.59 (i.e. no more than 59% of the energy carried by the wind can be extracted by a wind turbine).

$$u_2 = u_3 = \frac{2}{3}u_1$$

$$u_4 = \frac{1}{3}u_1$$

$$A_2 = A_3 = \frac{3}{2}A_1$$

$$A_4 = 3A_1$$

$$P_{m,ideal} = P_1 - P_4 = \frac{1}{2}\rho(A_1u_1^3 - A_4u_4^3) = \frac{1}{2}\rho\left(\frac{8}{9}A_1u_1^3\right)$$

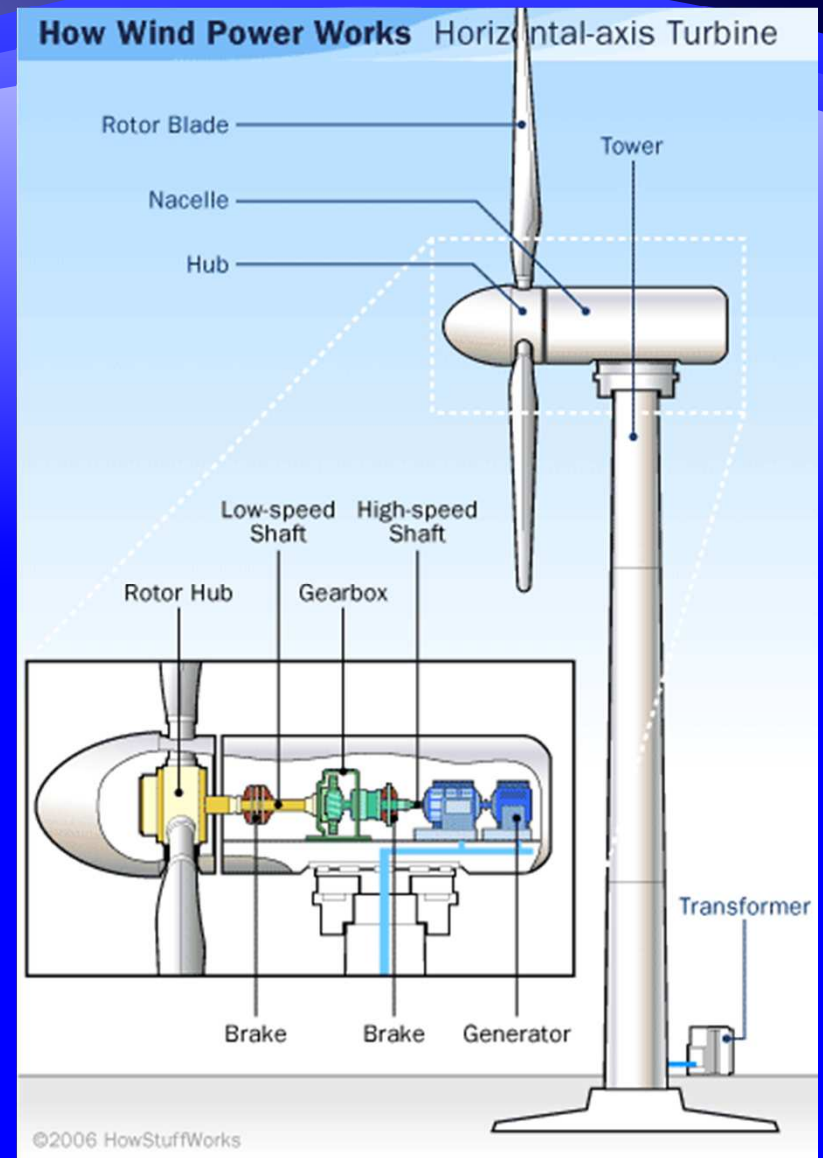
$$P_{m,ideal} = \frac{1}{2}\rho\left[\frac{8}{9}\left(\frac{2}{3}A_2\right)u_1^3\right] = \frac{1}{2}\rho\left(\frac{16}{27}A_2u_1^3\right)$$



# 30 KW WIND TURBINE DESIGN

Wind turbine types:

- 1- Horizontal axis:
- Horizontal-axis wind turbines (HAWT) have the main rotor shaft and electrical generator at the top of a tower, and must be pointed into the wind. Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor coupled with a servo motor. Most have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive an electrical generator.



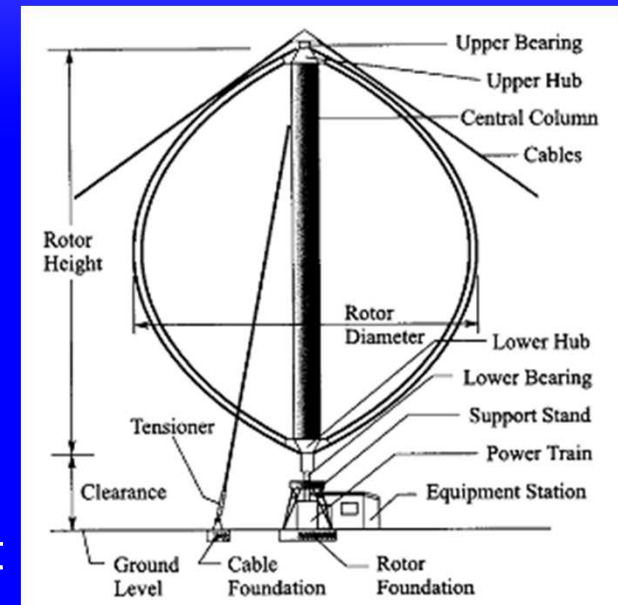


# 30 KW WIND TURBINE DESIGN

Wind turbine types:

2- Vertical axis:

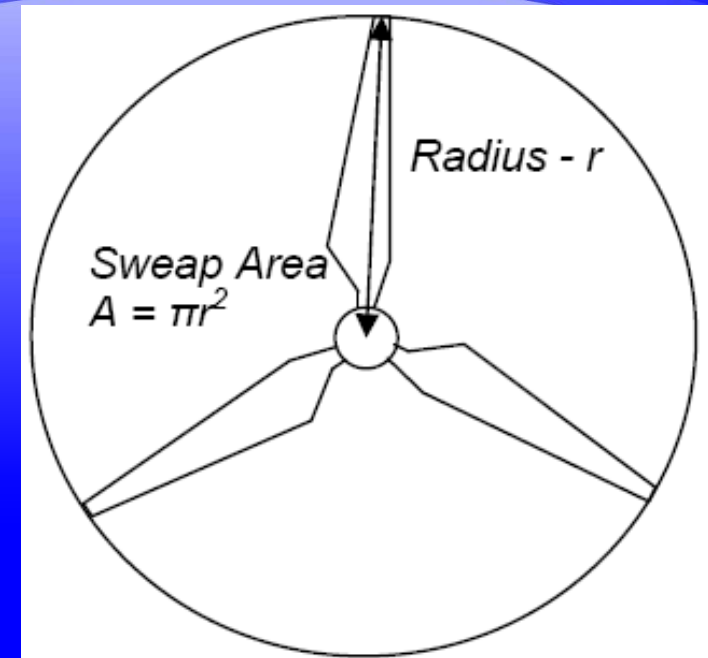
Vertical-axis wind turbines (or VAWTs) have the main rotor shaft arranged vertically. Key advantages of this arrangement are that the turbine does not need to be pointed into the wind to be effective. This is an advantage on sites where the wind direction is highly variable. With a vertical axis, the generator and gearbox can be placed near the ground, so the tower doesn't need to support it, and it is more accessible for maintenance. Drawbacks are that some designs produce pulsating torque.





## 30 KW WIND TURBINE DESIGN (CONT.):

$$P_m = C_p \left( \frac{1}{2} \rho A u^3 \right) = C_p P_w$$



- Assuming that  $C_p = 0.45$ ;
- $P_m = (0.45)(0.95)(0.90)(1.23\text{kg/m}^3/2)(380\text{m}^2)(7\text{ m/s})^3$
- $= 36.1\text{ Kw}$
- Generator efficiency: 90% (for good selected design).
- Gearbox efficiency: 95%
- **The  $P_e = 30.85\text{ Kw}$**



# 30 KW WIND TURBINE DESIGN (CONT.):

Gear box type:

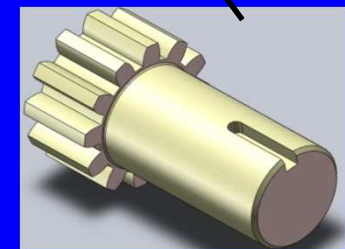
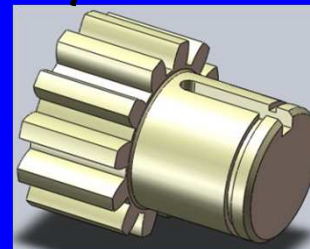
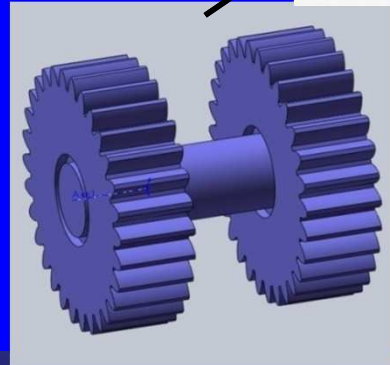
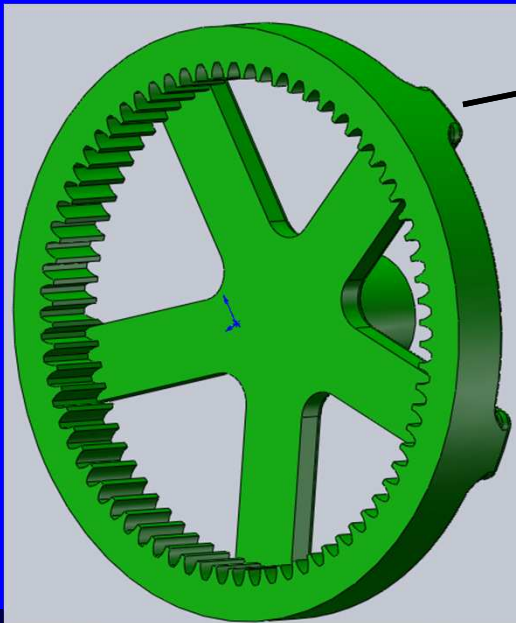
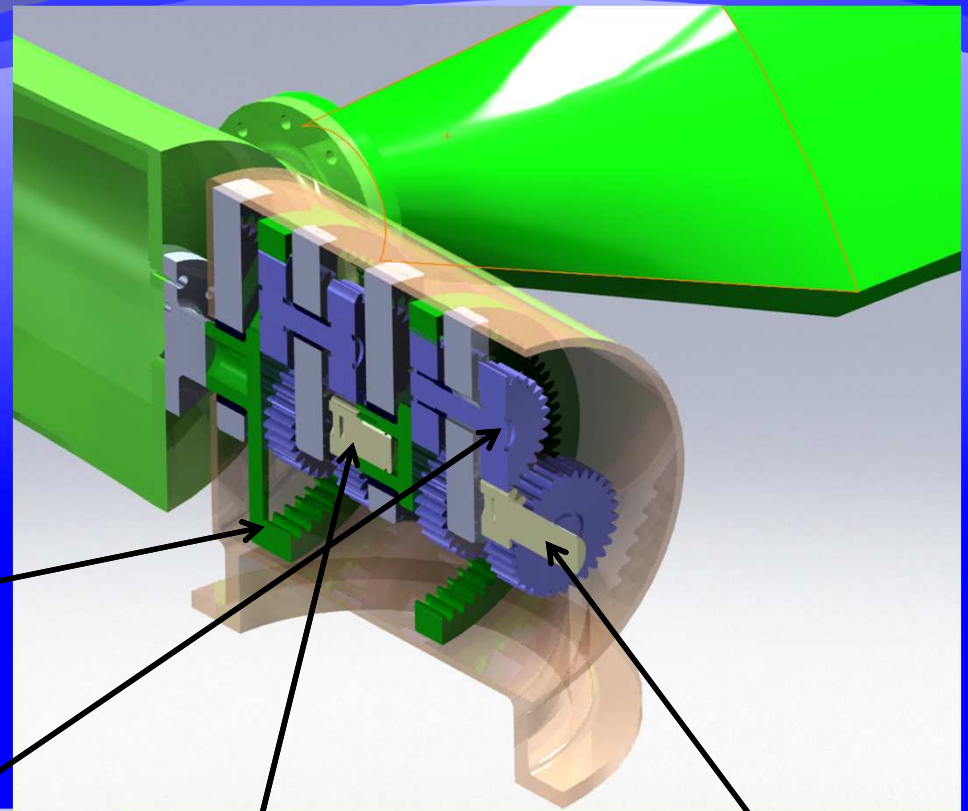
Planetary gear train

Two steps gearbox

Speed up ratio: 1: 36

Input speed: 38.18 rpm

Output speed: 1371.6 rpm





# 30 KW WIND TURBINE DESIGN (CONT.):

## 1<sup>st</sup> stage gears speed:

$$\omega_{\text{ring}} / \omega_{\text{planetary}} = n_{\text{planetary}} / n_{\text{ring}}$$

(n: number of teeth)

$\omega_{\text{ring}}$  is the same speed as propeller  
= 38.1 rpm.

$$38.1 / \omega_{\text{planetary}} = 30 / 72$$

$$\text{So, } \omega_{\text{planetary}} = 91.44 \text{ rpm.}$$

$$\omega_{\text{planetary}} / \omega_{\text{Sun}} = n_{\text{Sun}} / n_{\text{planetary}}$$

$$91.44 / \omega_{\text{Sun}} = 12 / 30$$

$$\text{So, } \omega_{\text{Sun}} = 228.6 \text{ rpm}$$

## 2<sup>nd</sup> stage gears speed:

$\omega_{\text{ring}}$  is the sun gear speed from previous stage = 228.6 rpm.

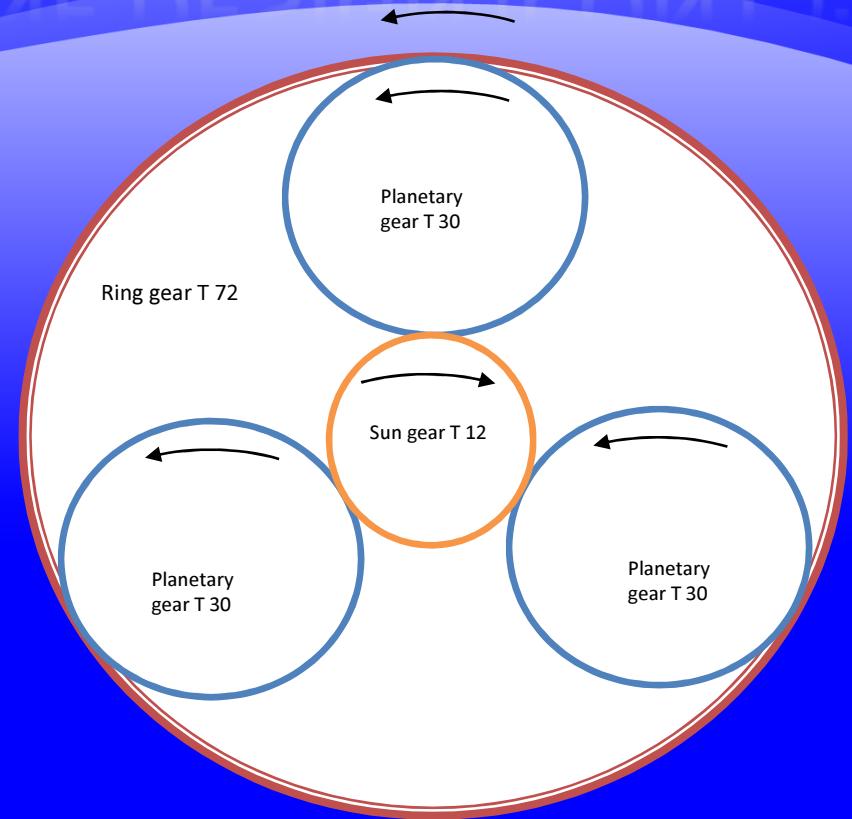
$$228.6 / \omega_{\text{planetary}} = 30 / 72$$

$$\text{So, } \omega_{\text{planetary}} = 548.64 \text{ rpm.}$$

$$\omega_{\text{planetary}} / \omega_{\text{Sun}} = n_{\text{Sun}} / n_{\text{planetary}}$$

$$548.64 / \omega_{\text{Sun}} = 12 / 30$$

So,  $\omega_{\text{Sun}} = 1371.6 \text{ rpm}$  (this sun gear is coupled with the generator).



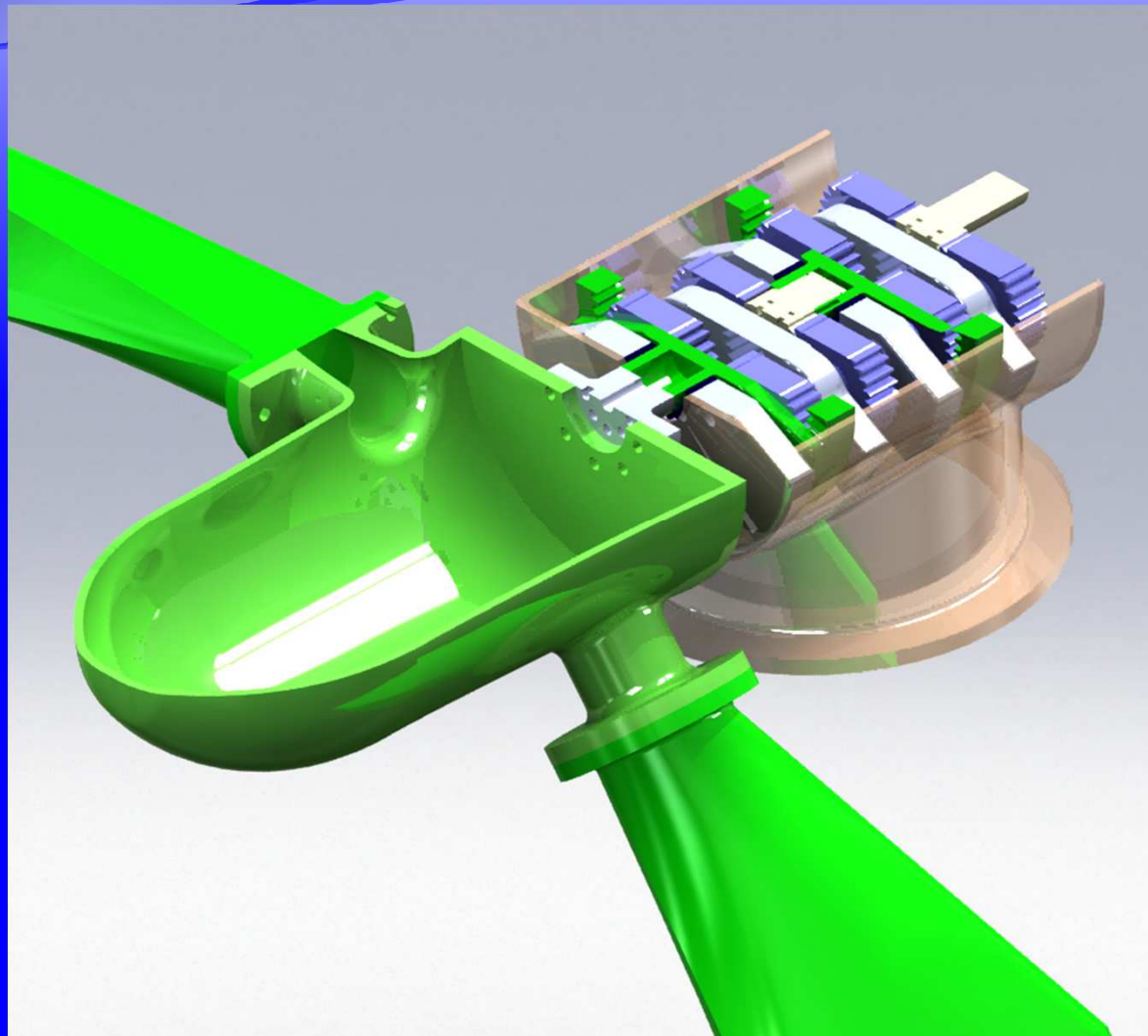
Planetary gear train schematic 1<sup>st</sup> stage  
(Direction of rotation looking from Hub side)



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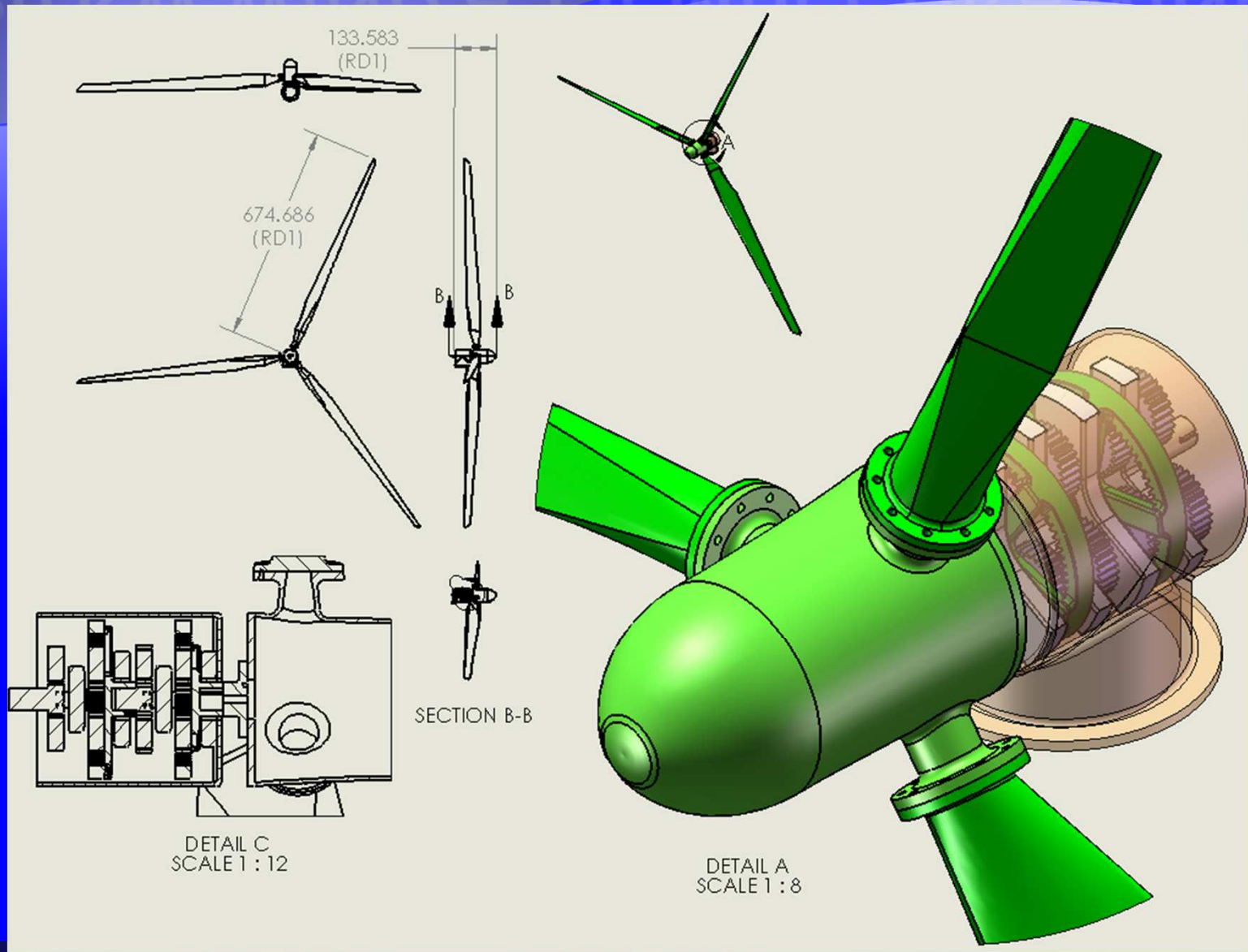
# 30 KW WIND TURBINE DESIGN (CONT.):

Gearbox-hub assembly [(horizontal cutaway)]



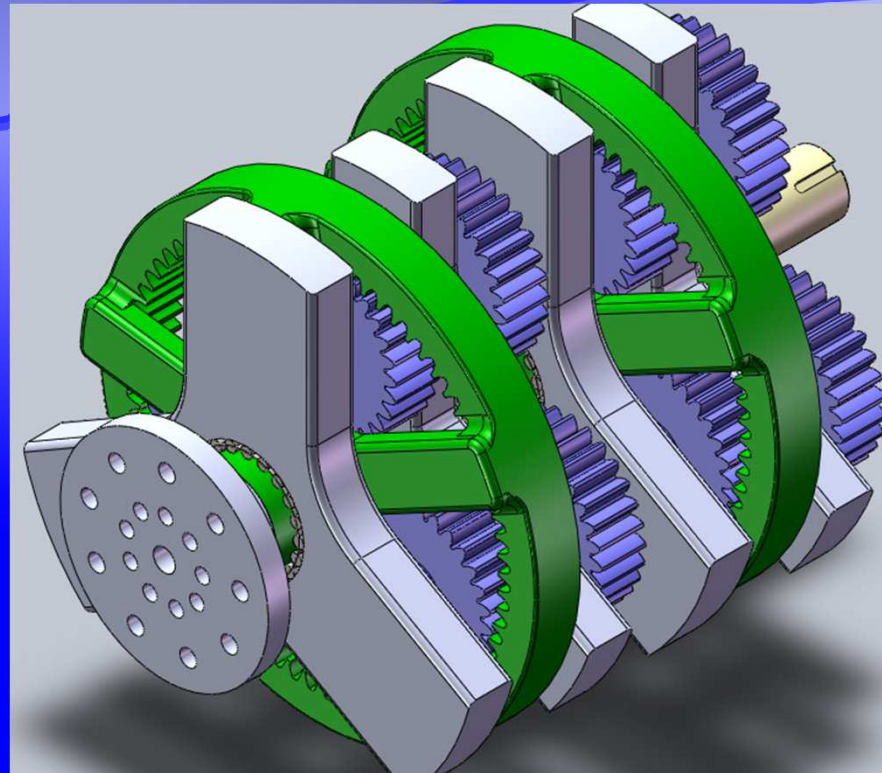


# 30 KW WIND ASSEMBLY DRAWING:





# 30 KW WIND TURBINE DESIGN (CONT.):



- Gear box torque calculation:  $P_m = 36.1$  Kw
- Torque input:  $T = P_m / \omega$ ; so  $T = 9046$  N.m
- Generator required speed: 1370 rpm
- Torque output :  $P_m \eta_m = P_t = 34.3$  KW
- $T_t = P_t / \omega = 34.3 / (137 * 2\pi / 60) = 239$  N. m

A speed up gear box increases angular speed but reduces torque



# 30 KW WIND TURBINE DESIGN (CONT.):

Shear stress calculation on the main shaft:

Torque input:  $T = P_m / \omega$ ; so  $T = 9046 \text{ N.m}$

$\tau_{\max} = Tc/J$  (where  $T$ : torque,  $c$ : shaft diameter, and  $J$ : polar moment of cross sectional area)

$J$  for a hollow shaft =  $\pi/2 (c_o^4 - c_i^4)$ .

$c_o = 0.0425 \text{ m}$

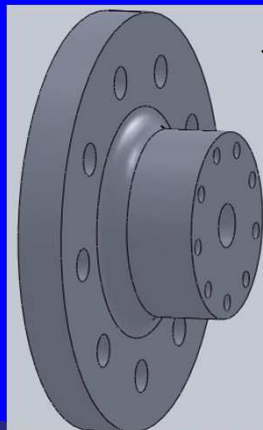
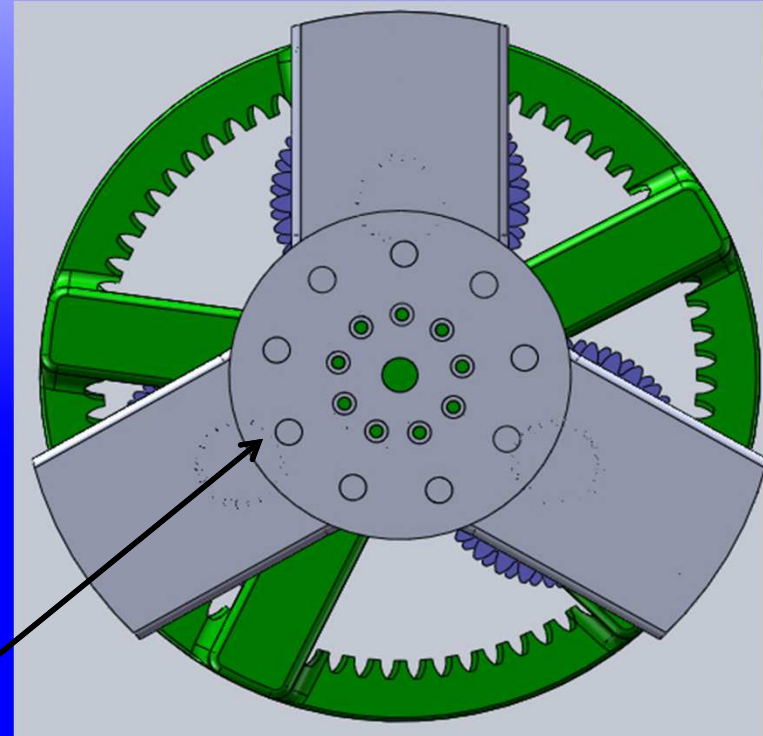
$c_i = 0.01 \text{ m}$

Hence,

$J = 5.10907 \text{ E-6}$

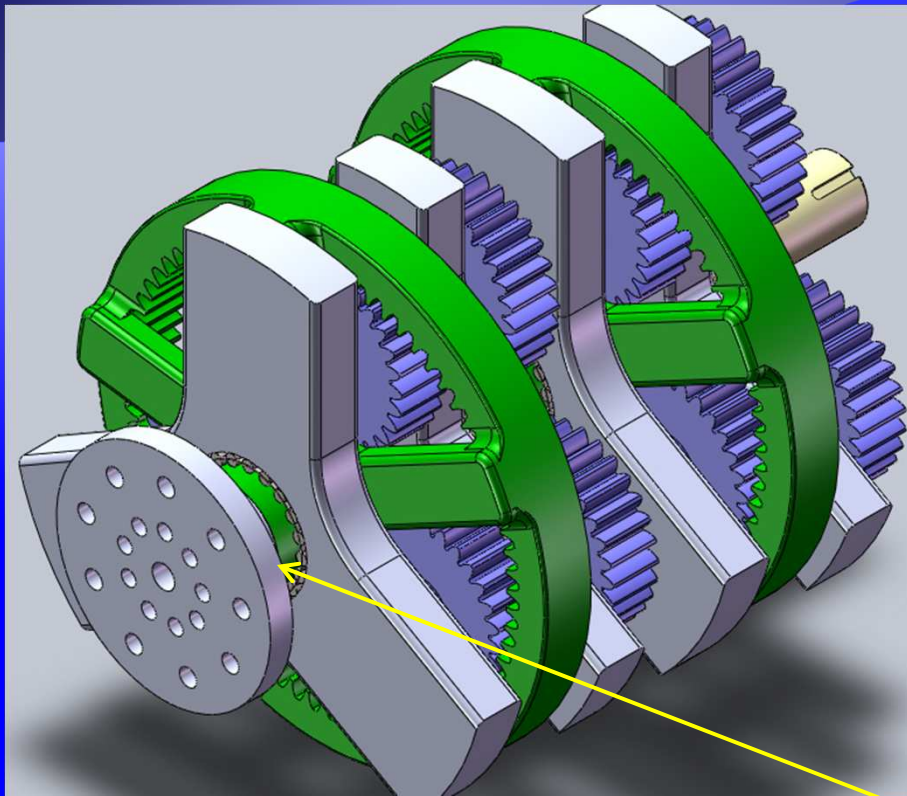
$\tau_{\max} = (9046)(0.0425) / 5.1090764 \text{ E-6}^5$

**$\tau_{\max} = 75.249 \text{ MPa}$**





# 30 KW WIND TURBINE DESIGN (CONT.):



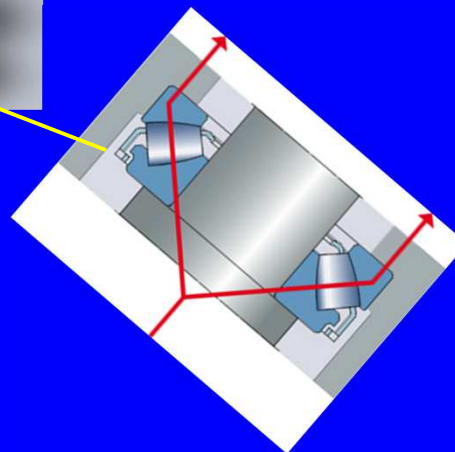
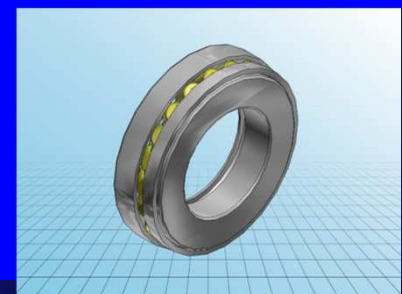
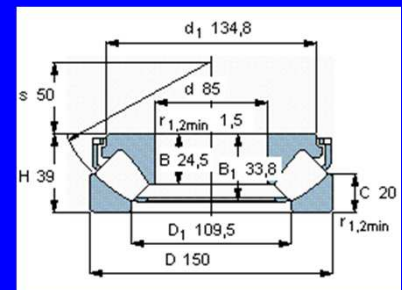
where  $A$  is the area of the plate,  $\rho$  is the density of air,  $u$  is the wind speed, and  $c$  is a constant depending on the size and shape of the plate but not greatly different from unity.

$$F_w = (1)(0.5)(1.23 \text{ kg/m}^3)(380 \text{ m}^2)(7 \text{ m/s})^2$$

$$F_w = 11.451 \text{ KN}$$

Thrust bearing is spherical roller bearing type. It is selected from SKF bearing manufacturer. Selected bearing dynamic loading capacity = 380 KN

Factor of safety F.O.S. = 33



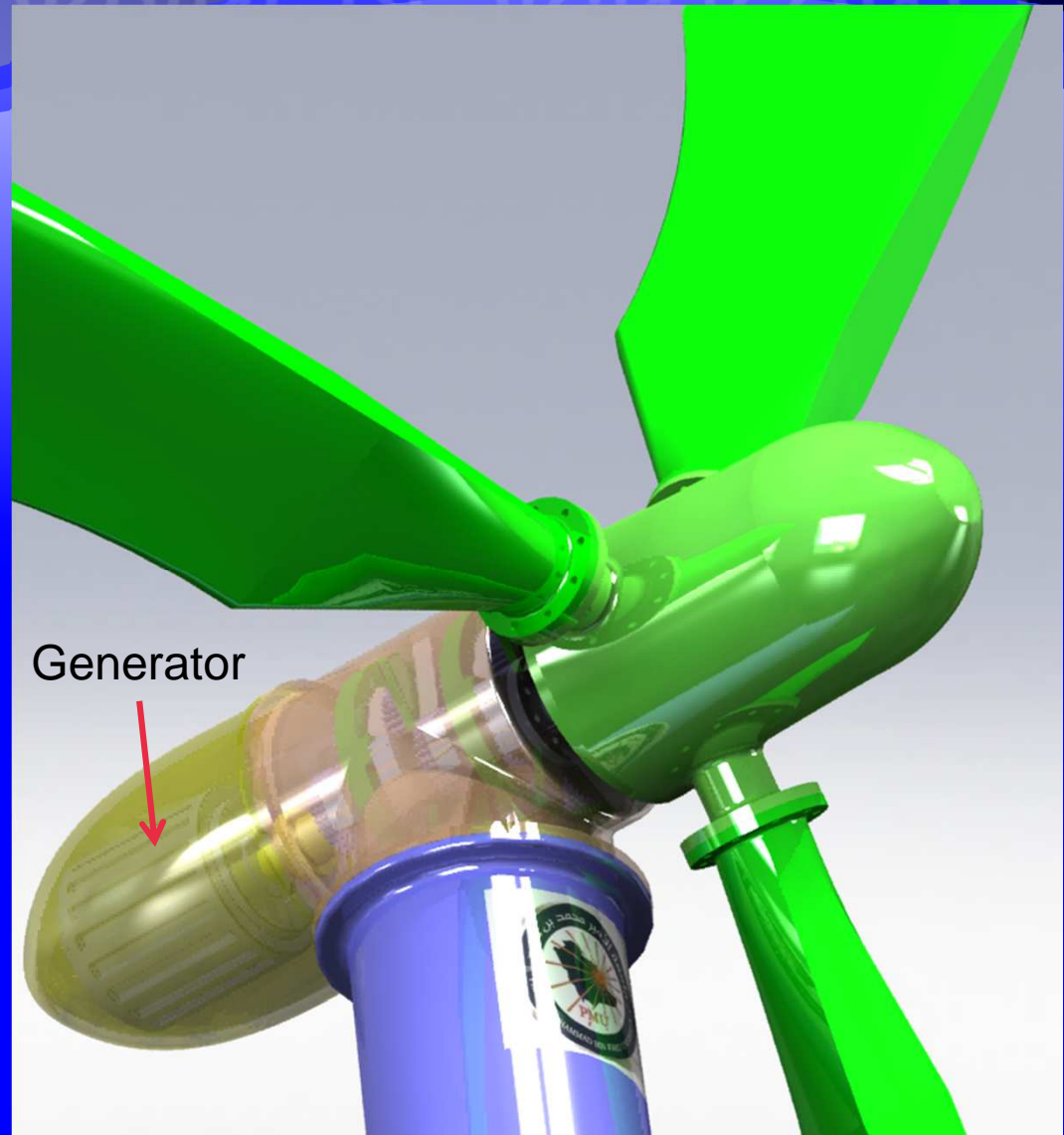
$$F_w = cA\rho\frac{u^2}{2} \quad \text{N}$$



# 30 KW WIND TURBINE DESIGN (CONT.):

## Generator:

Rated Power	30kW
Rated Voltage	400 Volt
Rated Current	46,2 Ampere
Frequency	50 Hz
Speed	1400 rpm
Weight	155 kg





# Thanks