# HAWC2 Course

Lesson 3: Control interface

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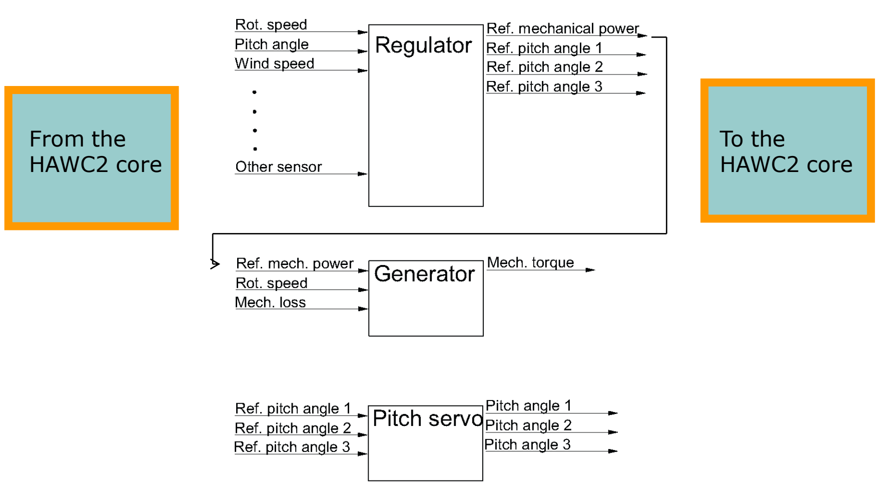
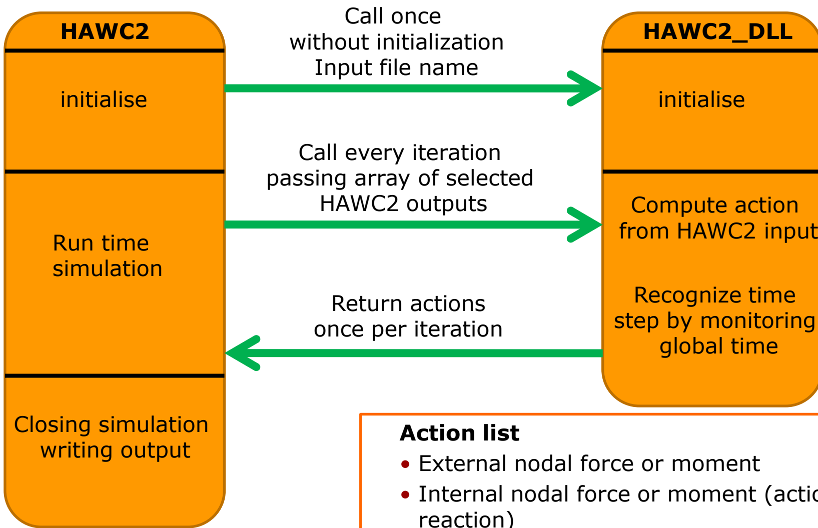
## Control through external DLL's



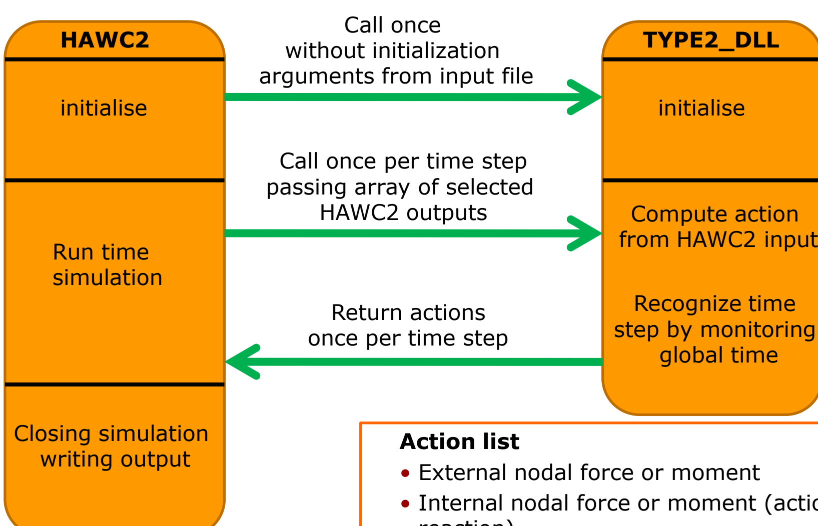
# HAWC2_DLL interface




**Action list**
- External nodal force or moment
- Internal nodal force or moment (action and reaction)
- Bearing angle
- Flap angle



# TYPE2_DLL interface




**Action list**
- External nodal force or moment
- Internal nodal force or moment (action and reaction)
- Bearing angle
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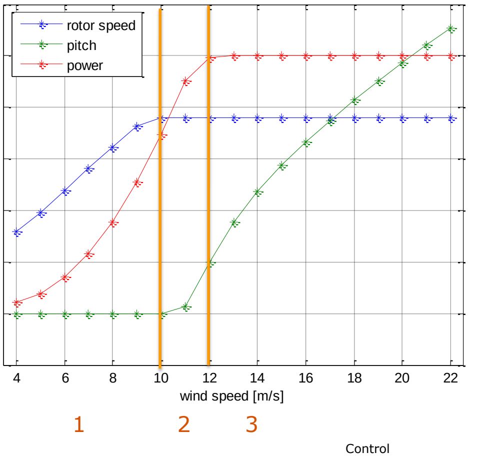
## Pitch control with variable speed

Objectives: Optimize power production below rated wsp, limit power and loads at high wsp.

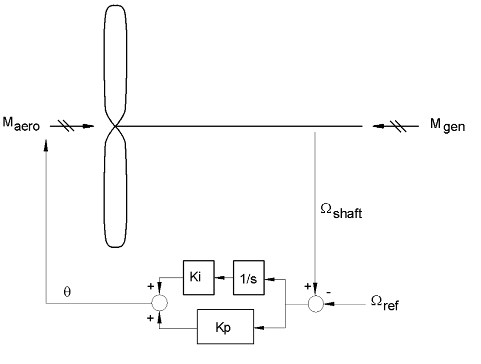
Region

1. Variable speed, opt. power tracking.
2. Constant speed.
3. Power limitation






## Pitch control at high wind speeds




Two different generator stragies:
-Constant power: Good power quality – decent drive train loads
-Constant torque: Good drive train loads – decent power quality

## The derivation of good controller constants

The 1 DOF model

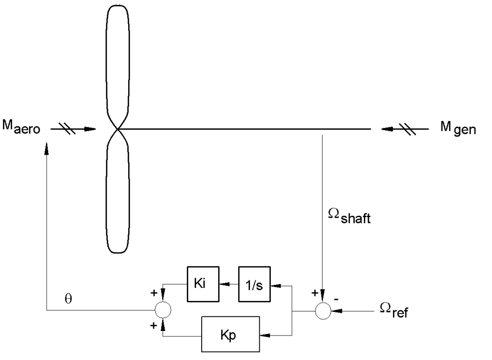
$$I\ddot{\varphi} = M_{aero} - M_{gen}$$

The generator torque

$$M_{gen} = M_0 = \frac{P_0}{\Omega_0}$$

"The aerodynamic model"

$$M_{aero} = \frac{1}{\Omega} P(V,\theta) \approx \frac{P_0}{\Omega_0} + \frac{1}{\Omega_0}\frac{\partial P}{\partial \theta}(\theta - \theta_0)$$




The controller

$$\theta = \theta_I + \theta_p$$

$$\theta_I = \int K_I(\Omega - \Omega_{ref})dt = K_I\varphi, \qquad \Omega_{ref} \equiv \Omega_0$$

$$\theta_p = K_p(\Omega - \Omega_{ref}) = K_p\dot{\varphi}$$



## Tuning of control parameters

Insertion of the aerodynamic terms

$$I\ddot{\varphi} = M_{aero} - M_{gen} = \frac{P_0}{\Omega_0} + \frac{1}{\Omega_0}\frac{\partial P}{\partial \theta}\left(K_I\varphi + K_P\dot{\varphi}\right) - \frac{P_0}{\Omega_0}$$

Rewritten into standard form

$$I\ddot{\varphi} + D\dot{\varphi} + K\varphi = 0$$

$$I = I_{rotor} + n^2 I_{gen} \qquad D = -\frac{1}{\Omega_0}\frac{\partial P}{\partial \theta}K_p \qquad K = -\frac{1}{\Omega_0}\frac{\partial P}{\partial \theta}K_I$$

Natural frequency and damping

$$\omega_0 = \sqrt{\frac{K}{I}} \qquad \zeta = \frac{D}{2I\omega_0} \qquad \omega_d = \omega_n\sqrt{1-\zeta^2}$$

The constants are now given as function of desired control frequency and damping

$$K_I = \frac{\Omega_0 I \omega_0^2}{-\frac{\partial P}{\partial \theta}} \qquad K_p = \frac{2\zeta K_I}{\omega_0}$$

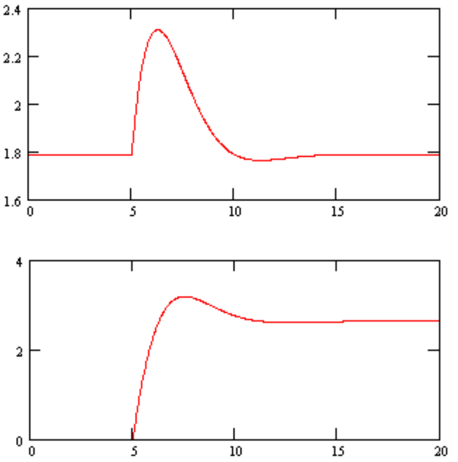
Rule of thumb: $\omega_0 = 0.1Hz \quad \zeta = 0.7$

## Response of system

Step change in external torque

Rotor speed

Pitch angle

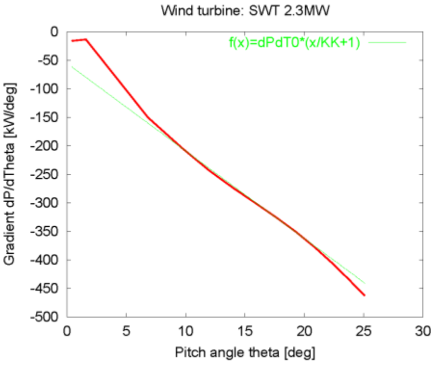



time [s]



## Gain scheduling

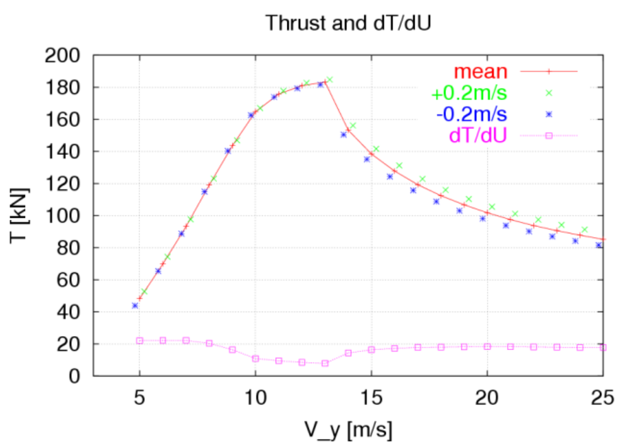
To ensure a similar response at different wind speeds.




$$G(\theta) = \frac{1}{1 + \dfrac{\theta}{KK}}$$

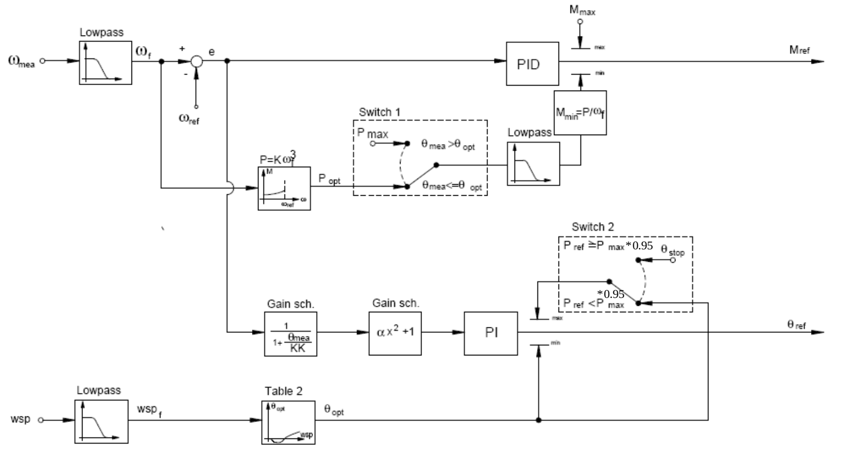
KK is the pitch angle where $dP/d\theta$ is 2* $dP/d\theta_0$

# Why is the control frequency so important?






# Control diagram "Risø" controller



# Additional parameters from control file

basic_3ba_input_ct10nl - Notepad

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```
1.267                   // omega_ref              [rad/s]
0.42                    // omega_min              [rad/s]
4.38                    // kga_set                [deg]
10.0                    // rel_limit              [-]
5000                    // Pmax  (mech)           [kW]
1                       // const power (1) or constant torque (0)
1431                    // Low speed K factor [kNm/(rad/s)^2], torque=K*omega^2, K=0.5*rho*A*Cp*R^3/lambda^3*0.8
0.4 0.7                 // f0,ksi                 [Hz],[-]  2'orderfilter variables
0.01                    // tau_gen                [s]
2                       // ndata optipitch
0.0     0.0             // wsp [m/s] pitch [deg]
50.0    0.0
5.0                     // tau_wsp [s]
0.1                     // f0 [Hz]
88                      // pitch stop angle [deg]
```

Ln 15, Col 35

Optimal power tracking at low wind speeds:

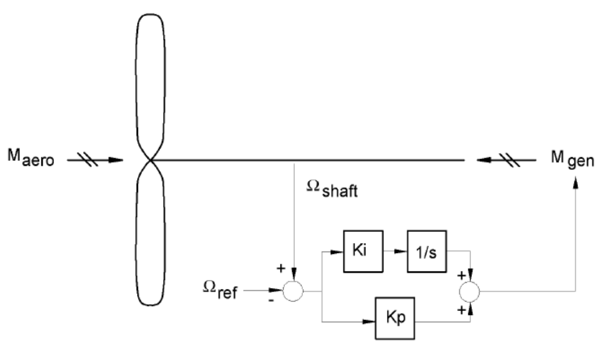
$$P = \tfrac{1}{2}\rho A C_p U^3 = \underbrace{\frac{\tfrac{1}{2}\rho A C_p R^3}{\lambda^3}}_{\text{Constant K}} \omega^3 \qquad \lambda = \frac{\omega r}{U}$$

$$T = \frac{P}{\omega} = \frac{\tfrac{1}{2}\rho A C_p R^3}{\lambda^3}\omega^2$$

In practise K is reduced with app 20% due to mech. losses and to ensure safe operation away from stall.



# Operation at intermediate wind speeds

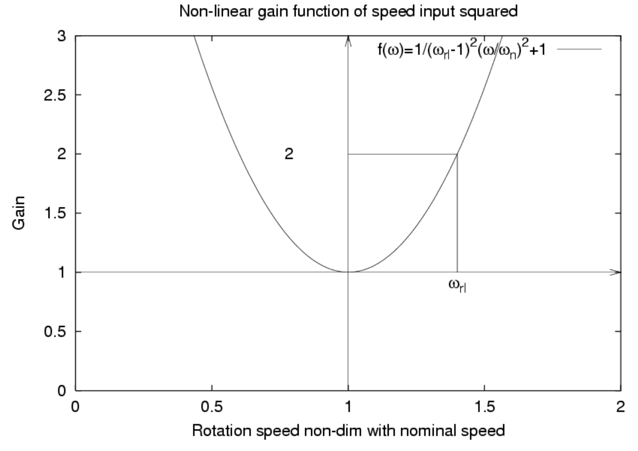



$$M_{aero} = M_{a0}$$

$$M_{gen} = K_{pg}(\Omega - \Omega_{ref}) + \int K_{Ig}(\Omega - \Omega_{ref})dt = K_{Pg}\dot{\varphi} + K_{Ig}\varphi$$

$$K_{Ig} = I\omega_0^2, \qquad K_{pg} = \frac{2\zeta K_{Ig}}{\omega_0}$$

## Non-linear gain

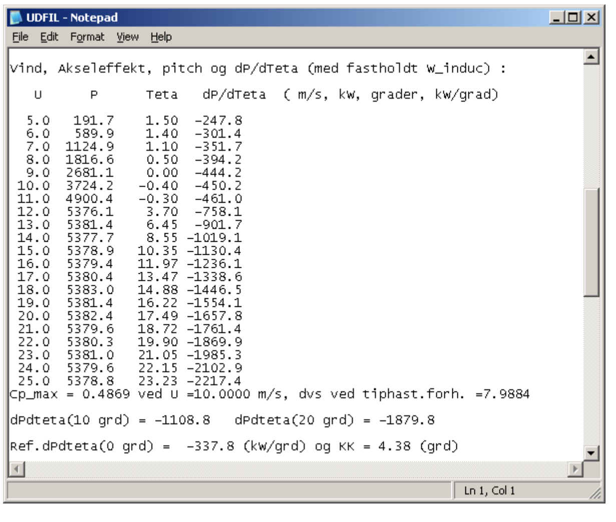



Gain function used with special low frequent towers (floating turbines etc.)

Parameter is non-dim rotor speed where gain equals 2.0



## Calculated results from small WT4 BEM code



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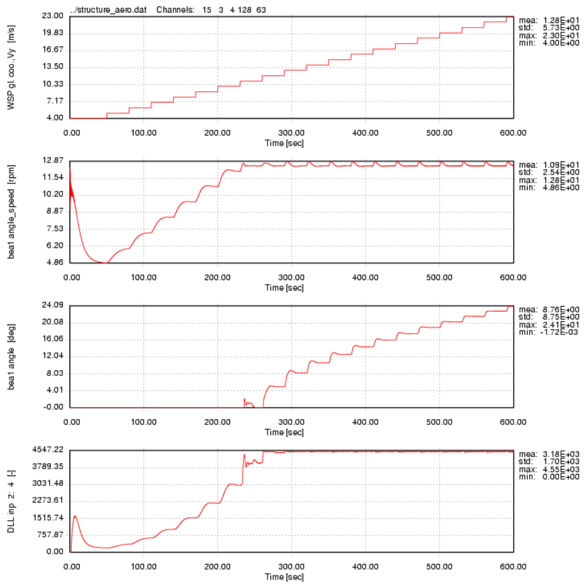
```
Vind, Akseleffekt, pitch og dP/dTeta (med fastholdt W_induc) :

   U       P       Teta    dP/dTeta  ( m/s, kW, grader, kW/grad)

  5.0   191.7    1.50   -247.8
  6.0   589.9    1.40   -301.4
  7.0  1124.9    1.10   -351.7
  8.0  1816.6    0.50   -394.2
  9.0  2681.1    0.00   -444.2
 10.0  3724.2   -0.40   -450.2
 11.0  4900.4   -0.30   -461.0
 12.0  5376.1    3.70   -758.1
 13.0  5381.4    6.45   -901.7
 14.0  5377.7    8.55  -1019.1
 15.0  5378.9   10.35  -1130.4
 16.0  5379.4   11.97  -1236.1
 17.0  5380.4   13.47  -1338.6
 18.0  5383.0   14.88  -1446.5
 19.0  5381.4   16.22  -1554.1
 20.0  5382.4   17.49  -1657.8
 21.0  5379.6   18.72  -1761.4
 22.0  5380.3   19.90  -1869.9
 23.0  5381.0   21.05  -1985.3
 24.0  5379.6   22.15  -2102.9
 25.0  5378.8   23.23  -2217.4
Cp_max = 0.4869 ved U =10.0000 m/s, dvs ved tiphast.forh. =7.9884

dPdteta(10 grd) = -1108.8   dPdteta(20 grd) = -1879.8

Ref.dPdteta(0 grd) =  -337.8 (kW/grd) og KK = 4.38 (grd)
```

Ln 1, Col 1

These results can also be obtained using the small matlab script RunWT4_v3.m

# Response to step change in wind






# Coupling of control to HAWC2

```
begin dll;
  begin hawc_dll;
    filename  ./control/basic_3ba_ct10nl.dll ;
    dll_subroutine regulation ;
    arraysizes  25 15 ;
;    deltat  0.02;
    begin output;
      general constant 1 ;    inputfile extension                  1
      general time ;                                               2
      constraint bearing1 hub_rot 1 only 2;   speed generator      3
      constraint bearing2 pitch1 1 only 1;                         4
      constraint bearing2 pitch2 1 only 1;                         5
      constraint bearing2 pitch3 1 only 1;                         6
      wind free_wind 1 0.0 0.0 -123.0 ; coordsys (1:glo, 2:ikkerot rotor), 7,8,9
      general constant 2.02 ;   Kp  pitch                           10
      general constant 0.764 ;  Ki   pitch                          11
      general constant 0.00 ;   Kd   pitch                          12
      general constant 2.43E7 ; Kp   torque                         13
      general constant 1.09E7  ;Ki   torque                         14
      general constant 0.0   ;  Kd   torque                         15
      general constant 750 ;    generator stoptime                  16
      general constant 0.2 ;    pitch stopdelay                     17
      general constant 8 ;      pitch stop velmax                   18
      general constant 0 ;      stop type (not used)                19
      general constant -1 ;     cut-in time                         20
      general constant 10 ;     pitch stop delay 2                  21
      general constant 2 ;      pitch stop velmax 2                 22
      general constant 10 ;     pitch velmax runtime                23
    end output;
```

# Coupling of simple generator

```
begin hawc_dll;
    filename  ./control/basic_3ba_ct10nl.dll ;
    dll_subroutine generator ;
    arraysizes  15 15 ;
;    deltat    0.02 ;
    begin output;
      general time ;
      dll inpvec 1 1; input til h2, dll no 1, plads no 1
      general constant 0.93;       Efficiency factor
      constraint bearing1 shaft_rot 1 only 2;   speed generator
      general constant 1.0 ;
    end output;
;
    begin actions;
      mbdy moment_int shaft 1 -3 shaft tower 10 ;   generator torque LSS
    end actions;
  end hawc_dll;
```



# Coupling of simple pitch servo

```
  begin hawc_dll;
    filename  ./control/basic_3ba_ct10nl.dll ;
    dll_subroutine pitchservo ;
    arraysizes  15 15 ;
    begin output;
      general time ;
      dll inpvec 1 2;
      dll inpvec 1 3;
      dll inpvec 1 4;
      constraint bearing2 pitch1 1 only 1;                        3
      constraint bearing2 pitch2 1 only 1;                        4
      constraint bearing2 pitch3 1 only 1;                        5
    end output;
;
    begin actions;
      constraint bearing2 angle pitch1;
      constraint bearing2 angle pitch2;
      constraint bearing2 angle pitch3;
    end actions;
  end hawc_dll;
end dll;
```

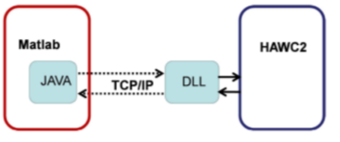
# Other dll possibilities

type2_dll

```
begin type2_dll;
  name  hss_convert ;
  filename  ./hss_convert.dll ;
  dll_subroutine_init 'initialize' ;
  dll_subroutine_update 'sensors' ;
  arraysizes_init  3 1 ;
  arraysizes_update  2 2 ;
  begin init ;
    constant 1 2.0 ; number of used sensors
    constant 2 112.43 ; gearbox ratio
    constant 3 112.43 ; gearbox ratio
  end init ;
;
  begin output ;
    constraint bearing1 shaft_rot 2 only 2 ; rotor
 speed in rpm
    constraint bearing1 shaft_rot 3 only 2 ; rotor
 speed in rad/s
  end output ;
;
  begin actions;
;    rotor_speed in rpm*gear_ratio
;    rotor_speed in rad/s*gear_ratio
  end actions;
end type2_dll;
```

tcp/ip communication with e.g. Matlab or Matlab/Simulink

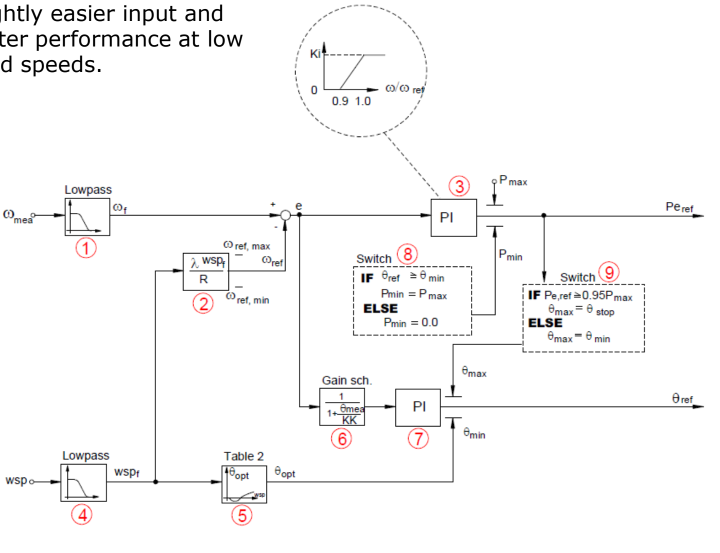
```
begin hawc_dll;
  filename  ./tcpip/TCPserver.dll ;
  dll_subroutine tcplink_delay ;
  init_string 1139 ;
  arraysizes  60 60 ;
begin output;
  continue_in_file ./htc/tcplink_sensors.htc ;
end output;
;
begin actions;
end actions;
end hawc_dll ;
```






# Recent updates - basic_3ba_ct12nl.dll

Slightly easier input and better performance at low wind speeds.



# Additional parameters from control file - basic_3ba_ct12nl.dll

basic_3ba_input_ct12nl - Notepad

File Edit Format View Help

```
0.89600                 // omega_ref              [rad/s]
0.45000                 // omega_min              [rad/s]
9.0                     // lambda
89.0954                 // radius             [m]
5.01327                 // kga_set                [deg]
10.0                    // rel_limit              [-]
10000                   // Pmax  (elec)           [kW]
1                       // const power (1) or constant torque (0)
0                       // Not used
0.4 0.7                 // f0,ksi                 [Hz],[-]  2'orderfilter variables
0.01                    // tau_gen                [s]
2                       // ndata for pitch data, wsp [m/sec], pitch angle [deg]
0.0     0.0             // wsp pitch
50.0    0.0
5.0                     // tau_wsp
0.01                    // f0
90                      // pitch stop angle [deg]
```

Ln 1, Col 1

Optimal power tracking at low wind speeds is done by generator torque control based on wind speed estimation and desired tip speed ratio:

$$\lambda = \frac{\omega r}{U}$$

$\lambda$ is normally set to 8-9,

Remember to have the minimum speed so 3P stays above the 1st tower frequency



# Exercise

- Run the file structure_aero_control.htc 600s

- Include the more recent controller basic_3ba_ct12nl.dll and run a similar load case.