Wind Turbine Dynamics Library

WTD Library

for Simulink

(Version 1.1)

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I. INTRODUCTION

Wind Turbine Dynamics (WTD) Library features a group of Simulink blocks for simulation of dynamic response of generic models of Wind Turbine Generators (WTG) on power system disturbances, which includes the General Electric (GE) Doubly Fed Induction Generator (DFIG) model.
The WTD Library features a set of Simulink blocks that models GE DFIG as well as conventional steam and hydro generating units that are connected to a transmission grid. The Library also includes a set of Matlab *m* and S functions which are used for power flow calculation and initialization of state variables of the models of GE DFIG and conventional steam and hydro generating units.
The library consists of the following Simulink blocks and demo examples:

- NETWORK, a block used for: power flow calculations, input of parameters of conventional generators and wind generators, and solution of voltage equations. To start a simulation using the library, it is necessary to input data into this block as well as to perform power flow calculations by using this block,
- GENERATOR, generator model E ' behind Xd',
- ZERO_GEN, a block that must be connected to the load nodes of the NETWORK block,
- HYDRO, this block includes: HYGOV model of governor and hydro turbine according to PSS/E 34 model library [2] and rotor model - also according to PSS/E 34 model library,
- HYGOV, governor model and hydro turbine model according to PSS/E 34 model library,
- THERMO, this model includes TGOV1 turbine model and steam turbine governor model according to PSS/E 34 model library, and rotor model - also according to PSS/E 34 model library,
- TGOV1, governor model and steam turbine model according to PSS/E 34 model library,
- PLL, Phase Locked Loop model for measuring of frequency of network voltage,
- ROTOR, an aggregated one mass model of rotor of turbine and generator,
- Vec_sig_selector, a block used to select a scalar signal from a vector signal input,
- DFIG, Doubly Feed Induction Generator model according to Ref. [1],
- WIND_TURBINE, wind power model based on Matlab built in Wind turbine model. This block is slightly changed in comparison to the same block in WTD Library Ver. 1.1,
- WTD_twelve_bus: Demo Simulink example for simulation of twelve bus system found in the Ref. [3],
- WTD_three_phase_fault: Demo Simulink example for simulation of three phase bus fault,
- WTD_wind_profile: Demo Simulink example for simulation of WTG response on a wind profile.

To clarify how to create network description csv files, read the help of NETWORK block and compare the contents of the csv file WTD_Y12 with the twelve bus system from the Ref. [3]. Initialization of state variables of the DFIG block is explained in Ref. [4].

IMPORTANT NOTICE: The only difference between the WTD Library Ver 1.0 and Ver 1.1 is in the WIND_TURBINE block (which is in the WTD_slx_library_ver1 folder). In order to this block works properly, please install the new version of WTD Library Ver 1_1.

REFERENCES
1. K. Clark, N. W. Miller, J. J. Sanchez-Gasca, *Modelling of GE wind turbine-generators for grid studies.*(Tech. Rep. version 4.5, General Electric International, One River Road, Schenectady, NY, USA, 2010.
2. PSS/E 34 Model Library, Siemens Industry, Siemens Power Technologies International, 2015.
3. J. Osmic, M. Kusljugic, A. Mujcinagic, *Fuzzy controller for inertial support of variable speed wind generator*, IET Digital Library.
4. E. Becirovic, J. Osmic, D. Toal, M. Kusljugic and N. Peric, Analysis and initialization of GE wind turbine control model, Applied Mechanics and Materials, vol. 789-790(2015), pp. 1085-1089, 2015.

II. How to include the WTD Library in Simulink Library Browser and Matlab path?

1. Close Matlab (if open)
2. Copy folders WTD_functions_ver1, WTD_slx_library_ver1 (for Matlab version 2012 or higher), and WTD_examples_ver1 on the desired location eg Local Disk (C:) -> Program Files -> Matlab (or any other desired location)
3. Open Matlab, from the Home (File) drop-down menu, select Seth Path-> Add Folder and add to the path of the mentioned folders.
4. Save the path. If Matlab allows you to save the path to the default location, continue with step 8.
5. If Matlab does not allow to save the path to the default location, save (file pathdef.m) to any desired *xyz* location. In this case, proceed from step 5. Close Matlab.
6. Find the matlab \ toolbox \ local \ pathdef file in the original Matlab path and rename it to eg pathdef_original.
7. The file pathdef that was saved to the xyz location copy to the folder Matlab \ toolbox \ local \
8. Open Matlab (if not already open) and Simulink. Make sure there is a library called wtd_library_ver1 in Simulink Library Browser,
9. Open this library (then the “Matlab creates repository message appears”). After a short time a library with the corresponding blocks appears.
10. **The library is ready for use.**
11. To check the operation of the library, run the example: Simulink demo example wtd_twelve_bus. The example is the simulation of a modified nine bus system that is supplemented by a DFIG wind generator (twelve bus system). After 3 seconds of the start of the simulation, an active power disturbance of 10 MW is introduced in node 8. Network data and initial values of network variables can be found in the Ref. [3].
12. Open each of the blocks and especially NETWORK and read the help.
13. To start the simulation, first open the NETWORK block, then open the Power Flow tab, then select initialization and power flow calculation and after this OK.
14. Check Matlab Workspace with command >> who for the existence of certain variables needed for simulation.
15. Start the simulation.

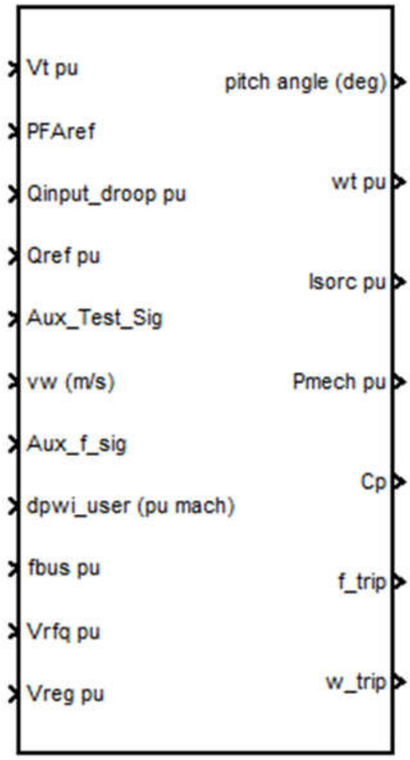
Recommended simulation settings are:
- Solver options: Type: Fixed step, Solver: ode3, Fixed step size: 0.002.

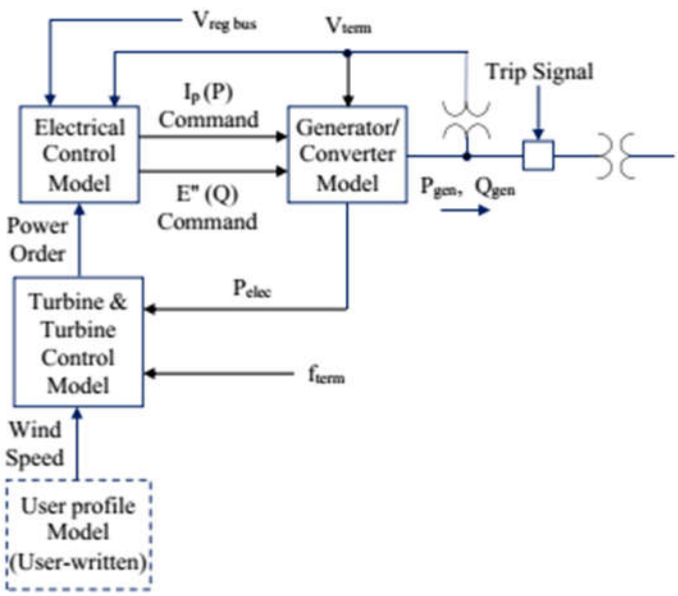
The References, csv files WTD_Y12 and WTD_Y12_2 used in demo wtd_twelve_bus, which describes the network before disturbance occurs and after clearance of the disturbance, is useful help for creating csv files of an arbitrary user network.

III. WTD Library BLOCKS

1. DFIG block

(According to Ref. 1)





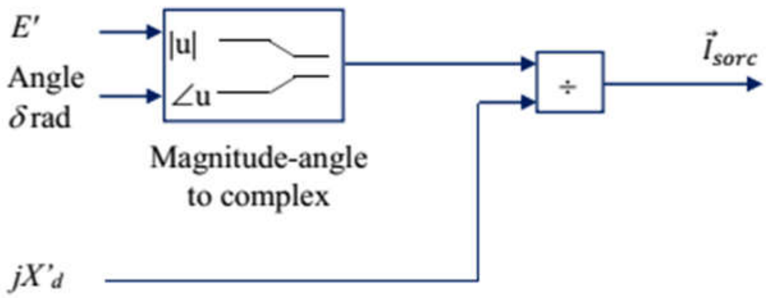
PARAMETERS, REGULATION CHOICES, INERTIAL SUPPORT (see Ref. 1)

INPUTS:
Vt pu : Complex voltage (pu) of DFIG terminal node
PFAref : Reference power factor
Qref : Reference reactive power (pu)
Aux_Test_sig : See Ref. 1 (usually zero)
vw (m/s) : Wind speed (m/s)
Aux_f_sig : See Ref. 1 (usually zero)
pwi_user (pu mach) : User additional power reference for inertial support (pu mach)
fbus pu : DFIG connection node voltage frequency pu of system base frequency
Vrfq pu : Reference of complex voltage which is controlled
Vreg pu : Measured complex voltage which is controlled

OUTPUTS:
pitch angle (deg) : Pitch angle deg
wt pu : Turbine speed pu
Isorc pu : Current of DFIG current source pu
Pmech pu : Turbine mechanical power pu
Cp : Power factor
f_trip : Frequency trip signal (= 1 if network frequency is higher than 1.04 pu for more than 1 sec, otherwise = 0)
w_trip : Turbine speed trip signal (= 1 if turbine speed is less than 0.2 pu)

NOTES:
WTG initial speed, WTG initial pitch angle, initial wind speed, initial active and reactive power are initialized by the Network block.
LVRT and HVRT capabilities are not supported. These capabilities can be programmed externally.
Pseudo Drag Term is not realized.
WindFree operation is not supported.
Open Loop Reactive Power Control is not supported.
Power flow and initial conditions are calculated, using Network block, with assumption that Active Power Control (APC) is disabled (apcflg = 0), regardless of the APC is enabled (apcflg = 1) or disabled. If APC is enabled then in the first moments of a simulation there is transition process to the steady state.
In order to use Wind Inertia (WI), parameter Kwi must be set to value > 0 and parameter Inertial support must be set to 1. There are two possibilities for Inertial support: General Electric algorithm generated inertial support signal or User inertial support algorithm generated inertial support signal. In order to use User inertial support generated signal, this signal must be connected to the input dpwi_user (pu mach) of DFIG block. In the case of using GE inertial support, default values of the parameters are: Kptrq = 3, Kitrq = 0.6 and Tpc =0.05 should be changed to the values:
Kptrq = 0.5;
Kitrq = 0.05;
Tpc = 4;

2. Generator block



Generator block includes E' behind Xd' generator model.

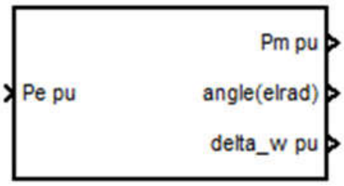
PARAMETERS:
Conection node number: Number of the node of network where generator is connected
E pu: Transient voltage of generator pu (disabled)
jXd pu: Generator transient reactance pu (disabled)

INPUTS:
angle(elrad): Rotor/generator angle in electrical radians

OUTPUTS:
Isorc pu: Current of an equivalent current generator

NOTES:
Generator block is initialized by the Network block.

3. Hydro block

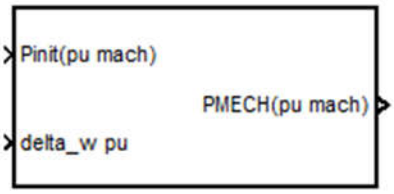


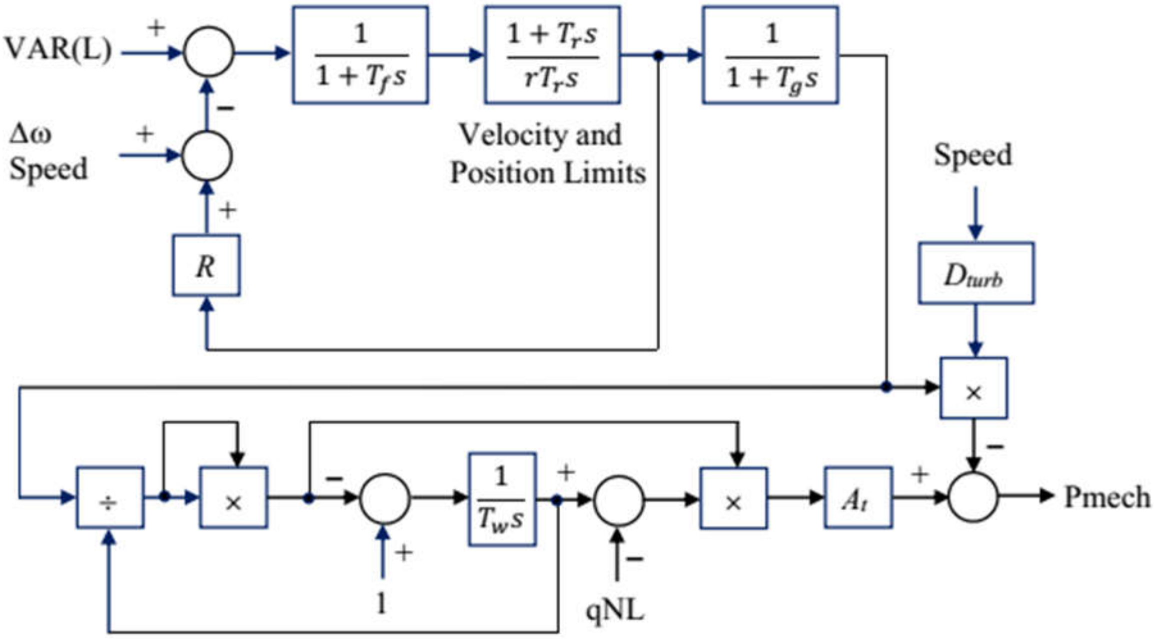
Hydro turbine/governor/rotor model

Model includes HYGOV PSS model, and rotor/load damping (D) model.

For explanation of the parameters of the block see PSS/E documentation (Ref. 2).

4. Hygov block

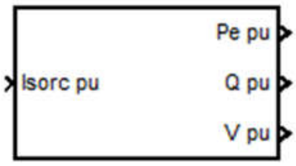




Parameter	Value	Description
R	0.05	Permanent droop
r	0.4	Temporary droop
T_r	8	Governor time constant
T_f	0.3125	Filter time constant
T_g	0.2	Servo time constant
VELM	0.5	Gate velocity limit
G_{max}	2	Maximum gate limit
G_{min}	0	Minimum gate limit
T_w	1.2	Water time constant
D_{turb}	0	Turbine damping
A_t	2.5	Turbine gain
qNL	0.068	No power flow constant

Model includes HYGOV PSS turbine-governor model
For explanation of the parameters see PSS/E documentation (Ref. 2)

5. Network block



Network block enables input of data required to perform power flow calculation.
Apart from this, data on disturbances, short circuit and reconfiguration of the network (disconnection of a transmission line) can be entered.
This block solves the network voltage equations during a simulation.
In addition, this block calculates initial data for turbines, conventional generators and wind generators.
For any simulation of the dynamic response of WTG, the Network block must be included.
Before simulation is started, it is necessary to perform power flow calculation using the Network block.

NOTES:
The generator nodes must be in the order of 1 and further.
The slack node must be the node number 1.
At minimum one generator must be connected to the network.
Precisely one generator is a slack generator (with an internal voltage angle equal to 0 rad).
All input and output signals are pu of the system base quantities.

PARAMETERS:
The network model accepts parameters either as variable names or as variable values that can be scalars or vectors.

INPUTS:
Isorc pu: Multiplexed input of complex currents of the equivalent current generators.
The inputs must be multiplexed so that input of the first generator is connected to the first node and so on. In each node of Network block, current source can be connected. If no current source is connected to appropriate node, ZERO_GEN block must be connected. The overall number of Generator blocks and ZERO_GEN blocks must be equal to the number of network nodes.

OUTPUTS:
Pe pu: Output vector of active power injected into the nodes of the network.
To select power injected to any node, this output must be connected to the input of Vec. Sig. Selector block located in the WTD Library.
As a parameter of this block, select the order number of the node in which the specified power is to be injected.
Qe pu: Similar to the previous one. Qe represents the vector of the reactive power injected into the nodes of the network.
V pu: Similar to the previous one. V represents complex vector of node voltages.

Network tab
Name of network description file: A name of the csv file (without quotation and without extension) by which the network is described. This block accepts a name of network description file so that the first character must be a letter (excluding special characters and space character).
The file is created by a text editor by putting csv file extension, or by using MS EXCEL. The sheet name is the same as the name of the file.
The file contents is as follows:

line order number, sending node order number, receiving node order number, line impedance (pu) (eg. 0.1+j*0.1 or 0.1+i*0.1), line susceptance j*B/2 (pu), shunt admittance (pu) both in the sending and receiving nodes
...
line order number, sending node order number, receiving node order number, line impedance (pu) (eg. 0.1+j*0.1 or 0.1+i*0.1), line susceptance j*B/2 (pu), shunt admittance (pu) both in the sending and receiving nodes

Line susceptance and shunt admittance in a j-th row of the network description file adds up to i-th diagonal element of network admittance matrix every time when there is number i (i-th node order number) in the second or the third column of the j-th row of the network description file.
The file must be saved in the Working directory. Based on this file, the Network block calculates the matrix of the network admittances.

Number of conventional generators: Enter the number of conventional generators (minimum 1).

Number of wind generators: Enter the number of wind generators, 0 if there is no wind generators.

Generators Conv. tab
Conventional generators nodes row vector: Enter nodes of conventional generators in square brackets with space or comma
(eg. [2 1 3] or [2,1,3]). If there is one generator then the number of node can be entered without brackets.
Conventional generators transient reactance row vector Xd pu sys:
Enter the row vector of transient reactance of conventional generators in the same order as the order of generator connection nodes.

Wind Gener. tab
Wind generators nodes row vector: See GENERATORS CONV.
Wind generators nominal power row vector (MVA): Enter the row vector of the nominal power of the wind generators.
Wind generators shunt reactance row vector Xd pu sys: See GENERATORS CONV.
Wind generators Ka constant row vector: Enter vector of Ka constants of wind generators (see Ref. 1). Ka=1/2*rho*A.
Wind generators Kb a constant row vector: Enter vector of Kb constants of wind generators (see Ref. 1). lambda = Kb*omega(pu)/wind speed (m/s).

Load tab
Load nodes row vector: Enter row vector of nodes in which loads are connected. The vector is entered as in the previous cases.
If there are no nodes with loads then place the empty brackets [].
Complex power load vector (MVA): Enter row vector of complex load power in MVA (eg 50 + j * 35) in the same order as input load nodes. If there are no load nodes enter empty brackets [].
A load cannot be added to the generator node.

Fault tab

Type of the fault: Power, Short circuit or Line disconnection. This menu allows to select the three types of disturbances / faults.
In the case of selecting Power fault/distrubance, a complex disturbance power may be entered in the MVA (eg 10 + j * 5).
In a case of selecting Short circuit it is possible to enter fault impedance (pu sys). Take care that the fault impedance is higher than zero!
Fault time: Enter the time when a disturbance occurs. Enter inf if there is no fault (fault is in infinity).
Faulted node number: Enter number of a node in which the fault appears (the node number input is obligatory).
Fault node additional power: Enter the complex power of disturbance in the MVA. On the basis of this power, impedance of the fault is calculated using the node voltage before the fault. This entry is mandatory.
Disconnect line identification number: Enter the line number of the line that is disconnected (only one line can be disconnected at the time).
Clear time: Enter the time when the fault is cleared. In the case that the fault will last forever, enter inf (mandatory input).
Csv file: See the NETWORK: Name of the network description file

Power Flow tab

Conventional generator nodes initial voltages row vector pu sys: The modules of voltages of the PV nodes are accepted in the same format and in the same order as the connecting nodes of conventional generators (see Generators conv.)
Conventional generator nodes initial active power row vector (MW): Initial active power of conventional generators in MW in the same order and in the same format as the connecting nodes of conventional generators.
Wind generator initial conditions: Two choices are possible: Active power or Wind speed.
In the case of the first choice, it is possible to input the initial active wind turbine power in MW.
In case of a second choice, it is possible to input the initial wind speed.
Wind generators nodes initial voltages row vector pu: The modules of voltages of the PV nodes where wind generators are connected pu sys.

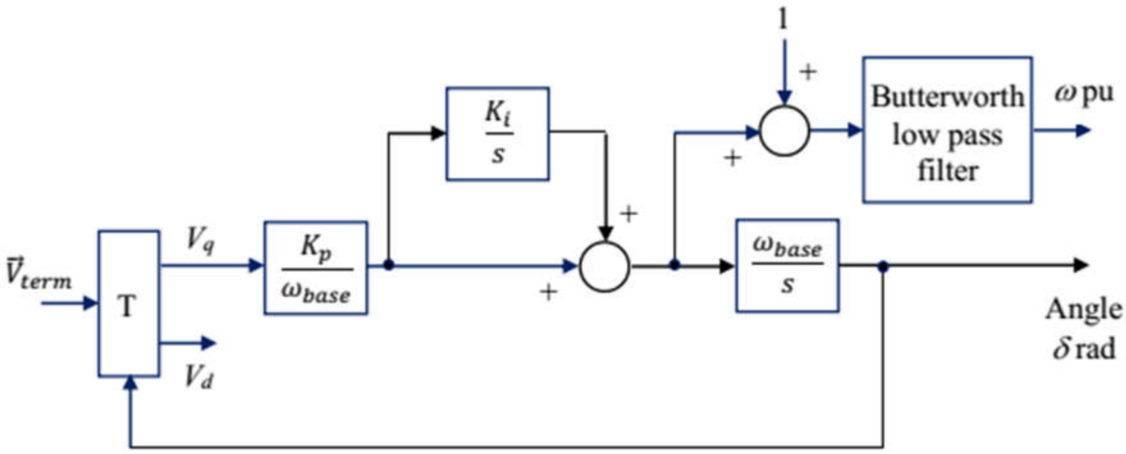
Initialization and Power Flow Calculation: By selecting this field, the power flow calculations and initialization of the wind turbine/generator speed, pitch angle and initial wind speed (or initial active power) are performed.
All required variables are recorded in the Workspace (the meaning of the variable is clear from their names):
baseSystemPower: System base power in MVA
clearaugYMatrix: Network admittance matrix with included generator and load admittances after clearance of the fault
clearfaultYMatrix: Network admittance matrix after clearance of the fault
complexPower: Vector of complex powers injected into the nodes
faultaugYMatrix: Network admittance matrix with included generator and load admittances after the fault
genTranReactance: Vector of generator transient reactance xd'
internalGenVoltage: Vector of E' of generator internal voltages
invclearaugYMatrix: Inversion of clearaugYMatrix matrix
invfaultaugYMatrix: Inversion of faultaugYMatrix
invsystemaugYMatrix: Inversion of systemaugYMatrix
noGridNodes: Number of grid nodes
nodeVoltage: Vector of phasors of node voltages
pitchAngleVec: Vector of initial pitch angles of wind turbines
systemFrequency: System frequency
systemYMatrix: Network admittance matrix (before the fault)
systemaugYMatrix: Network admittance matrix with included generator and load admittances (before fault)

turbSpeedVec: Vector of initial speed of wind turbine/generators
windSpeedVec: Vector of initial wind speed of wind turbine/generators
windturbKaParam: Vector of Wind turbines Ka parameters (see Ref. 1)
windturbKbParam: Vector of Wind turbines Kb parameters (Ref. 1)

In order to re-execute the power flow calculations, the field must first be deselected and re-selected.
The rule is: after any changes to entries in Network block it is necessary to re-initialize and re-calculate power flow by selecting the appropriate field. By closing the Network block dialog box, this field is automatically deselected.
In each iteration node voltages are calculated by using formula
nodeVoltage=invsystemaugYMatrix*Isorc
Where invsystemaugYMatrix is inversion of the network admittance matrix with included load admittances and generator admittances.

Additional iterations at the start and at the end of fault?:
By selecting this field additional iterations (during the two Simulink steps) are performed by using Gauss Siedel algorithm with constraints. In the most of the cases this functionality can reduce peaks in the voltage and electrical power response, immediately after fault or immediately after the fault clearance. The peaks are result of the fact that in the iterations of network equations the equations of Low Voltage Active Current Management and High Voltage Reactive Current Management are not included(they are included in the WTG model).

6. PLL block



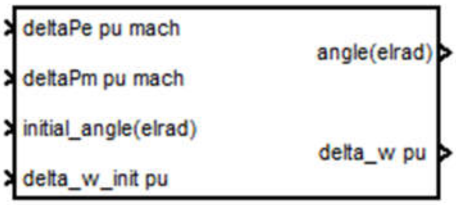
PLL (Phase Locked Loop) block is used for measurement frequency of a signal.

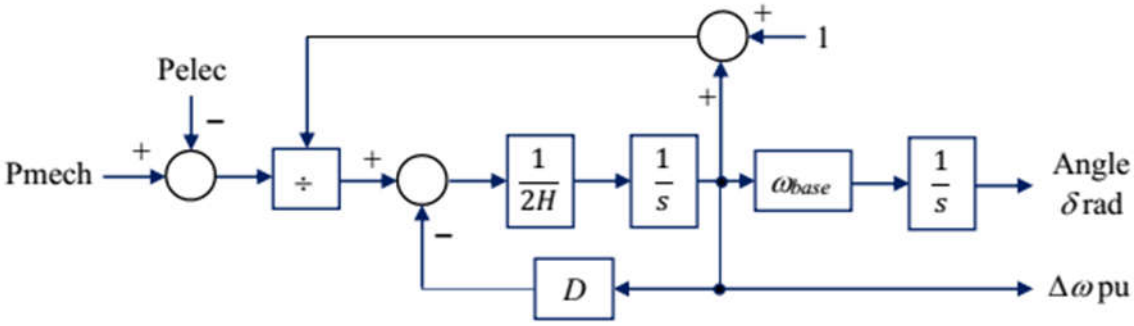
PARAMETERS:
Measurement node number: Measurement signal node number
Proportional gain: Proportional gain of the PI controller (default 30)
Integral gain: Integral gain of PI controller (default 0)

INPUTS:
Input in this block is node voltage phasor pu.

OUTPUTS:
Output of this block is voltage angle frequency pu filtered by low pass fourth order Buttherworth filter with bandwidth frequency of 25 Hz

7. Rotor block





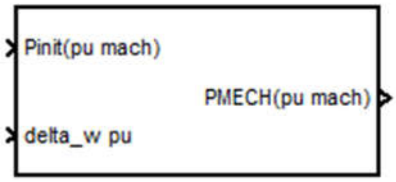
Single mass turbine/generator rotor/damping (D) model.

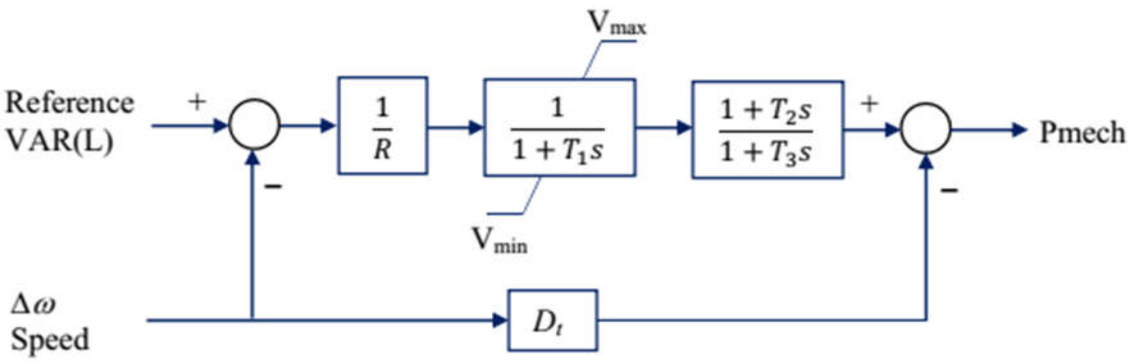
PARAMETERS:
Base system speed (rad/s)
Machine inertial constant H (s)
Load damping D pu

INPUTS:
deltaPe pu mach: Deviation of electrical power (pu) from initial electrical power, pu of turbine/generator rated power
deltaPm pu mach: Deviation of turbine mechanical power from initial, pu of turbine/generator rated power
initial_angle(elrad): Rotor initial angle in electrical radians
delta_w_init pu: Initial deviation of turbine/generator angle speed, pu of base system speed

OUTPUTS:
angle(elrad): Deviation of rotor angle from the initial rotor angle in electrical radians
delta_w_init pu: Deviation of turbine/generator angle speed from the initial angle speed, pu of the base system speed

8. Tygov1 block



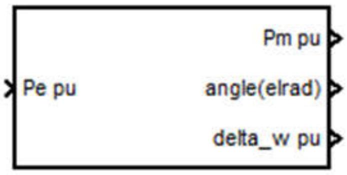


Parameter	Value	Description
R	0.05	Droop constant
D_t	0	Turbine damping
T_1 (>0) (sec)	0.2	Governor time constant
T_2 (sec)	2.1	T_2 / T_3, fraction of total turbine power generated by HP section
T_3 (>0) (sec)	7	Reheat time constant
V_{max}	1	Turbine valve maximum limit
V_{min}	0	Turbine valve minimum limit

Model includes turbine-governor TGOV1 PSS model

For explanation of the parameters see PSS/E documentation (Ref. 2)

9. Thermo block



Thermo block includes TGOV PSS model and rotor/load damping (D) model.

For explanation of the parameters see PSS/E documentation (Ref. 2)

10. Vec_sig_selector block

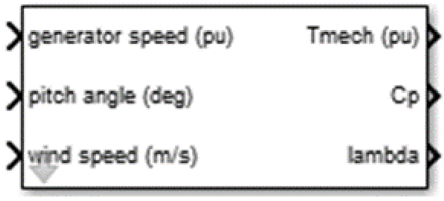
Block selects appropriate node signal from vector node signal input

PARAMETERS:
Node number: Number of node which signal belongs to

INPUT:
in: Vector signal

OUTPUT:
out: Scalar signal output

11. Wind_turbine block
(According to Matlab/Simulink documentation)



Wind Turbine block is similar to the Simulink/SimPowerSystems/Wind Turbine.mdl block.
Wind Turbine block implements the same aerodynamic model used in built in Simulink Wind Turbine.mdl block but it has different parameters and outputs.

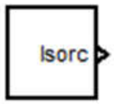
PARAMETERS :
Nominal mechanical output power: The nominal output power in watts (W).
Base power of the electrical generator: The nominal power of the electrical generator coupled to the wind turbine, in VA.
This parameter is used to compute the output torque in pu of the nominal torque of the generator.
Base wind speed v1 (m/s): The base value of the wind speed, in m/s, used in the per unit system.
The base wind speed is the mean value of the expected wind speed. This base wind speed produces a mechanical power which is usually lower than the turbine nominal power.
Maximum power at base wind speed (pu of nominal turbine power): The maximum power at base wind speed in pu of the nominal mechanical power.
Base rotational speed wb (pu of base generator speed): The rotational speed at maximum power for the base wind speed.

For a synchronous or asynchronous generator, the base speed is the synchronous speed.
For a permanent-magnet generator, the base speed is defined as the speed producing nominal voltage at no load.
The turbine inertia must be added to the generator inertia.

INPUTS:
generator speed (pu): generator speed pu of base generator speed
pitch angle (deg): pitch angle in degrees
wind speed (m/s): wind speed in m/s

OUTPUTS:
Tmech (pu): simulink output of the mechanical torque of the wind turbine, in pu of the nominal generator torque.
The nominal torque of the generator is based on the nominal generator power and speed.
Cp: power coefficient of turbine (maximum value 0.48 among others @ wind speed = v1, pitch angle = 0 deg and generator speed = wb)
lambda : tip speed ratio (optimal value 8.1 among others @ wind speed = v1, generator speed = wb)

12. Zero_gen block



This block represents current source that injects zero current into a network node to which no generator is connected.

It should be connected to Isorc input of the Network block.

The overall number of Generator blocks and ZERO_GEN blocks must be equal to the number of network nodes.

OUTPUT:
Isorc : Equal to the complex number 0+j*0

IV. WTD MATLAB FUNCTIONS

admMatCalcCsv_Ver2

This function is used for calculation of network admittance matrix from network description csv file.

augYFun

This function is used for calculation of network admittance matrix with included equivalent load admittances, and generators transient reactance.

initGridFunPro_Ver3

By calling the other WTD Library functions, this function is used for power flow calculations, initialization of DFIG block and initialization of the other WTD blocks.

initPelecFun

This Matlab function calculates DFIG wind turbine speed, wind turbine pitch angle and initial mechanical power of DFIG wind turbine if the initial wind speed is given.

initvwFun

This Matlab function calculates DFIG wind turbine speed, wind turbine pitch angle and initial wind speed if initial mechanical power of DFIG wind turbine is given.

powerFlowFun

This Matlab function performs power flow calculations using Newton-Raphson iteration method.

s_power_flow_fault_gs_nr

This Matlab S-function implements Gauss-Siedel iteration method with constraints for calculation of network variables after disturbance/fault and after disturbance/fault clearance.