Project: “Energy conversion, renewable energy and smart grid”

Electrical Engineer: Tanya Asaad Mohamaed abid

ID: 8323

Submission date: 19th December 2023

Content

Abstract

Renewable energies generation are improved rapidly particularly wind energy, further, number of wind farms connected to the power system grid are becoming more and more. New concepts have been developed for distribution power in the small local community. Too many investigations in wind turbine participated in developing it, and realizing new models to increase efficiency and facing fickle winds. Currently, new intention is to change stereotype idea about consumer is to contribute the power system. This assignment describes the basic concepts for design a small-scale power generation based on wind energy, and dynamic modeling for DFIG with functionality in different situations. In addition, a carry out MATLAB simulation on the existing DFIG model to earn the response with difference cases. Moreover, alter the old style power distribution systems to active distribution system and showing opportunities of smart grid notion to change consumers from passive to an active part.

Task 1:

In this project wind power energy is used as renewable source to energize local community with electricity power through Uninterruptable Power Supply (UPS) to insure continuity of power supply, for unwanted emergency case such as system faulty the whole system is connected with grid network for delivering to the load.

Schematic diagram of project Design:

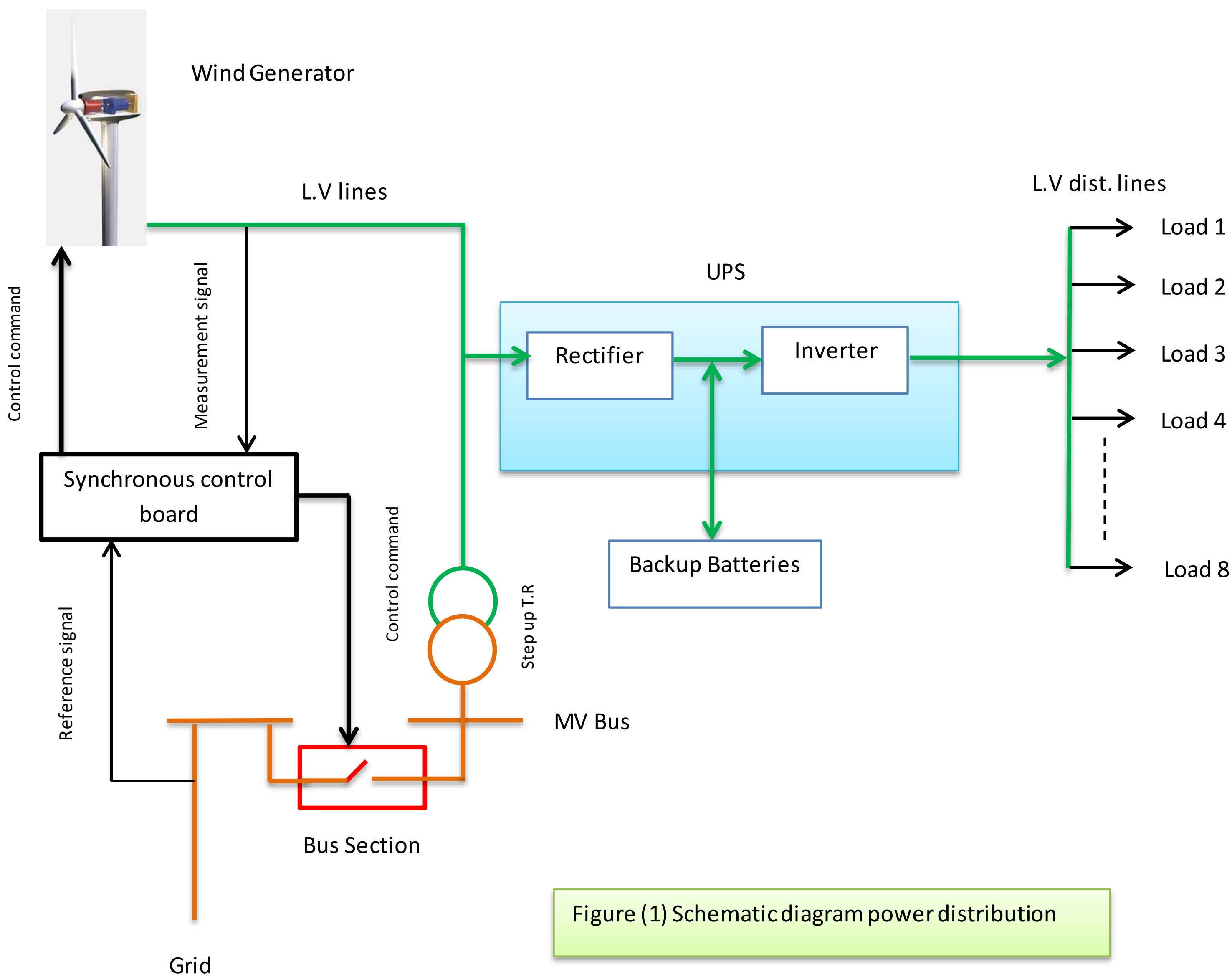


Figure (1) Schematic diagram power distribution

1.1 Design:

1.1.1 Load Calculation:

The first step to design network power system is load calculation, in this project individual load consumption assumed (5 KW) and number of loads is (8 houses). In addition the project is designed for next (5) years, while assumed growth load is (2.5%) for each year, hence:

$$Total\ Load = Houses\ load + grwoth\ increase\ load\ in\ next\ 5\ years$$
$$= (5Kw * 8) + (2.5\% * 5\ years * 5KW * 8)$$
$$= 45\ KW$$

1.1.2 UPS Calculation and Selection:

- Total Load = 45 KW
- Assume UPS work (80%) of its full rated and remain (20%) is safe side.

$$\therefore UPS\ Rating = 45KW + (20\% * 45KW)$$
$$= 54\ KW$$

Emerson Company provides various types of UPSs with wide range capacity, suitable UPS for our design is (Liebert® NX, 60 kW UPS) [2].

Assume Power Factor of UPS = 0.96

Backup batteries calculation for UPS:

$$Max.UPS\ Line\ current = \frac{UPS\ Rated\ Power}{\sqrt{3} * Line\ voltage * p.f}$$

$$= \frac{54 * 1000}{\sqrt{3} * 400 * 0.96} = 81\ A$$

[3] Battery capacity = I_{max} * K * T

Where:

- $I_{max:}$ Maximum UPS current.
- K: UPS constant provided by Emerson company in relation with backup time table (1) [3].
- T: backup time

T (time)	0.5	1	2	3	4	5	6	8	9	10
K (25^0)	2.86	2	1.64	1.34	1.26	1.2	1.12	1.07	1.03	1

Table (1) Time & UPS constant K Relation

For 10 hours backup time, K=1 from Table (1)

∴ Battery Capacity = 81*1*10= 810 Ah

That is mean UPS able to provide power to the load (10 hours) period continuously.

1.1.3 Generator Calculation and Selection:

- Generator produces power at (90%) of its rated capacity and remains (10%) safe side.

$$Generator\ Capacity = (45KW) + (10\% * 45KW) = 49.5\ KW$$

The UK Company (Endurance Wind Power) has series of wind power generators contributes to the national renewable energy and carbon emission reduction targets [4]. Suitable wind power turbine is (E-3120 50 KW). Table (2) shows technical data for mentioned turbine.

Turbine	
Configuration	3 blades, horizontal axis, downwind
Rated power @ 9.5 m/s	50kW
Applications	Direct grid-tie
Rotor speed	43 rpm
Cut-in wind speed	3.5 m/s (7.8 mph)
Cut-out wind speed	25 m/s (56 mph)
Survival wind speed	52 m/s (116 mph)
Overall weight	3 990 kg (8 800 lbs)
Rotor	
Rotor diameter	19.2 m (63.0 ft)
Swept area	290 m² (3120 ft²)
Blade length	9.00 m (29.5 ft)
Blade material	Fiberglass/Polyester
Power regulation	Stall control (constant speed)
Generator	
Type	Induction generator
Configurations	3ϕ, 400 VAC @ 50 Hz

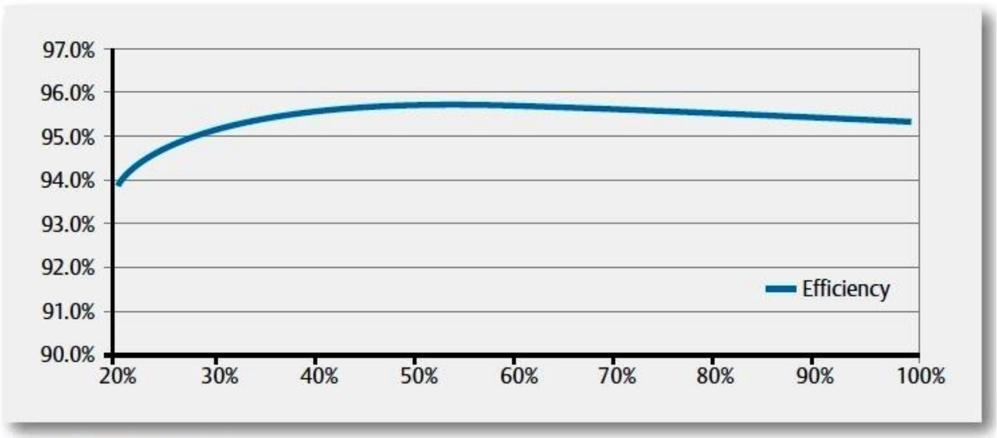
Table (2) Technical Data E-3120 50KW Turbine

1.2 Overall system efficiency:

In this project plan, efficiency split into two equipment (UPS and Wind Turbine) neglecting power losses in low voltage transmission cables.

1.2.1 UPS efficiency:

It can be seen from figure (2) that (Liebert® NX, 60 kW UPS) has high efficiency at 80% of its rated load almost equal to (95.5%)



Liebert® NX - efficiency curve

Figure (2) Efficiency Curve UPS Liebert NX source: Emerson Network

1.2.2 Wind Turbine Efficiency:

Output power from wind generator = 50 KW at wind speed 9.5 m/s. see table (1)

Input power to the wind turbine = ½ * ɤ*A*V^3

Where:

- ➢ ɤ: is the air density in Kilograms per cubic meter (kg/m^3).
- ➢ A: is the swept rotor area in square meters (m^2)

∴ Input power = ½ * 1.225*290*$(9.5)^3$

= 152 KW

$$Efficiency = \frac{output\ power}{inputpower} = \frac{50\ KW}{152\ KW} = 32\%$$

Obviously, it can be seen that wind turbine has low efficiency due to various losses in it, for instance [5]:

1. Mechanical losses: such as gear box, windage and ball bearing losses.
2. Copper losses: include primary and secondary winding losses in generator.
3. Iron losses: Eddy current and hysteresis losses.

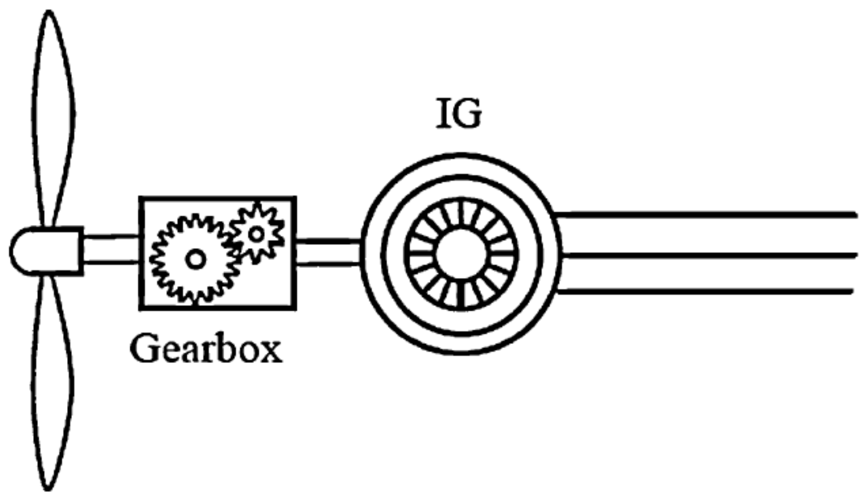


Figure (3): System configuration with IG, Appendix [5]

1.3 Overall System Configurations:

1.3.1 Synchronous board and bus section:

The bus section in figure (1) consists of M.V circuit breaker, its takes action to close and connect main grid with WT when active command come from synchronous board. The function of synchronous board is to match between main grid power and WT power to enable working in parallel when they satisfy condition of synchronous:

1. The same voltage between two sources.
2. The same frequency between two sources.
3. The same direction of sequence rotation.
4. Zero angle between the same phase for the two sources.

1.3.2 UPS:

An Uninterruptible Power Supply (UPS) is an electrical apparatus that provide emergency power to a load when an input power, typically main power fail. In this project (Liebert® NX, 60 kW UPS) is used, it has a property called online double conversion figure (5), It is called a double-conversion UPS due to the rectifier directly driving the inverter. [6]

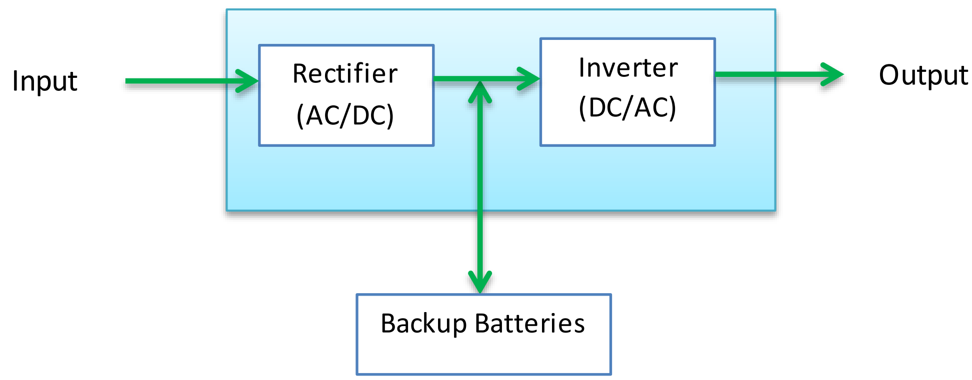


Figure (5): Online UPS Simply layout [6]

1. *Rectifier:* Function of rectifier is to change input AC voltage to DC supplying inverter and charging batteries.
2. *Inverter:* to invert DC voltage to output AV voltage and supplying a load.
3. *Backup Battery:* to feed inverter input DC voltage while input rectifier voltage interrupted.

1.3.3 Wind Turbine:

Wind turbines are energy convertor, it convert the kinetic energy of the flowing air mass into rotational mechanical energy. While it drive generator to produce power electricity. Turbine may be vertical or horizontal [7].

Figure (6) shows typical layout of (E-3120 50 KW) turbine.

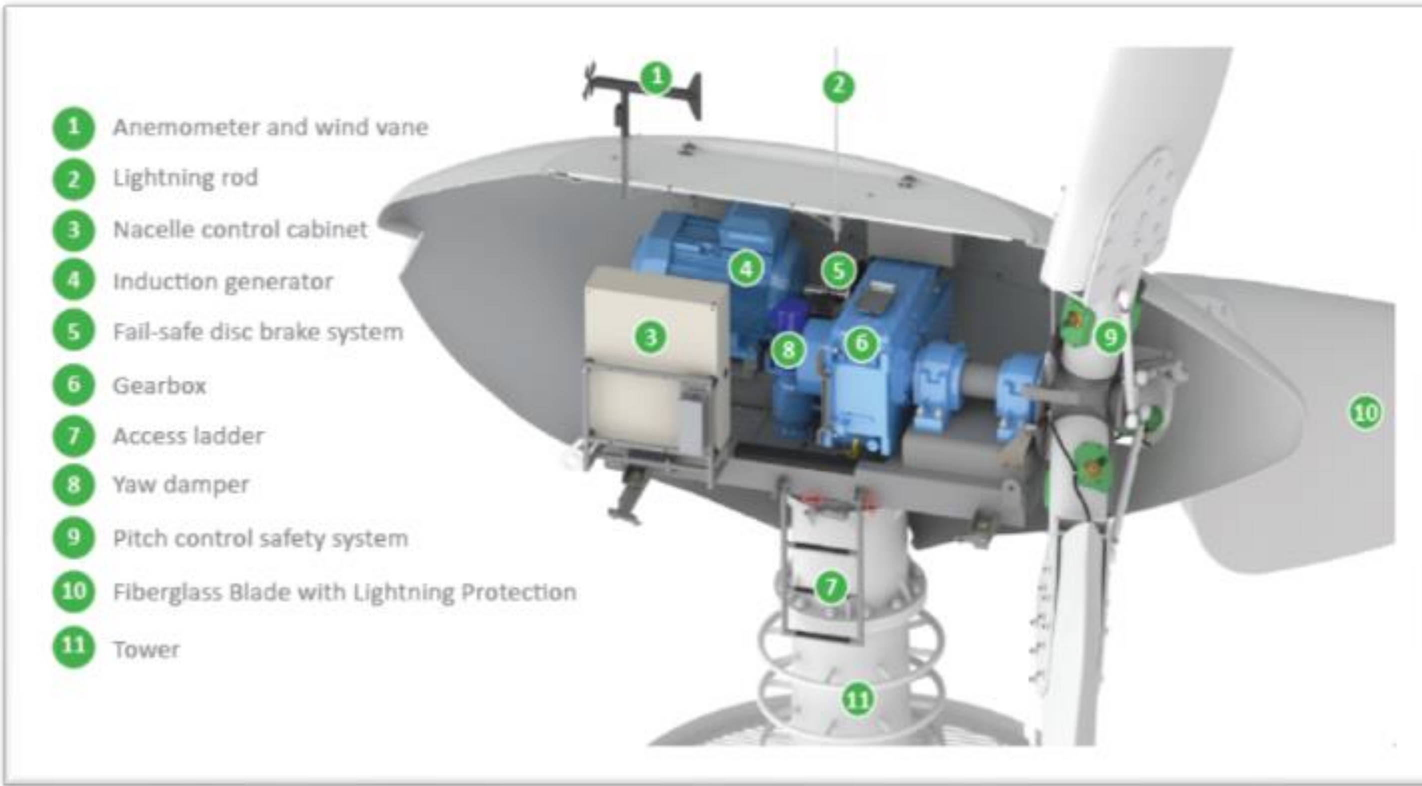


Figure (6): Wind (E-3120 50 KW) horizontal turbine structure [4]

1. ***Anemometer and wind vane:***

International standards IEC and IEA listed anemometer as most advance sensor to measure wind speed. It produces either analogue or digital voltage, the value of voltage directly proportional to the speed of anemometer rotation and the wind speed [7]. The function of wind vane is to direct a rotor with face of wind.

2. ***Lightning rod:***

It protects the turbine from lightning strikes [4].

3. Nacelle control cabinet:

It is locate at the top of tower and act as a shelter for turbine equipment like generator, and gear box, protect them from outside environment effects [4].

4. Induction generator:

Produce electricity power, no need to power electronics [4].

5. Fail-safe disc brake system:

It protect wind turbine from damage in bad situation like extreme wind or transmission grid faulty.

6. Gearbox:

Transfer speed from low in rotor side to high in generator side, it has high reliability [4].

7. Access ladder:

It use by staff to maintain equipment inside nacelle.

8. Yaw damper:

'While the turbine is aerodynamically oriented by the wind, the yaw damper smooth's the movement to ease tower and rotor loads.' [4]

9. Pitch control safety system:

It controls the pitch angle for different wind speed and protect rotor from high wind speed [4].

10. Fiberglass Blade with lighting protection:

It is designed to capture wind energy, and blades act as contactor to make path for lightning strikes on tower.

11. Tower:

It is monopole tower carry nacelle with blades [4].

1.4 Wind Turbine Sitting:

In order to install a wind turbine to produce electricity power, some criteria should take in consideration in planning stage:

1. Wind speed: The first step to assess wind speed value obtained by general meteorological data, as well as to verify orography at the site [7], Landscape and Visual Impact Assessment (LVIA) is a standard process for examine wind speed in area region[9].

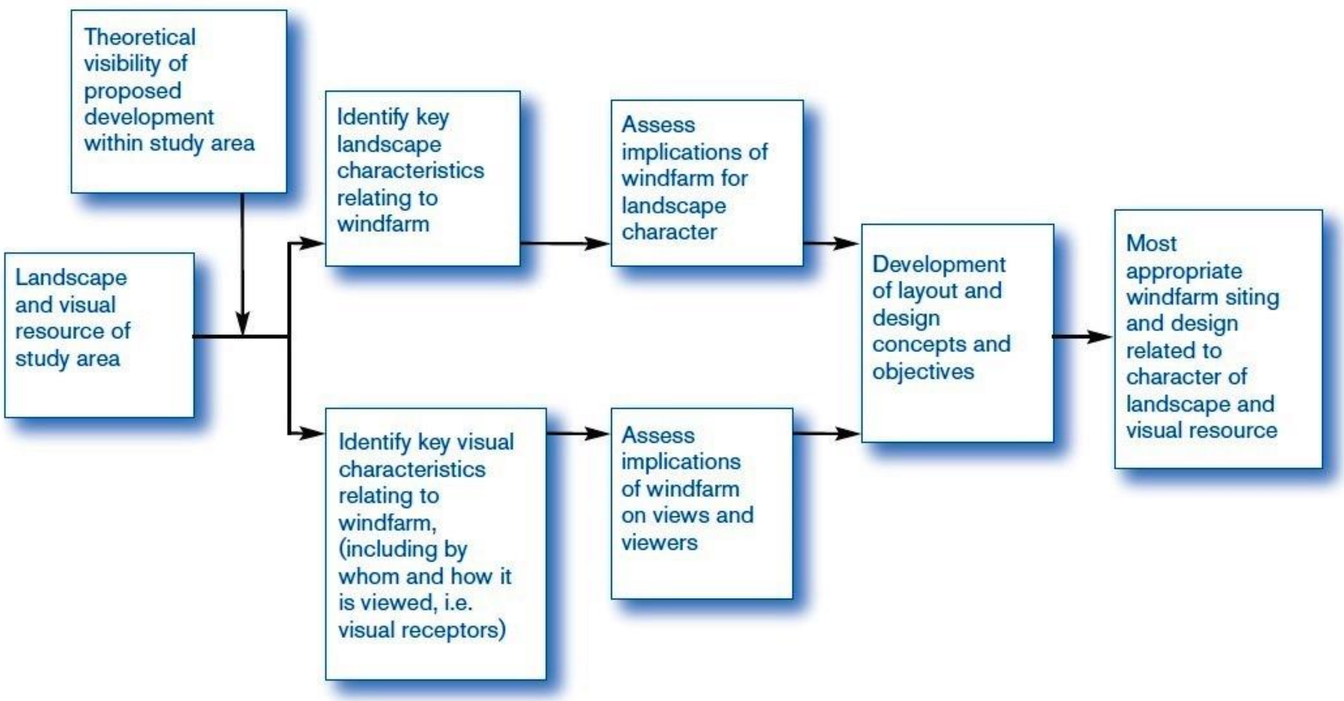


Figure (7): Wind assessment process [9]

2. The availability of grid connection and capacity, and obtain pervious acceptance from operator to connect your generator with it [7].
3. Government approval: it should necessary approval been taken in early stage of project [1].
4. Accessibility and transportation to the site: it should check road access for transportation of equipment's and suitable place for crane [7].

1.5 Wind Power Advantages and disadvantages:

1. Advantages of wind power [10]:
   - ✓ Clean fuel source.
   - ✓ It has no pollution gas like power plant uses fossil fuel.
   - ✓ Don't produce greenhouse gasses which caused acid rain.
   - ✓ The source for wind energy is wind that is mean infinite source and can't be used up.
   - ✓ It has the lowest price energy source.
   - ✓ It is domestic source of energy can be use individually by ordinary people on their houses.
   - ✓ Exploit small area on land.

2. Disadvantages of wind power [1]:
   - ✓ Noise disturbances: turbines create noise sound on people surrounding the wind farm.
   - ✓ Threat to wildlife: like birds of prey.
   - ✓ Wind can never be predicated.
   - ✓ Visual impact.
   - ✓ Intermittent source of power: the capacity factor of wind energy is low in practically reach max. 40%.
   - ✓ Financing: it has challenge when looking for investment.

1.6 Wind economics and development:

The main factors governing wind power economics are [1] & [11]:

1. Investment costs, including wind turbines, civil working foundation and grid connection.
2. Operational and maintenance cost which is high especially for gearbox maintenance.
3. Electricity production: it has low power production almost 45% in maximum situation, and huge losses in turbine make its efficiency low.
4. Turbine life time.
5. Discount rate: including Tax incentives

1.7 Wind Energy policy:

[7] Two principles are taken in account when analyzing wind power market, firstly where governmental support is motivated by environmental concerns, secondly when support on energy need.

With a view of developing renewable energy market, policy framework assistant require. The following policy terms necessary to motivate renewable energy:

1. Public fund for program and demonstration projects.
2. Guaranty premium prices for electricity particularly from wind power.
3. Financial incentive such as loans or favorable interest rates.
4. Tax incentives.

Figure (8) shows typical markets for wind energy [11]

Environment-driven markets	Energy-driven markets
- No need for additional capacity - Financing available - Wind energy only contributes a small part of total energy supply - Desire and obligation to reduce CO_2 - Wind energy development is not very sensitive to variations in international fuel prices	- Immediate need for additional energy - capacity shortfall - Shortage of foreign currency - Dependant on importing fossil fuels - Moderate to high economic growth - Need for technology transfer and local production - Very sensitive to variations in inter national fuel prices

Figure (8): typical markets for wind energy [11]

Task 2.1:

In this Task a dynamic modeling drive of wind power generation is done based on (DFIG) with variable rotor speed and pitch controller, in addition, drive train is tow-mass model.

Modeling:

2.1 Wind Turbine Model:

[12] The generation power by wind generator captured from kinetic energy of wind and it depends on power coefficient, the expression is given in equation (1):

$$P_{wti} = C_p P_{wind} = {}^1\!/_2 \; Cp \; \rho \; A \; v_w^3 \quad \dots \dots \dots (1)$$

Where:

- P_{wti}: wind power generation.
- P_{wind}: air stream kinetic energy.
- C_p: power coefficient exclusive for each turbine.
- ρ : air density.
- A: area of swept blades $(A = \pi r^2), r: length\ of\ blad$.
- v_w: Average wind speed at hub height.

$$C_p \; (\lambda, \theta_{pitch)} = c_1 \left(c_2 \frac{1}{\Lambda} - c_4 \theta_{pitch}^{c_5} - c_6 \right) e^{c_7 \frac{1}{\Lambda}} \quad \dots \dots \dots (2)$$

Where:

- θ_{pitch}: Pitch angle of blads.
- λ : Tip speed ratio.

$$\lambda = \frac{w_t \; R}{v_w} \dots \dots \dots (3)$$

And

$$\frac{1}{\Lambda} = \frac{1}{\lambda + c_8 \theta_{pitch}} - \frac{c_9}{1 + \theta_{pitch}^3} \dots \dots \dots (4)$$

Where:

- (c_1 …c_9) are constants for each designed turbine.
- W_t: low speed shaft speed angular speed.

2.1.1 Drive train Model:

[13] In two mass model shaft systems, independent masses are used to configure low and high speed in turbine and generator respectively as shown in figure (9). The coupling shaft between turbine and generator modeled as a spring and dumper. The electromechanical dynamic equations are:

$$2H_t p w_t = T_m - D_t w_t - D_{tg}(w_t - w_r) - T_{tg} \ldots\ldots\ldots (5)$$

$$2H_g p w_r = T_{tg} + D_{tg}(w_t - w_r) - D_g w_r - T_e \ldots\ldots\ldots (6)$$

$$pT_{tg} = K_{tg}(w_t - w_r) \ldots\ldots\ldots (7)$$

Where:

- $p = \frac{d}{dt}$
- w_t and w_r are the turbine and generator totor speed respectively.
- T_m applied mechnical torque on turbine, T_e is electrical torque of generator.
- T_{tg} internal torque of the model.
- $H_t$andH_g are interia constants of the turbine and the generator respectively.
- D_{tg} damping coefficient of the flexiable coupling (shaft)between the two masses.
- K_{tg} shaft stiffness.
- N_r/N_g is the gear ratio.

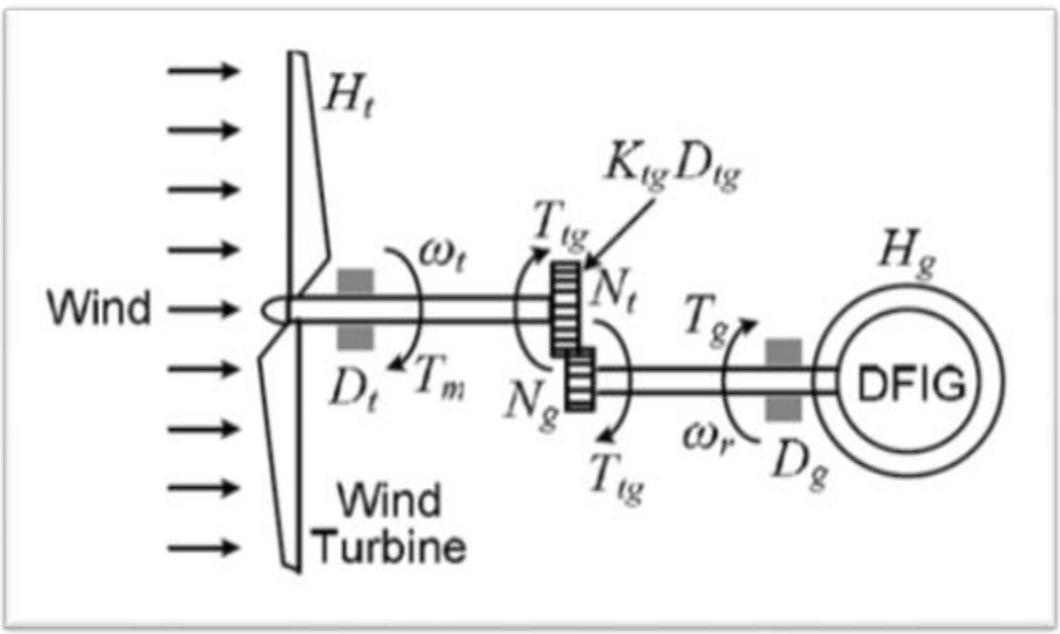


Figure (9): DFIG wind turbine shaft system (Two-mass) [13]

2.1.2 Pitch System Model:

[12] The figure (10) shows pitch system model which is consist into two sub systems; pitch controller and pitch angle actuator. The first part; pitch controller obtain pitch angle reference β_{ref} from the difference between measured and optimum rotor speed, it has regulating turbine speed called GAINS technique (Gain Scheduling function block) and Power Electronic controller. The mentioned is used in nonlinear systems. The second part consists on actuator responsible to rotate all the blades to optimum degree.

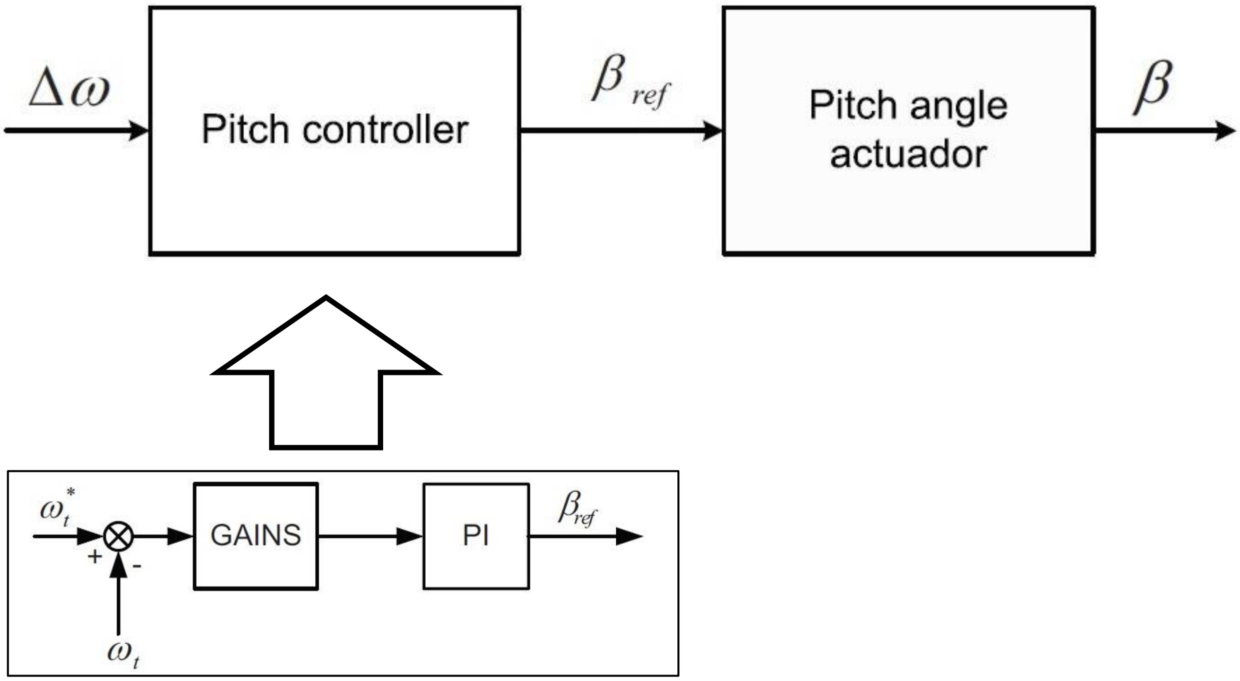


Figure (10): Pitch system configuration [12]

Since pitch actuator is a nonlinear system it can be modeled as closed loop first order dynamic system with limit output signal derivation and saturation amplitude. The operating of the pitch actuator in the linear region as shown in the figure (11) and described by equation:

$$\beta = \frac{1}{\tau_{pitch}}\beta + \frac{1}{\tau_{pitch}}\beta_{ref} \dots\dots\dots (8)$$

Where

- τ_{pitch} : is the time constant.

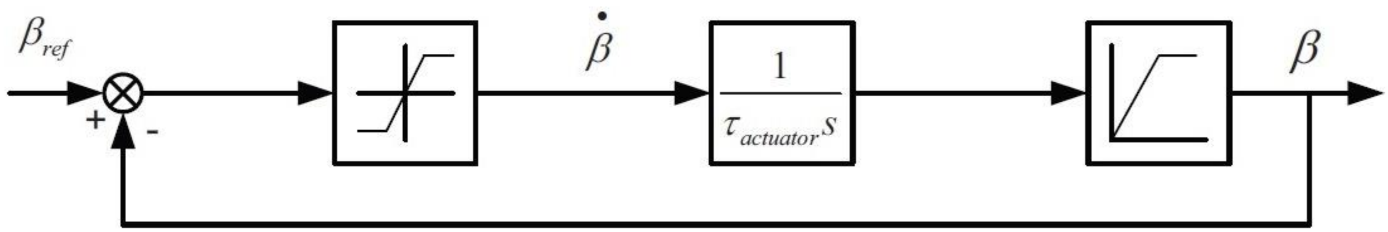


Figure (11): Model for pitch angular actuator [12]

2.1.3 DFIG Model:

[12][13][14] The induction generator in this task is single cage wounded rotor type. The stator and rotor equations can be written in term of instantaneous variables as shown in Figure (12):

$$v_{sabc} = r_s i_{sabc} + p\lambda_{sabc} \dots \dots \dots (9)$$

$$v_{rabc} = r_r i_{rabc} + p\lambda_{rabc} \dots \dots \dots (10)$$

Applying d-q transformation to equation (9) and (10), the voltage equations become:

$$v_{ds} = r_s i_{ds} - w_s \lambda_{qs} + p\lambda_{ds} \dots \dots \dots (11)$$
$$v_{qs} = r_s i_{qs} + w_s \lambda_{ds} + p\lambda_{qs} \dots \dots \dots (12)$$

$$v_{dr} = r_r i_{dr} - (w_s - w_r)\lambda_{qr} + p\lambda_{dr} \dots \dots \dots (13)$$

$$v_{qr} = r_r i_{qr} + (w_s - w_r)\lambda_{dr} + p\lambda_{qr} \dots \dots \dots (14)$$

Where

- w_s is a rotational synchronous speed, w_r is a rotor speed, p is $\frac{d}{dt}$, λ is flux linkage. The equation of flux linkages are given by:

$$\lambda_{ds} = L_{ls} i_{ds} + L_m(i_{ds} + i_{dr}) = L_s i_{ds} + L_m i_{dr} \dots \dots \dots (15)$$
$$\lambda_{qs} = L_{ls} i_{qs} + L_m\left(i_{qs} + i_{qr}\right) = L_s i_{qs} + L_m i_{qr} \dots \dots \dots (16)$$

$$\lambda_{dr} = L_{lr} i_{dr} + L_m(i_{ds} + i_{dr}) = L_m i_{ds} + L_r i_{dr} \dots \dots \dots (17)$$
$$\lambda_{qr} = L_{lr} i_{qr} + L_m\left(i_{qs} + i_{qr}\right) = L_m i_{qs} + L_r i_{qr} \dots \dots \dots (18)$$

Where: $L_s = L_{ls} + L_m, L_r = L_{lr} + L_m; (L_{ls}\ is\ stator\ , L_{lr}\ is\ rotor\ and\ L_m\ is\ mutual\ )$ inductances.

For synchronous purpose between rotor and stator EMF, the frequency of rotor current w_{rf} must be satisfying the slip frequency:

$$w_{rf} = w_s - w_r = sw_s \; \ldots\ldots\ldots (19)$$

The electromagnetic torque equation (per-unit) is given by:

$$T_e = \lambda_{ds} i_{qs} - \lambda_{qs} i_{ds} = \lambda_{qr} i_{dr} - \lambda_{dr} i_{dr} = L_m\left(i_{qs} i_{dr} - i_{ds} i_{qr}\right) \ldots\ldots\ldots (20)$$

Assume power losses in stator and rotor are ignored, and then the active and reactive stator powers are:

$$P_s = \frac{3}{2}\left(v_{ds} i_{ds} + v_{qs} i_{qs}\right) \ldots\ldots\ldots (21)$$

$$Q_s = \frac{3}{2}\left(v_{qs} i_{ds} - v_{ds} i_{qs}\right) \ldots\ldots\ldots (22)$$

For rotor active and reactive powers are given by:

$$P_r = \frac{3}{2}\left(v_{dr} i_{dr} + v_{qr} i_{qr}\right) \ldots\ldots\ldots (23)$$

$$Q_r = \frac{3}{2}\left(v_{qr} i_{dr} - v_{dr} i_{qr}\right) \ldots\ldots\ldots (24)$$

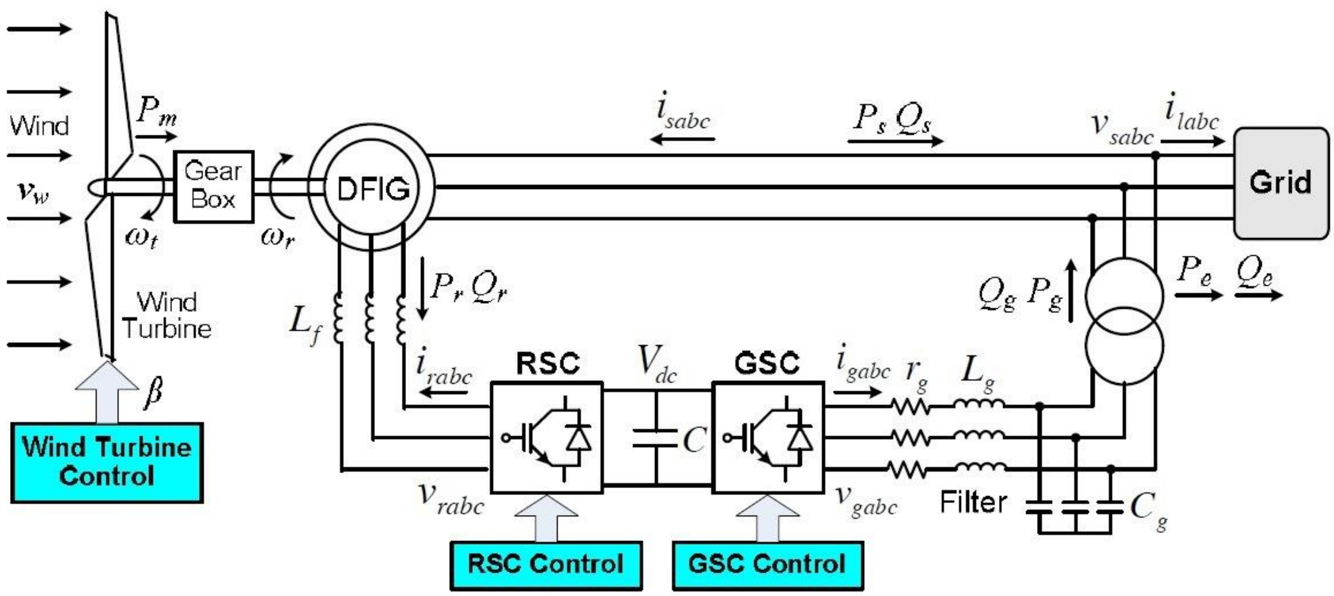


Figure (12): Configuration of a DFIG wind turbine connected with utility grid [13]

2.2 Discussion on Turbine control systems (Active and Reactive power control):

[13][15] The main purposes of the control system in DFIG wind turbine are:

- Obtain maximum output power from the wind for different wind speed range (Power optimization).
- Output power limitation up to rated power for high wind speed (Power Limitation).
- Active and Reactive powers adjustment to a specific point declared by wind farm control system (Power Regulation).

The d-q vectors are rotate at synchronous speed, d-axis behind q-axis by 90^o. The d-axis vector concur with the maximum of the stator flux, that is mean $v_{qs} = v_{terminal}$ and$v_{ds} = zero$. In DFIG wind turbine output power controlled either electrically by power converter or mechanically by the blade pitch angle. Therefore to work efficiently the power convertor must be controlled in cooperation with the blade pitch angle control. The d-q axes of rotor voltages are controlled by converter. This permit the convertor separated control on active and reactive power.

Two control systems will be presented to control active and reactive power. For the reactive power control, the two control systems have the same principle based on controlling d-axis rotor voltage v_{dr} . The v_{dr} controller obtains direct component of rotor voltage authorize the wind turbine operation with required reactive power, figure (13) shows control loop for the reactive power controller.

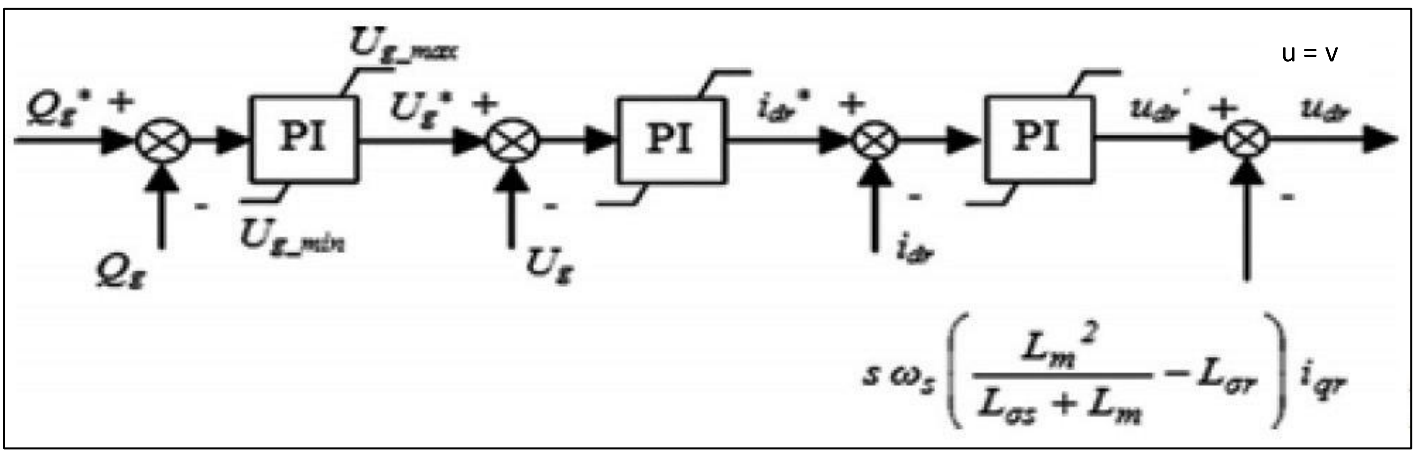


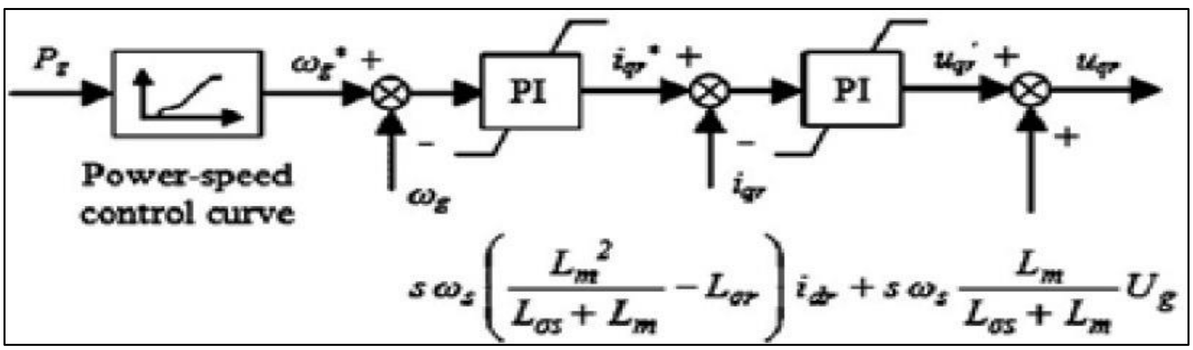
Figure (13): Reactive Power controller [15]

2.3 First Control System: (Maximum Power Tracking via speed control loop)

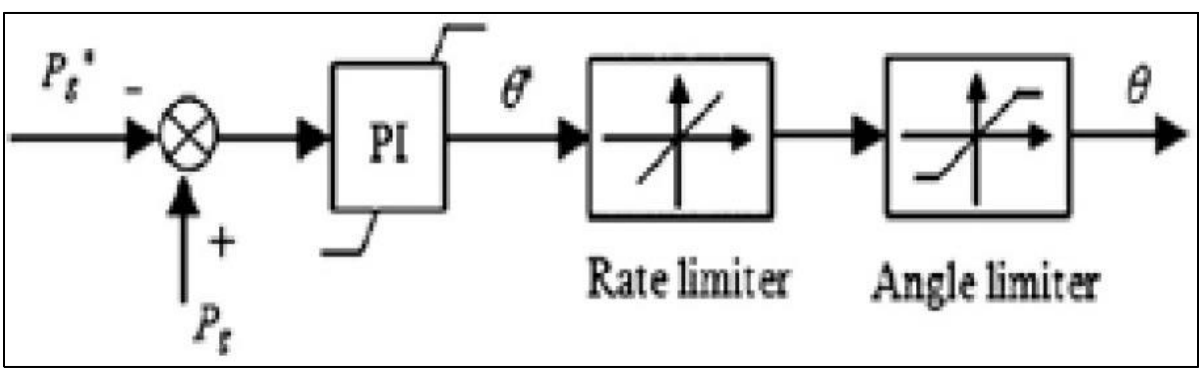
[15] This control system has three properties:

1. Quadrature component of the rotor voltage v_{qr} control the rotor speed w_r.
2. Pitch blade angle β control the active power.
3. As mentioned before direct component of rotor voltage v_{dr} control reactive power.

The v_{qr} [figure (14 a)] controller is a rotational speed controller(Speed Control Loop) , which control the IG speed to produce maximum power captured from wind (Power Optimization) taking in consideration rated power of generator (Power Limitation) or according to required output power by wind farm regulation (Power Regulation). The pitch angle controller [figure (14 b)] acts like power active controller to adjust the pitch angle. From this point view the power coefficient $C_p(\beta,\lambda)$ and power extracted from the wind energy are controlled. Hence the controller set pitch angle at optimum degree based on power optimization strategy.



14 a



14 b

Figure (14): First Control System [15]

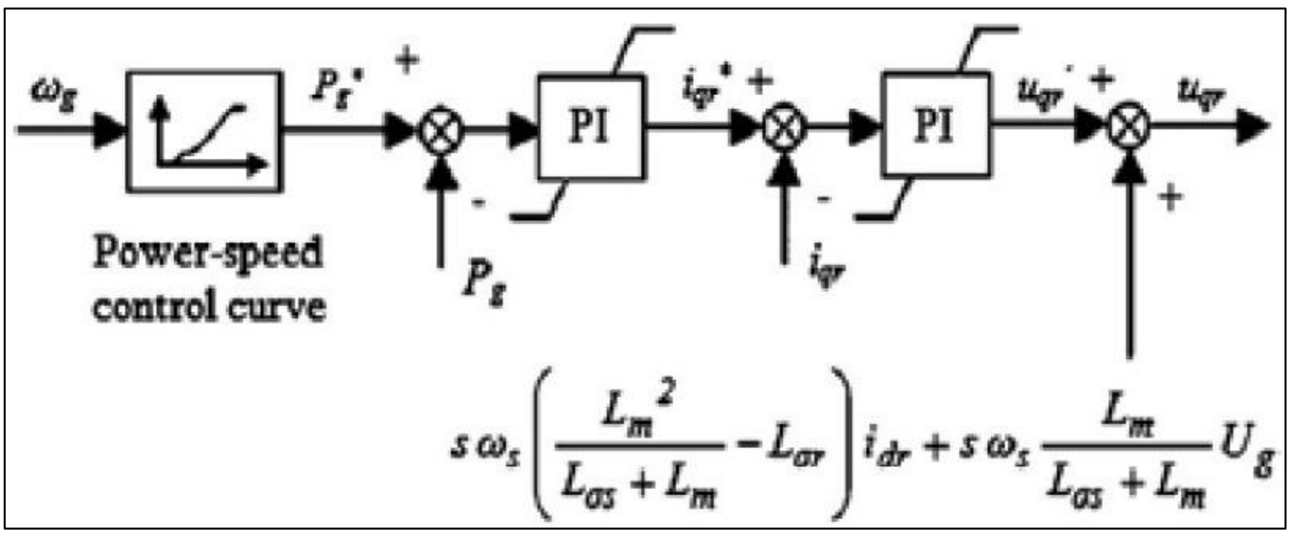
2.4 Second Control System:

[15] This control system also has three properties:

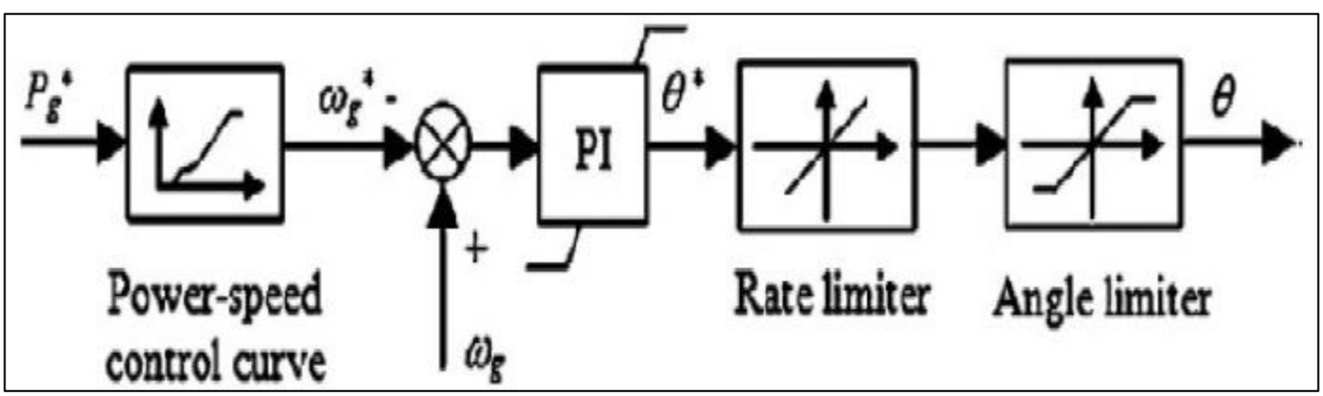
1. Quadrature component of the rotor voltage v_{qr} control the active power.
2. Pitch blade angle β control rotor speed w_r.
3. As mentioned before direct component of rotor voltage v_{dr} control reactive power.

The v_{qr} controller [figure (15 a)] is an active power controller that control the output power by v_{qr}, produce optimum power taking in consideration generator rated power and power regulation. The controller Based on power speed curve, use actual rotational speed to define reference power. The controller optimizes the output power to the value derived from the power speed curve and actual rotational speed.

From [figure (15 b)] the blade pitch angle affect like speed controller adjusting the pitch angle to decrease the power coefficient $C_p(\beta,\lambda)$and obtained power from the wind energy. Where references speed is produced from the optimum power speed curve and the power reference.



15 a



15 b

Figure (15): Second Control System [15]

Task 2.2:

2.2.1 Introduction:

[16] In this task results from simulation of Double Fed Induction Generator (DFIG- Phasor Type) based wind farms performed in MATLAB SimPowersSystems are presented. It can be seen from the given MATLAB example that DFIG uses two-mass model, variable speed rotor with pitch controller. Numerous simulate outputs data for wind turbine and grid prepared in the given example, user able to look at it in the given two Scopes.

2.2.2 Description of Simulation Model:

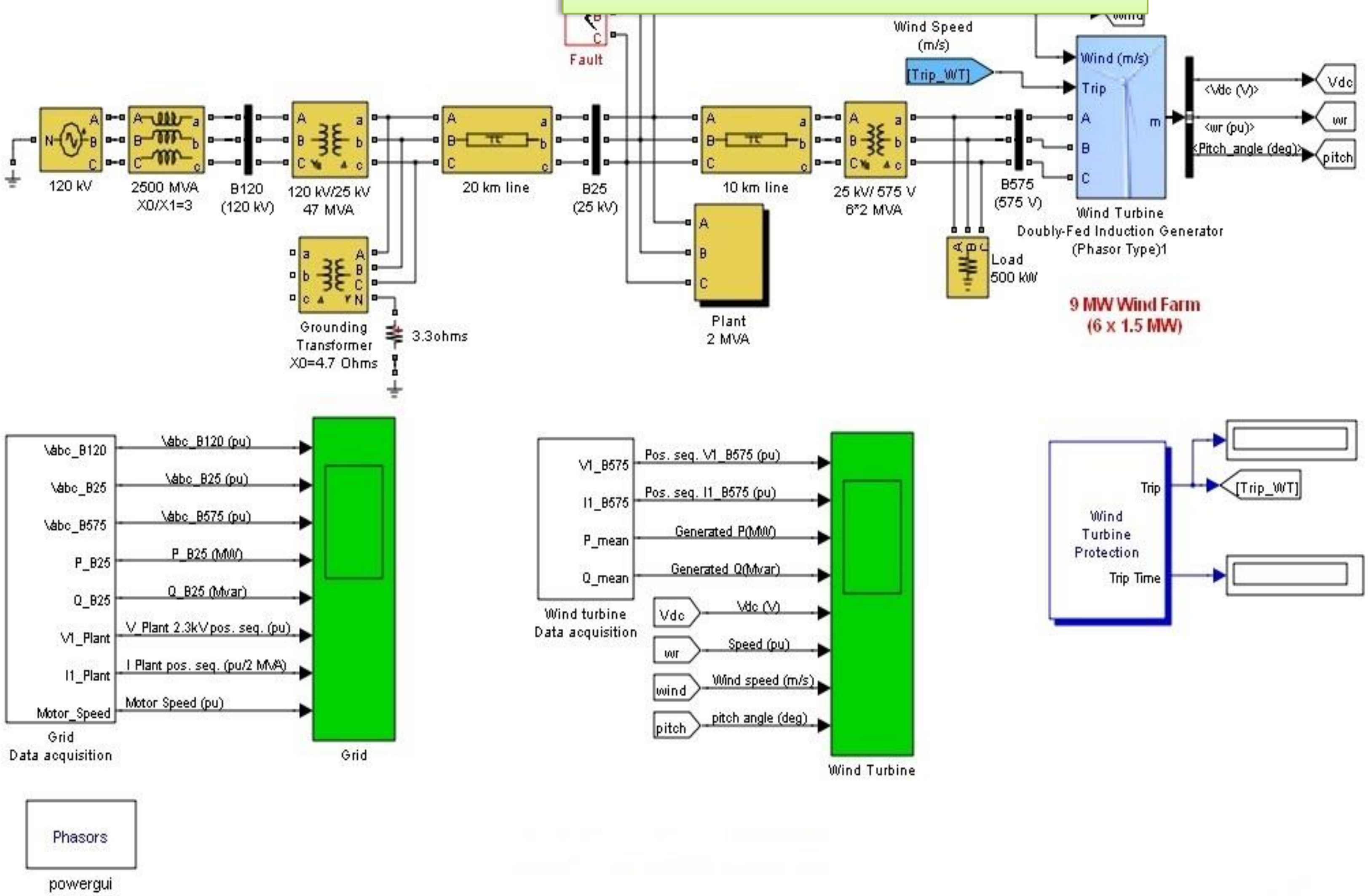
- **Description of schematic Model diagram:**

[16] A wind farm shown in figure (16) produce 9MW power over 6 unit turbines each 1.5 MW at rated 0.575KV terminal voltages and 60 Hz frequency has a resistivity load 0.5 MW, connected to six steps up transformers 2 MVA rising voltage up to 25 KV, the system connected through 10 Km transmission line to 25 KV bus bar (B25). A step down substation plant 2 MVA (25/2.3) KV connected to the 25 KV side voltages has an induction motor load (1.68 MW, P.F=0.93) and power factor correction capacitor 800 KVAR.

The system connected to a next 120 KV bus bar (B120) along another 20 Km transmission line, just before (B125) the voltage rose up to 120 KV with aid of a step up transformer 47 MVA, a grounding transformer connected just before this transformer for protection purpose.

The overall system connected with a 120 KV grid, it should be mentioned that an expected fault designed on 25 KV transmission line just before (B25), to analysis the system meanwhile phase to phase or phase to earth faults occur.

Figure (16): Wind Farm DFIG Phasor Model [16]



- **Turbine Scope:**

[16] The turbine scope in figure (16) has eight inputs used to measurement:

1. Positive sequence terminal low voltage of generator.
2. Positive sequence output load current of generator unit.
3. Generator active power.
4. Generator reactive power.
5. DC voltage of bus capacitor.
6. Rotor angular speedw_r.
7. Wind speed from anemometer.
8. Blades pitch angleβ.

- **Grid Scope:**

[16] Figure (16) the grid scope also has eight input parameters in grid side system use to measure:

1. Voltage at bus 125 KV (B125).
2. Voltage at bus 25 KV (B25).
3. Low voltage at bus 0.575 KV (B575).
4. Active power at the (B25).
5. Reactive power at the (B25).
6. Positive sequence voltage at bus 2.3 KV.
7. Positive sequence current at bus 2.3 KV.
8. Angular speed of the squirrel cage induction motor.

- **Wind Turbine Protection:**

[16] A protection relay device for the system figure (17) has four input sensor signals (B575) voltage and current, DC bus capacitor voltage and rotor angular speed). It takes four mentioned signals and monitors them for abnormal condition. In case abnormal condition the relay will send trip command to the wind turbine to turn off and disconnecting main circuit breaker to prevent generator from damage as well as recording instantaneous trip time. The relay has ten protection functions:

1. Instantaneous AC Overcurrent.
2. AC overcurrent (+ve sequence).
3. AC current unbalance.
4. AC under voltage (+ve sequence).
5. AC overvoltage (+ve sequence).
6. AC voltage unbalance (-ve sequence).
7. AC voltage unbalance (zero sequence).
8. DC over voltage.
9. Under speed.
10. Over speed.

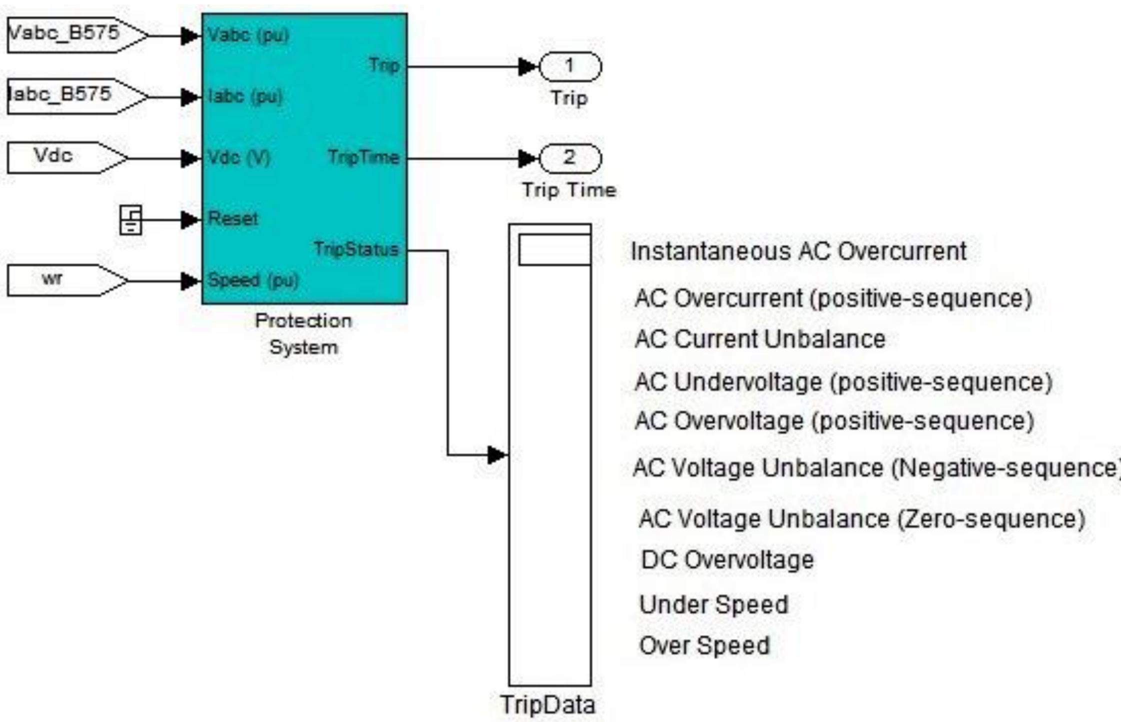


Figure (17): Protection system of WT [16]

- **Wind Turbine:**

The given MATLAB model based steady state power characteristics of the two mass turbines, while the drive train stiffness, fraction factor and moment of inertia of both generator and turbine are combined and coupled into turbine. The normalized per unit (pu) equation of turbine is given by:

$$P_{m\_pu} = k_p c_{p\_pu} v_{wind\_pu}^3 \ldots \ldots \ldots (25)$$

Where:

$P_{m_{pu}}$: $Power\ in\ pu\ for\ particular\ values\ of\ \rho\ and\ A.$

$c_{p_{pu}}$: $Power\ coefficient\ in\ pu.$

v_{wind_pu}: $Wind\ speed\ in\ pu, base\ wind\ is\ mean\ value\ of\ expected\ wins\ speed\ in\ m/s.$

k_p: $Power\ gain, value\ less\ than\ or\ equal\ to\ 1.$

C_p is function of λ and θ, equation is given by:

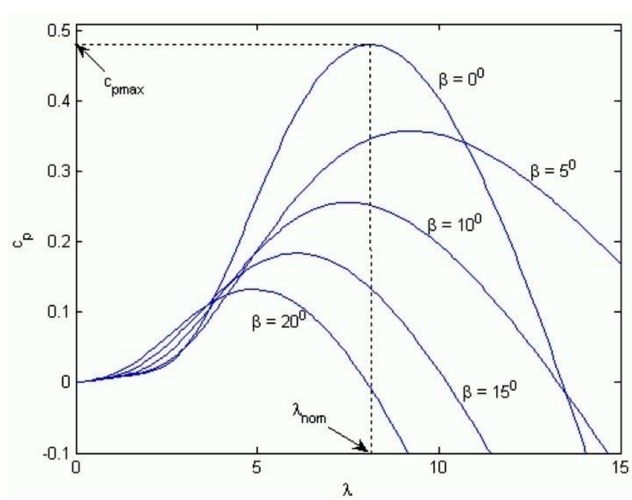
$$C_p(\lambda, \beta) = c_1 \left(\frac{c_2}{\lambda_i - c_3\beta - c_4}\right) e^{-c_5/\lambda_i} + c_6\lambda_i \ldots \ldots \ldots (26)$$

And

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \ldots \ldots \ldots (27)$$

The coefficients $(c_1 c_2 c_3 c_4 c_5 c_6)$ equal to (0.5176, 116, 0.4, 5, 21, 0.0068) respectively, from figure (18) can be seen $c_p - \lambda$ characteristics for different value of pitch angleβ. The maximum value of $c_{p\_max} = 0.48$ when $\beta = 0$ and$\lambda = 8.1$.

Figure (18): $c_p - \lambda$ characteristics for different β [16]



From Simulink model shown in figure (19) the generator output torque has three inputs generator speed w_{r_pu}, pitch angle β in degree and tip speed ration λ in pu, where λ can be found by dividing turbine rotational speed on wind speed.

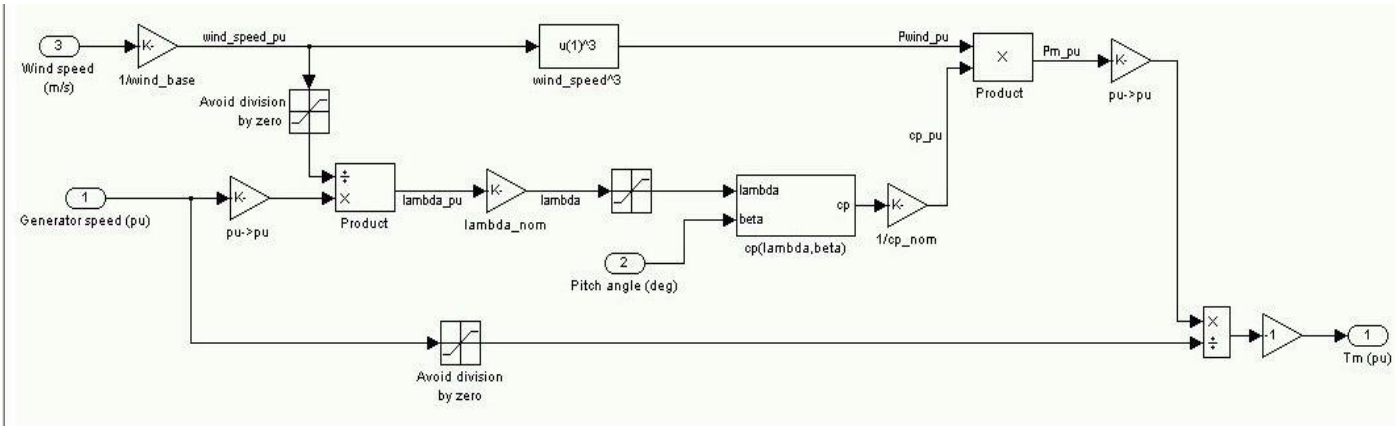
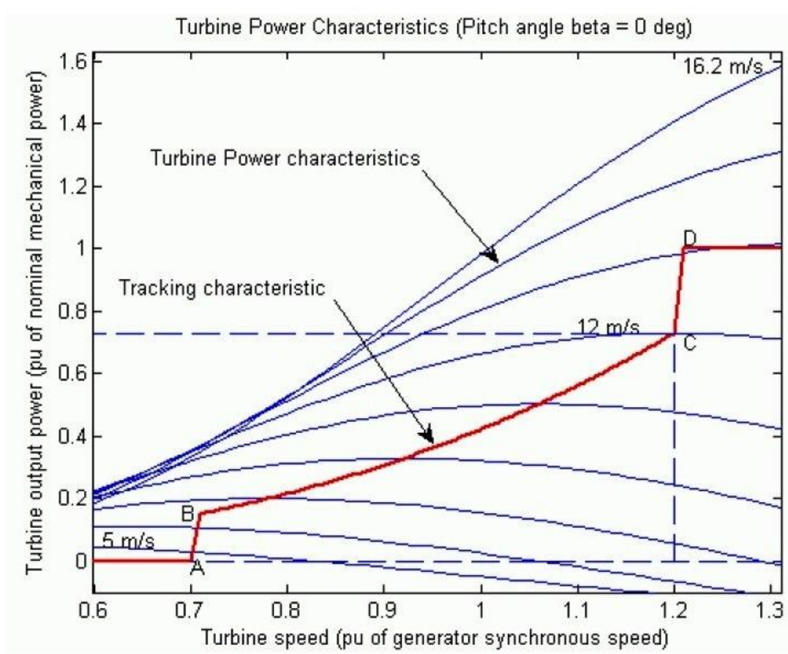


Figure (19): Block diagram of gen. output torque [16]

- **Turbine output power curve vs. turbine speed:**

The characteristic turbine output power with regard to turbine speed shown in figure (20), which is called tracking characteristic. The ABCD represent mechanical power curve of the turbine for different speed. The tracking characteristic is obtained by four point A, B, C and D from zero to maximum rated speed. Between point B and C the tracking characteristic is the spot of maximum power of the turbine.

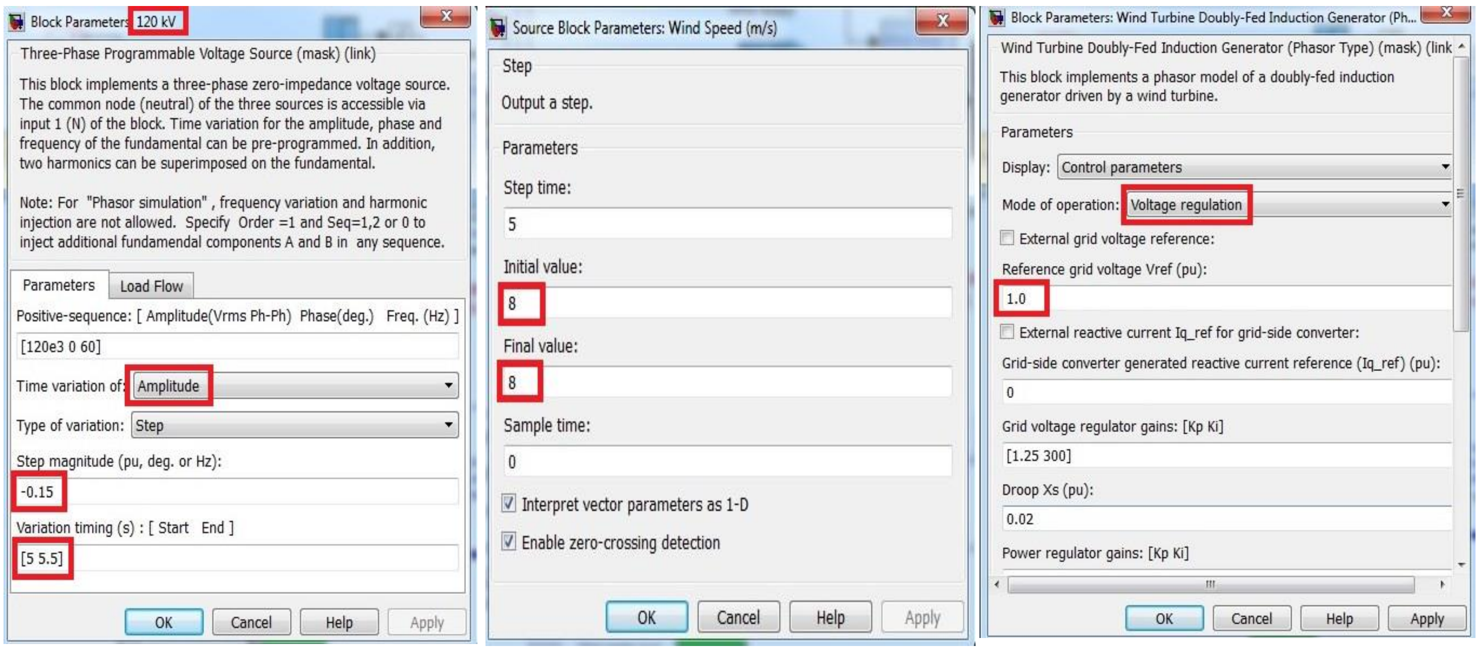
Figure (20): Tracking characteristic of WT [16]



2.2.3 Dynamic response under grid voltage drop:

Case 1:

The Grid voltage is collapsed by -0.15 pu, wind speed is constant at 8 m/s and turbine control mode on "Voltage Regulation", figure [(21) a,b,c].



a

b

c

Figure (21): wind, turbine and grid parameters [16]

The grid voltage dropped by -0.15 pu for 0.5 second, but plant still in normal situation and it doesn't trip because the wind turbine generated 5 MVAR reactive power which support voltage and kept it above threshold 0.9 pu (Under voltage relay), while the plant voltage during voltage drop was 0.93 pu, as shown in figure (22). A disturbance occurred in DC bus capacitor voltage meanwhile drop duration to modify generator output voltage, as well as fluctuation in turbine speed.

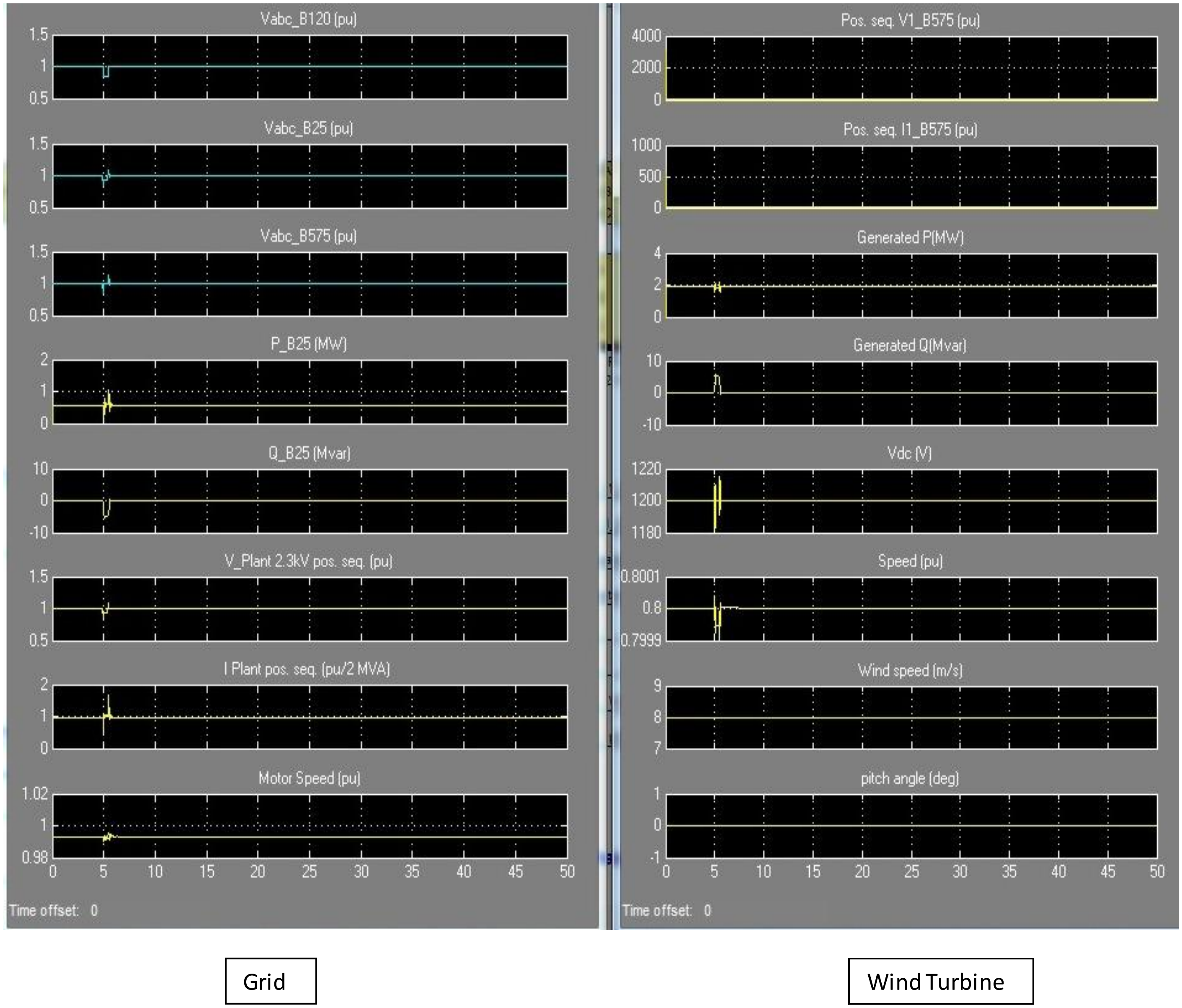
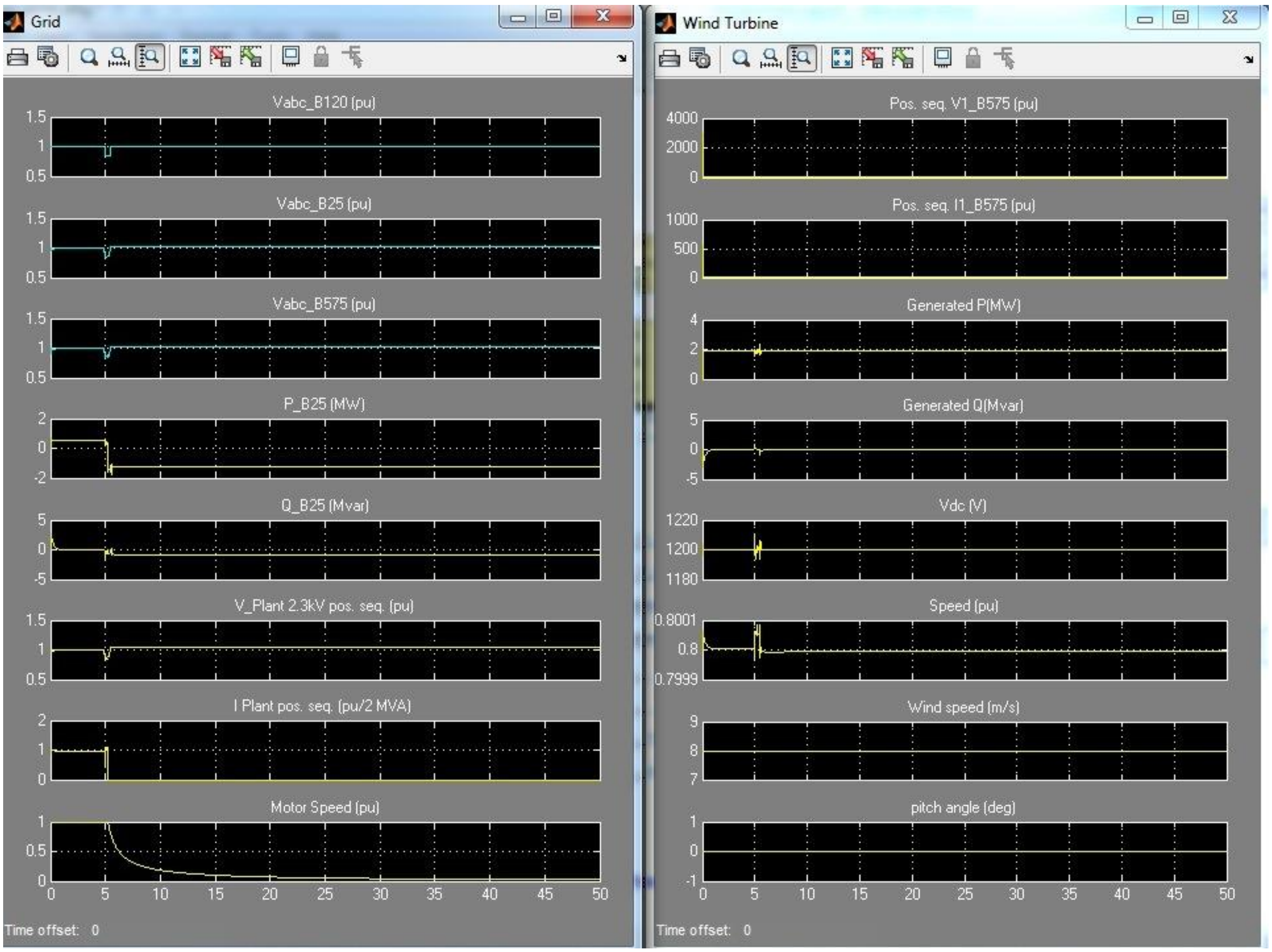


Figure (22): grid and wind turbine outputs [16]

Case 2:

[16] Refer to figure (21 c), the parameters remain the same as mentioned in (case 1) before except mode of operation is changed to "Var Regulation" from figure (23) that shows that wind turbine produce 1.87 MW when t=5s, the voltage falls below threshold value 0.9 pu and at time=5.22 s the protection system became active and send trip command plant circuit breaker to disconnect power line due to under voltage detection. Therefore the plant load current falls to zero and motor speed goes to standstill. In contrast, wind farm still energize the grid with 1.87 MW after plant tripping.



Grid

Wind Turbine

Figure (23): grid and wind turbine outputs [16]

2.2.4 System testing for variable-speed wind power input:

Case 3:

[16] Refer to the figure (24), the initial wind speed is set on 8 m/s, at t=5 s it will gradually increase till it reach 14 m/s. From t= 0 – 5 s generator output active power just over zero, then after 5s became increase gradually with increase rotor speed up to rated power 9MW almost at 15s, over that period rotor speed increased by 0.41 pu, while pitch angle remain constant at zero degree. On the other hand, GSC control the generator reactive power output so as output voltage (Vabc_B575) remain at certain value (1 pu) by producing (-0.68 MVAR capacitive load) figure (25), whereas the wind speed increase the pitch angle increase too to compensate mechanical input power to the turbine up to 0.76 degree, the turbine follow the power curve as it shown in figure (20) to generate optimum power at given speed.

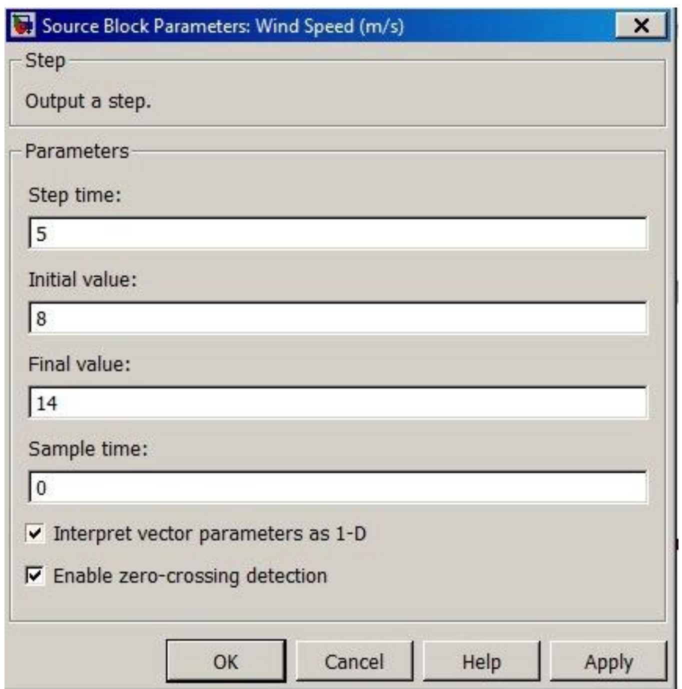
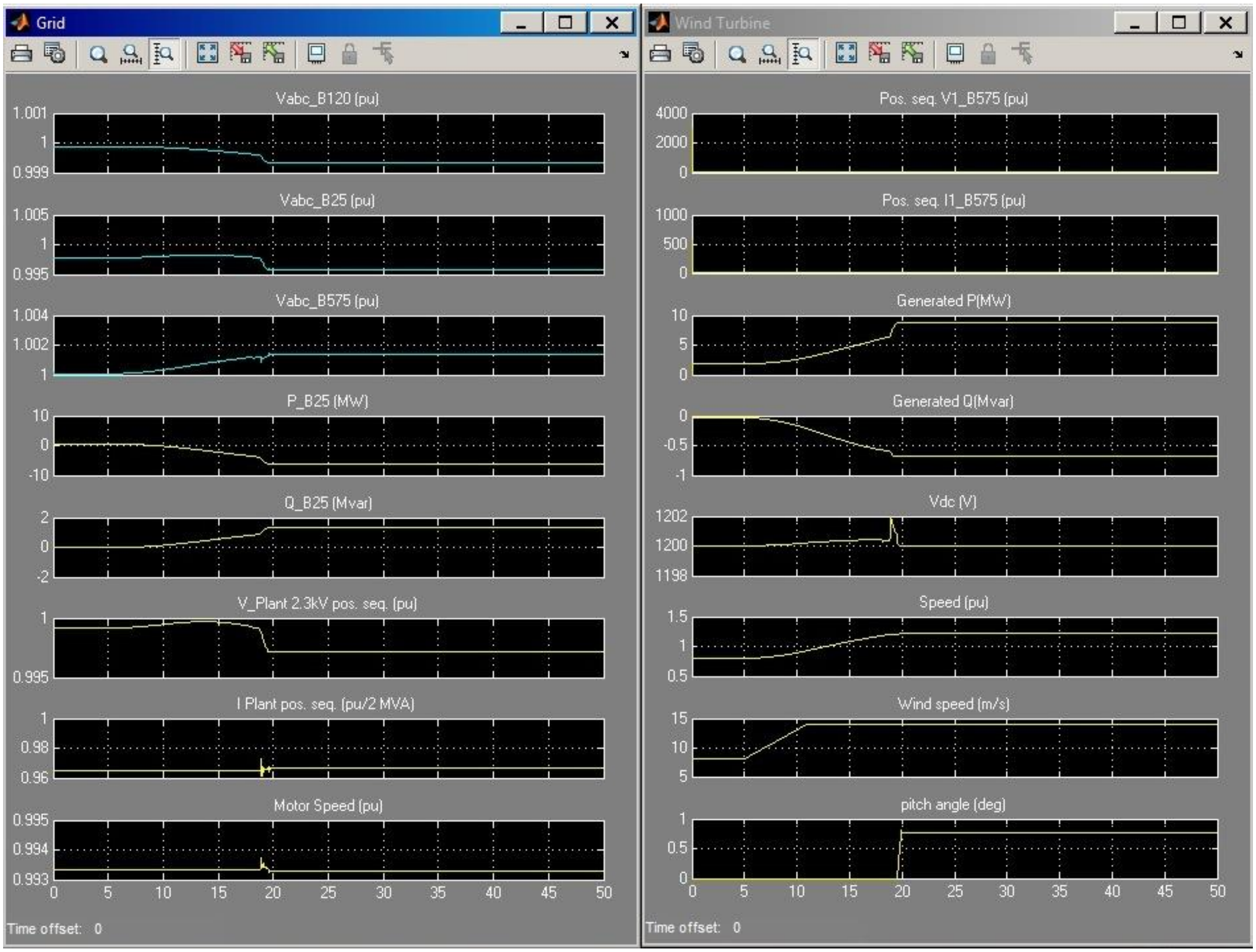


Figure (24): wind speed block [16]



Grid

Wind Turbine

Figure (25): grid and wind turbine outputs [16]

Case 2:

[16] Refer to figure (26), mode of operation changed to “Var regulation” which is mean generator reactive power set to zero. It can be seen that output voltage will increase up to 1.021 pu when wind turbine reach nominal power as shown in figure (27).

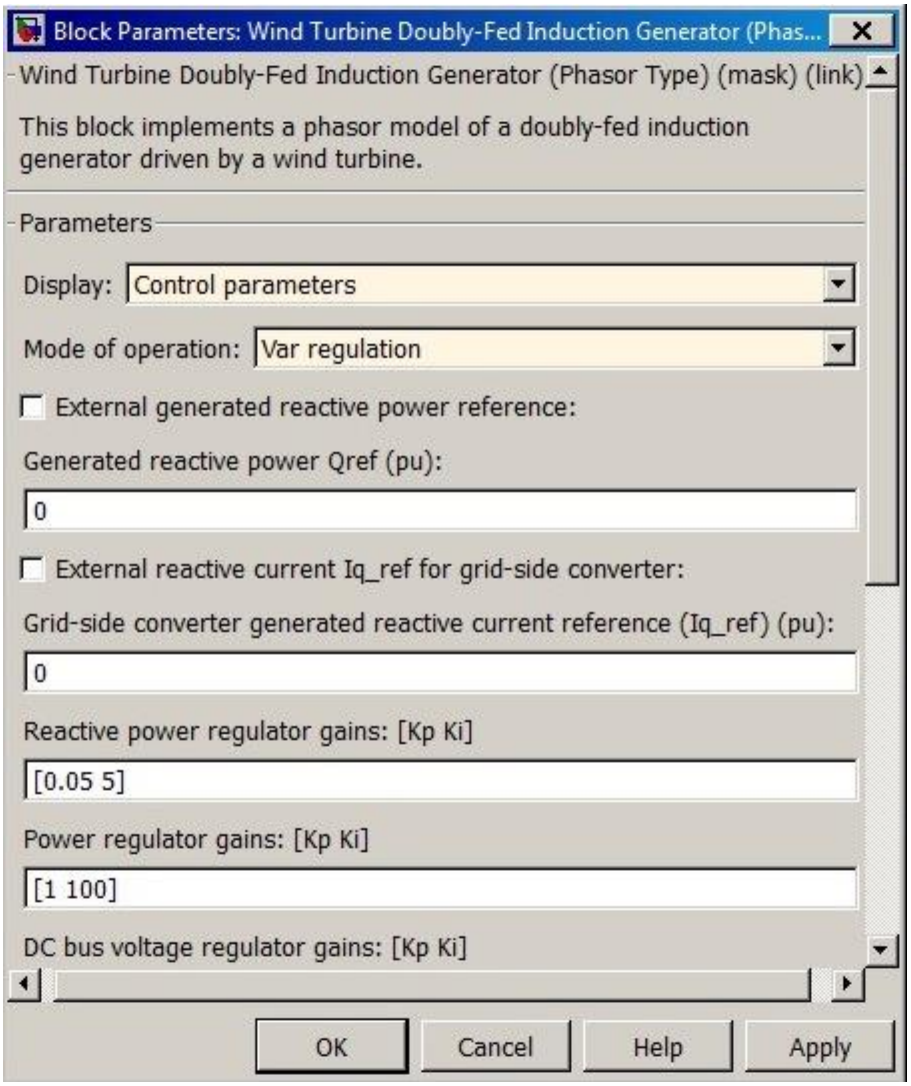
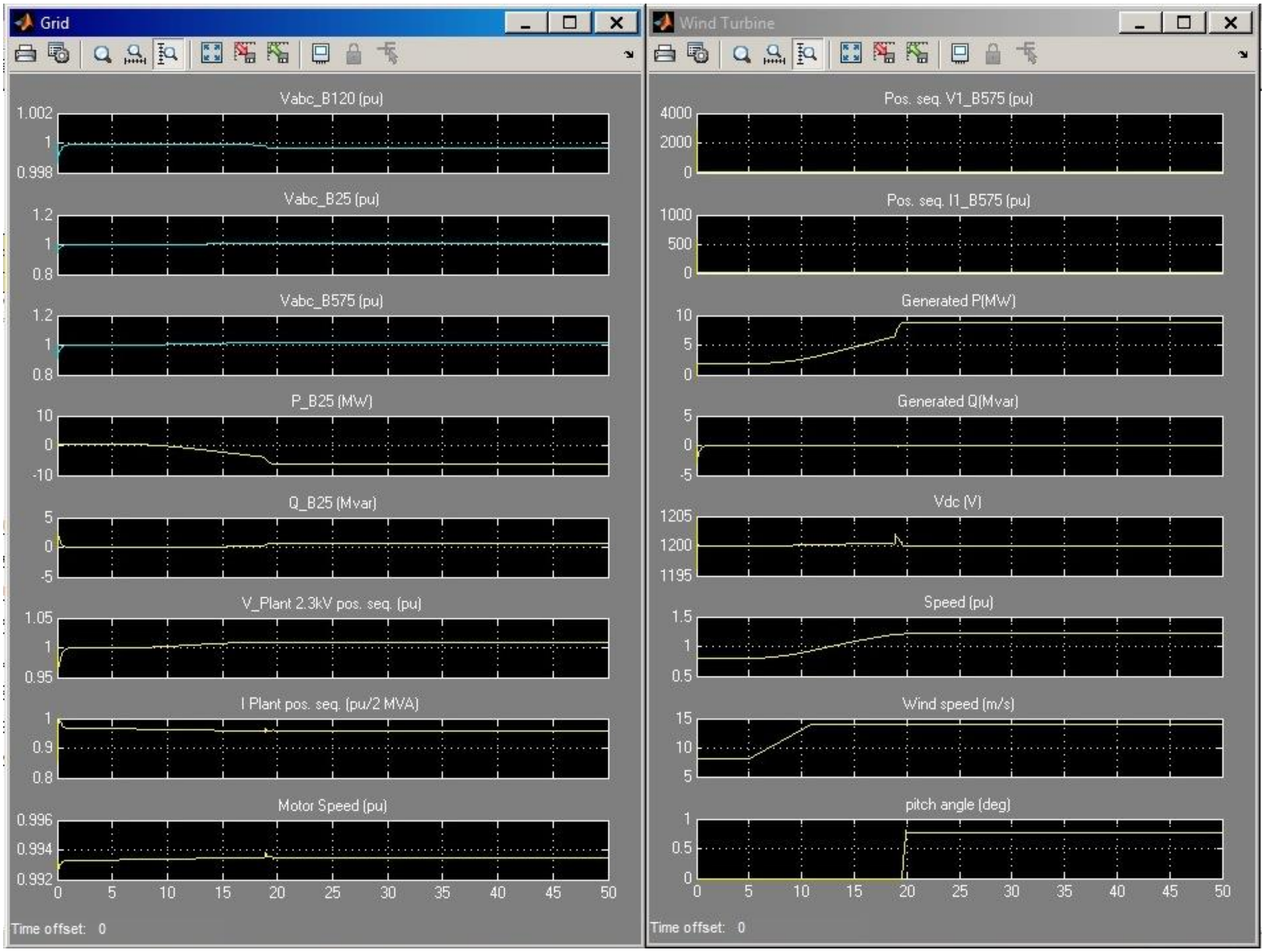


Figure (26): Turbine parameter [16]



Grid

Wind Turbine

Figure (27): grid and wind turbine outputs [16]

Task 3:

3.1 Introduction:

[17] The smart grid technology assists of integrating renewable energy sources to the power systems. The term SMART GRID is defined by the Smart Grid European Technology Platform as " an electricity network that can intelligently integrate the actions of all users connected to it- generators, consumers and those that do both, in order to efficiently deliver sustainable, economic and secure electricity supply" [18]

The main target of a smart grid is to transfer the optimum amount of data and control the load of consumers, distributor sectors and network operation to minimize load demands and costs, conversely increase system efficiency.

The main concept of smart grid is to produce energy by using renewable energy sources according to smart grid environments which lead to minimum emission, lower energy costs, and higher flexibility to shape distributed renewable energy sources.

In this task basic concept of wind power integration into the grid is presented based on different grid codes.

3.2 Integration of Large and Small Scale wind Turbine into the Grid:

3.2.1 Grid Code:

[19] In order to connect wind power turbine into the grid different requirements (Grid Code) should be satisfied from generation side, to maintain the security and stability of the transmission grid. The grid codes may be differs from country to another, while the main aspects of grid codes are:

1. Fault Ride Through.
2. Active Power and frequency control.
3. Reactive power control.

Where, the mentioned grid codes are given for Point of Common Coupling (PCC) which is mostly defined on the high voltage sides on wind farm transformers.

3.2.2 Fault Ride Through:

[19] The wind farm connected to the distribution system (small scale) or transmission system (large scale), should be remain connect and energize system by power continuously during any disturbances for specified period time. The figure (28) shows voltage vs. time characteristics which described fault ride through for different countries. Conventionally, some code required from wind turbine increase reactive power generation during disturbance to provide grid voltage support as synchronous generator in over excited operation.

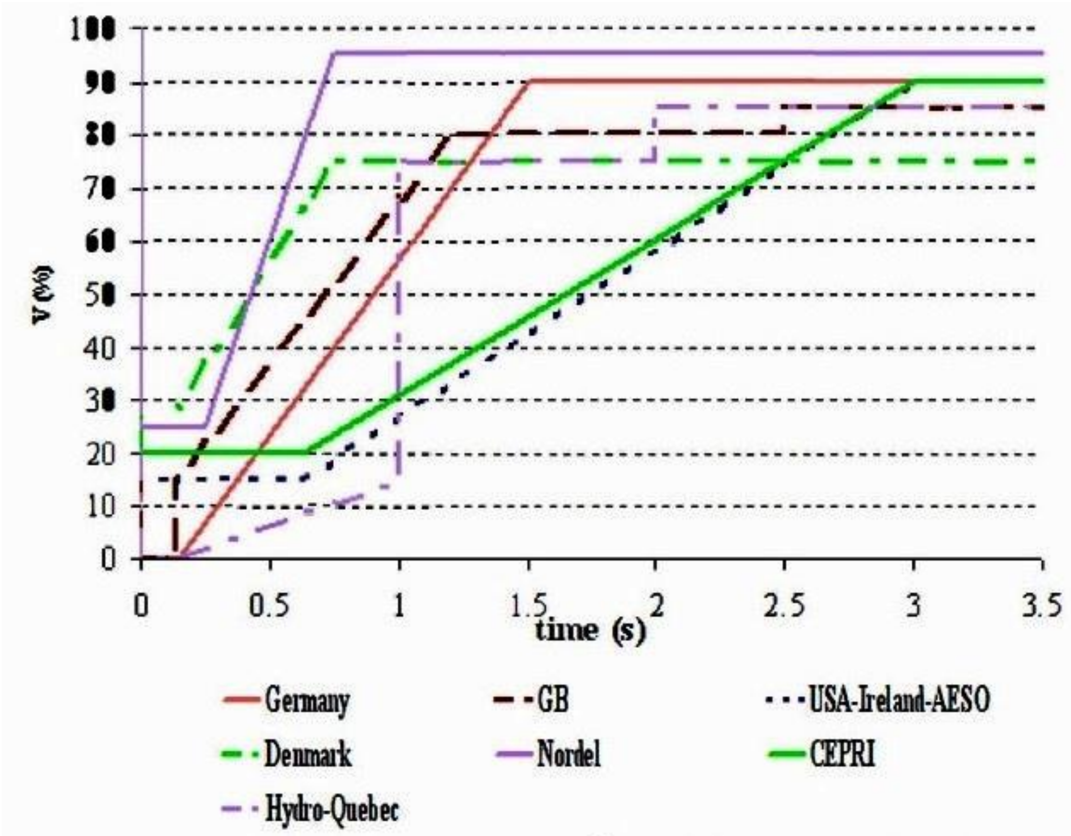


Figure (28): FRT curves for different countries [19]

3.2.3 Active Power and Frequency control:

[19] The grid code require from wind power to operate continuously at system frequency range for example (50 Hz) in addition it should be able of providing frequency response. While, other requirement is output power regulation which force the wind farm to change its output power to certain level by add/disconnect wind turbine or by pitch angle control.

3.2.4 Reactive Power range and voltage control capability:

[19] Other requirement from wind farm is that ability to control reactive power and voltage at PCC, figure (29) shows active and reactive grid code for different countries.

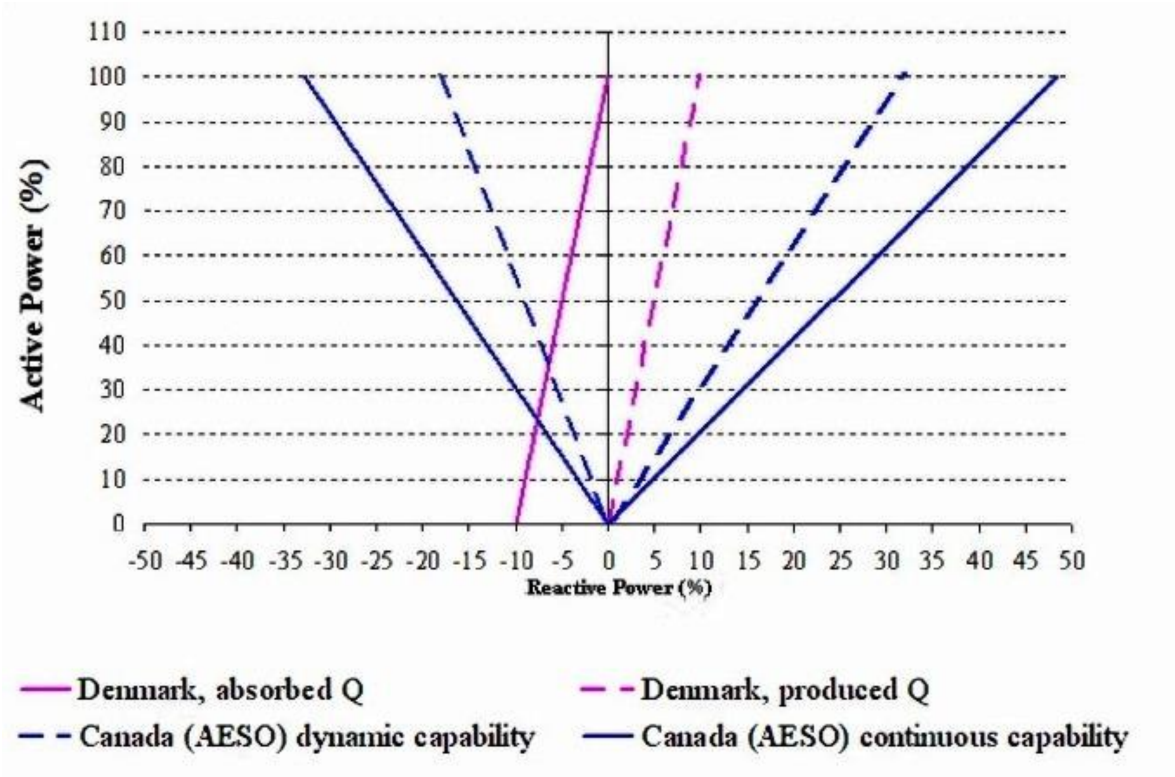


Figure (29): Active-Reactive grid code for different countries [19]

3.2.5 Advanced Wind Energy management System:

[19] To achieve the grid code requirements the advanced technical solutions for massive wind power transmission and grid integration are essential and necessary. Typically, wind energy management system should be able to:

- Prepare advanced wind resource monitoring with control by sophisticated user interface, to enable operator to inject that wind production into the transmission system based on grid configurations.
- Integrate real time environment conditions with wind power production.
- Maintain the stability of transmission line as well as the security.
- Conduct wind scenario simulation.

3.3 Connections:

[19] There are two types of connection for wind power generation with the grid: High-Voltage AC (HVAC) and High-Voltage DC (HVDC). The former is used with small-scale wind power with short connection distance, while latter is used for large wind power over long transmission distance, figure (30) shows typical diagram for large and small generator connection with power system grid and distributed grid respectively.

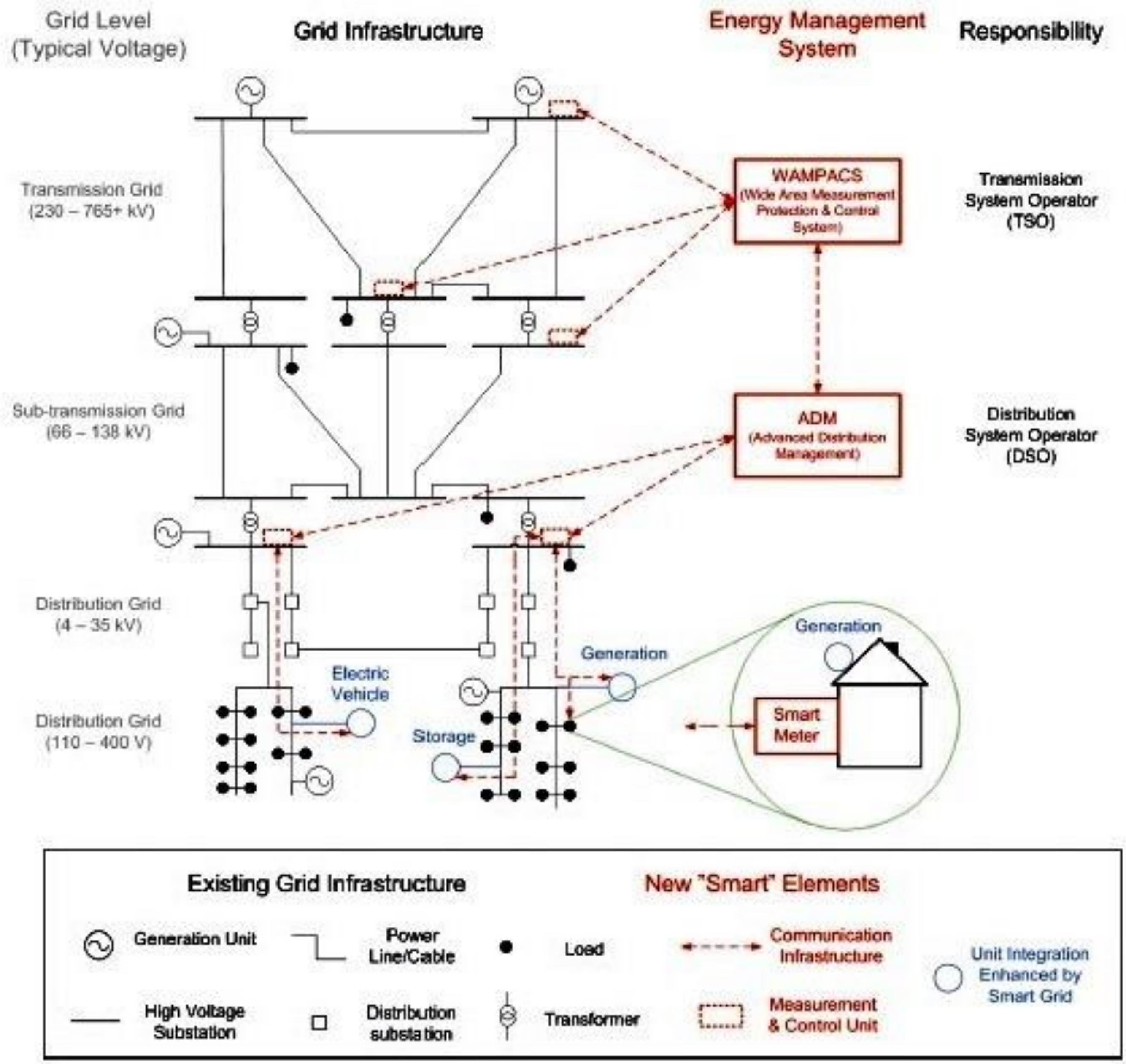


Figure (30): Typical Active power distribution system

3.3.1 AC connection (Small-Scale wind power):

[19] It very useful with small scale wind power and short distance, because it is simple and economic. However, in some situation use to satisfy the connection agreement requirements power electronics based FACTS (Flexible AC Transmission Systems) devices need to install, for instance Static Var compensator (SVC) or Static Synchronous Compensator (STATCOM).

The main action of SVC is to control reactive power or closed-loop AC voltage control by controlling the equivalent shunt impedance. SVC consists of Thyristor Controlled Reactor (TCR) and (TCR) Thyristor Switch Capacitor. While, SATACOM based on VSC (Voltage Control Convertor) equipped with IGBT coupled to a DC capacitor. The operation concept is controlling the AC voltage amplitude generated which is to control generator reactive current.

3.3.2 DC connection (Large-Scale wind power):

[19] The HVDC system is preferred for connecting large wind farm particularly for long distance, due to some advantages, like:

- Defined of power flow and easy controllable (V & I).
- AC sending and receiving end separated by DC system lead to isolate fault occur on the transmission line.
- No effect of cable charging on DC transmission line.
- Low losses transmission line comparing with AC systems.

There are two main technologies solutions used to connect wind farm with the grid based on HVDC transmission concept; Voltage Source Convertor (SVC) and Line Commutated Convertor (LCC).

3.4 Smart Grid:

[20] Consumers in traditional power system are almost “Passive” not contribute to the energy demand in power system. Distributed systems have not been historically established to combine huge number of energy resources. Moreover power generation like wind energy is often in form of intermittent power supply, therefore it required particular management especially when it is production rate become massive. At the end of development of distribution system the end user may be become “Active” when it represent all the possibility of “Load control”, “Local generation” and “energy-storage” figure (30) illustrated contribution of consumer to the system, while figure (31) shows SCADA control and communication for over system .

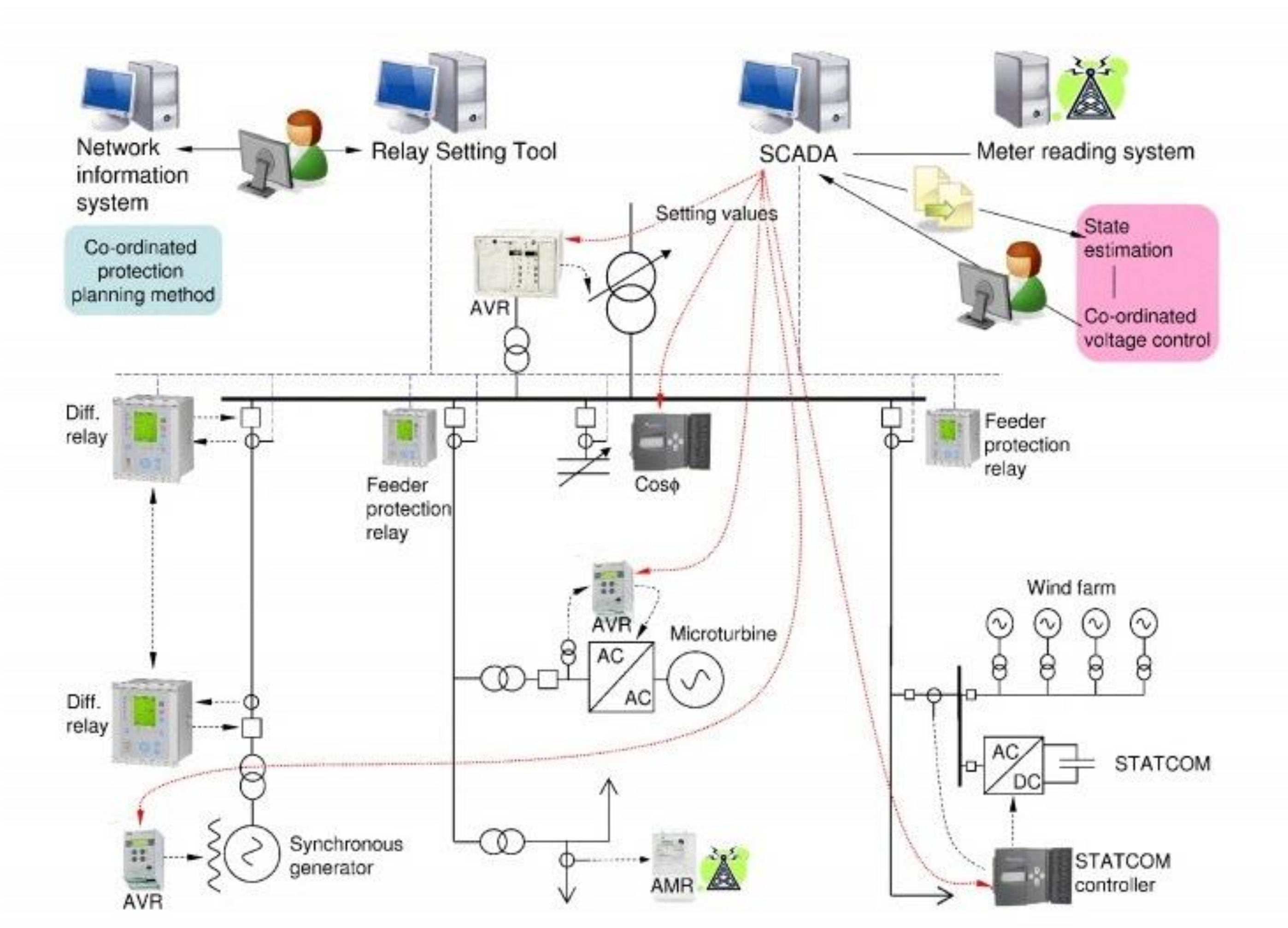


Figure (31): SCADA monitoring and control system

Appendix:

1. Lecture on module (Energy conversion, renewable energy and smart grid) 2013, University of Liverpool, UK.
2. http://www.emersonnetworkpower.com, keyword (Liebert® NX, 30-60 kW UPS)
3. Training Course at Emerson Power Network, Shenzhen, China 2009.
4. http://www.endurancewindpower.co.uk/e3120.html
5. Book "Wind Energy Conversion Systems", Technology and Trends, S.M.Muyeen, 2012.
6. Book "Uninterruptible Power Supply and Active Filters" Ali Emadi, Addolhosein Nasiri, Stoyan B. Bekiarov, 2005.
7. Book "Wind Power Plants" Fundamentals, Design, Construction and Operation. Robert Gash and Jochen Twele, Second Edition, 2012.
8. Book "DOUBLY FED INDUCTION MACHINE" Modeling and control for wind energy generation, by Gonzalo Abed, 2011.
9. Scottish Natural Heritage "siting and Designing wind farms in the landscape", version 1, December 2009.
10. U.S Department of energy/ Energy efficiency and renewable energy/ wind program (www1.eere.energy.gov).
11. The European wind energy association (www.ewea.org).
12. Mikel de P. G., Andreas S., Oriol G. B., " Modeling and control of pitch-controlled variable-speed wind turbine by a DFIG with frequency control support in PSS/E", 2012 IEEE.
13. Wei Qiao, "Dynamic Modeling and Control of Doubly Fed Induction Generators Driven by Wind Turbines", 2009 IEEE.
14. Wei Qiao, Wei Zhou, Jose M. Aller, and Ronald G. Harley "Wind speed Estimation Based Sensorless Output Maximization Control for a Wind Turbine Driving a DFIG", 2008 IEEE.
15. Seyed Zeinolabedin Moussavi, Reza Atapour, "Dynamic Modellling and Control of Doubly Fed Induction Generator Variable Speed Wind Turbine", Page 78-86.
16. Matlab Simulink Help.
17. Carlo C., Geev M., Antonio P., "An Overview on the Smart Grid Concept" 2010 IEEE.
18. European Technology Platform Smart Grids, "Strategic Deployment document for European's Electricity Network of the future", Draft for 3rd General Assembly, Belgium, 8-9 October 2008.
19. Meiqi Yao, Liangzhong Yao, "Integration of Large Scale Wind Turbine Farm into Electrical Grids", 2010, China International Conference on Electricity Distribution.
20. I. Sehgal, Subir Sen, R. Kumar, "Smart Grid Pilot Project in India- Case Study".