Overview of Different Wind power technology Connected to Grid & Modelling of wind Turbine

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***Abstract*-Nowadays, the renewable energies are the only sources that can replace fossil combustibles. These new sources are mainly clean, safe and quite cheep for the user. Among them, the wind power has driven a considerable attention these last fifteen years. Recently, variable-speed Permanent Magnet Synchronous Generator (PMSG) based Wind Energy Conversion Systems (WECS) are becoming more attractive in comparison to fixed-speed WECS. In the variable-speed generation system, the wind turbine can be operated at maximum power operating points over a wide speed range by adjusting the shaft speed optimally. Moreover, the use of Permanent Magnet reduces size and weight of overall WECS. As there is no need of field winding and its excitation system, the absence of rotor winding also reduces heat dissipation in the rotor and hence improves the overall efficiency. The Power Electronics plays an important role in the reliable operation of modern wind energy Conversion system (WECS).This paper discusses different power control topology connected to grid. Different wind turbine characteristics are obtain in MATLAB/SIMULINK & PSIM 9 software environment.**

***Keywords*-Wind Energy Conversion System, Wind turbine, wind turbine generator, power electronic converter, Grid-connection, Harmonics, Flicker, voltage-dip, Fault Ride through Capability, voltage dip. Point of common coupling.**

I DIFFERENT TYPE OF WIND TURBINE GENERATORS

A. Wind Turbine Generators in the Present Market.

Classification of WTGs can according to its operating speed and the size of the associated converts as below:
1 VSWT (Variable Speed Wind Turbine)
2 FSWT (Fixed Speed Wind Turbine
3 FSFC (full scale frequency converter)
4 PSFC (partial scale frequency converter)

FSWT including SCIG (Squirrel-Cage Induction Generator), led the market until 2003 when Double Fed Induction Generator), which is the main concept of VSWT with PSFC, overtook and has been leading WTG concept with 85% of the market share reported in 2010[4].Perment Magnet Synchronous Generator) has been drawing more attention and increasing its market share in the past recent year due to the Benefits of PMSG and drawback of WRSG. There are two advanced concepts of the WTG [2].

1 BDFIG (Brushless Double Fed Induction Generator).

It is the most popular VSWT with PSFC types in the current research are of DFIG. This wind Turbine are currently most popular in current market, along with the it's brushless aspect. Figure 1, shows two cascades connection are connected. One is for the control Aspect and another is generation [3].

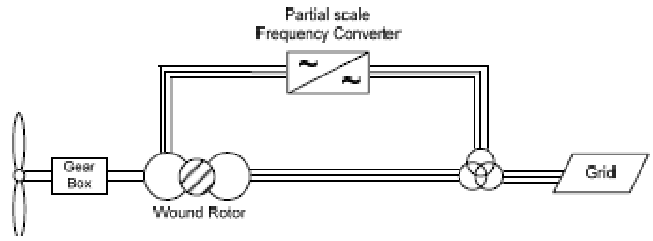

Figure 1.The conceptual diagram of BDFIG [3].

2 BDFRG (Brushless Doubly Fed Reluctance Generator).

This Machine is two-cascaded-stator concept of VSWT with PSFC type in area of research. Figure shows one different design compared with BDFIG is its reluctance rotor, which is usually an iron rotor without copper winding which are the lower cost than wound rotor or Perment Magnet rotor.

Higher efficiency, easier construction and control including power factor control capability as well as the cost reduction And higher reliability including of failsafe operation due to Reculatance rotor.

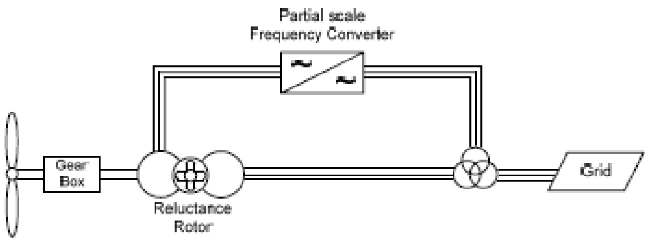

Figure 2 The conceptual diagram of BDFRG [3].

Drawback of BDFRG exist such as complexity of rotor design, its larger machine size due to a lower torque-volume ratio. Also is used Aircraft industry with highly reliable construction.

B. Comparison of Different Wind Turbine Generators

1) SCIG (FSWT)

Advantage
- Robust operation
- Lower cost
- Easier to design, control and construction

Disadvantage
- Higher losses on gear
- Low energy yield
- High mechanical stress
- No active/reactive power controllability.

2) PMSG (VSWT-FSPC)

Advantage
- Low mechanical stress
- Highest energy yield

- No copper loss on rotor
- Absence of brush/slipring
- Higher active/reactive power

Disadvantage

- High cost of PM Material
- Demagnetisation of PM
- Complex construction process
- Higher cost on PEC
- Higher losses on PEC
- Large size

3) WRSG (VSWT-FSPC)

Advantage

- High energy yield
- Higher Active/reactive power controllability
- Absence of brush/slipring
- Low mechanical stress

Disadvantage

- Large size
- Higher losses on PEC
- Higher cost on PEC
- Higher cost of copper winding

4) DFIG (VSWT-PSPC)

Advantage

- High energy yield
- High active/reactive power controllability
- Low cost on PEC
- Lower losses by PEC
- Less Mechanical stress
- Compact size

Disadvantage

- High losses on gear
- Existence of brush/slipring

5) BDFIG (VSTW-PSPC)

Advantage

- High energy yield
- High active/reactive power controllability
- Low cost on PEC
- Lower losses by PEC
- Less Mechanical stress
- Compact size
- Absence of Brush/slipring

Disadvantage

- Early technical stage
- Complex controllability, design and assembly
- Higher losses on Gear

6) BDFRG (VSTW-PSPC)

Advantage

- High energy yield
- High active/reactive power controllability
- Low cost on PEC
- Lower losses by PEC
- Less Mechanical stress
- Absence of Brush/slipring
- No copper loss on rotor

Disadvantage

- Early technical stage
- Complex controllability and rotor design
- High loose on Gear
- Larger size than DFIG

II POWER ELECTRONIC CONVERTERS

A) Topology of Power Electronic Converters

As the Requirement of Power Electronics Converter connected to grid so requirement of inverter may play important role in grid connected [13].

1) PWM (Back-to-back) Converters

This Topology also called two-level PWM converter. It consist of two PWM-VSI (Voltage source inverters)and a Capacitor in between. Here DC-link capacitor is provided separated out the two converters.

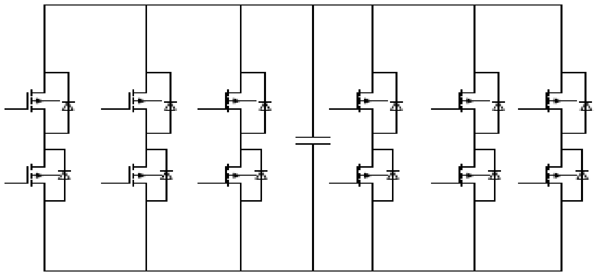

Figure 3 PWM (Back-to-Back) converter [14].

Here DC link capacitor main drawback of PWM converter because it decrease the overall lifetime of system. There are other disadvantage including switching loss, high frequency Harmonics, which result in EMI-filter.

1) Multilevel Converters

Compared two level PWM converter, multilevel (ML) Have three or more voltage levels, which result in lower harmonic distortion (THD) than back-to-back PWM converter. It offer higher voltage and power capability, which advocates the trends of that switching loss are smaller in ML converter than two-level PWM converter by 25%.

Disadvantage

1) Voltage imbalance caused by DC link capacitor.
2) Design of ML converter is uneven current stress on the
3) Switches due to its circuit design and characterises more Number of switches and control is complex.

1) Matrix Converters

Matrix converter is Different from the MLP and PWM converter. It is single stage AC-AC converter. It can directly convert an ac power supply of fixed voltage into an ac voltage of variable amplitude and frequency. The Matrix converter can contribute to the realization of low volume, sinusoidal input current, and bidirectional power flow. [11-12].

Matrix converter consists of an array of bidirectional switch Cell functioning as the main power circuit element. Each switch cell is composed of two forced commutated switches in an Anti-parallel configuration. Basic topology of this type converter is shown on fig 4.

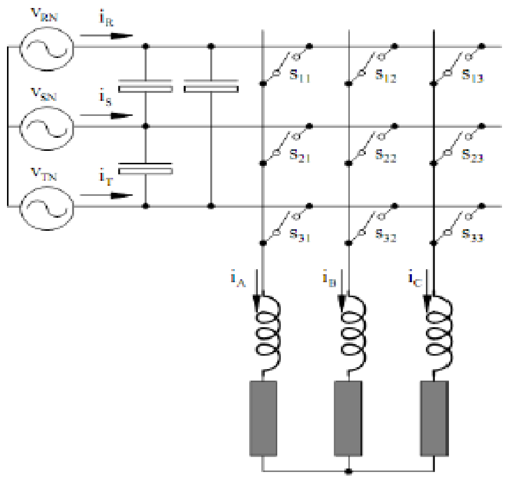

Figure 4 Basic matrix converters [12].

Advantage of Matrix Converters
1) No dc link capacitor or inductor
2) Sinusoidal input and output current
3) Possible power factor control
4) Four-quadrant operation
5) Compact and simple design
6) Regeneration capability

Disadvantage of Matrix Converters
1) Reduced maximum voltage transfer ration (0.866).
2) Many bi-directional switches needed.
3) Increased complexity of control.
4) Sensitivity to input voltage disturbances
5) Complex commutation method.
6) Topologies of Matrix Converters

1) Single Phase Matrix Converter.

It consists of a matrix of input and output lines with four bidirectional switches connecting the single-phase input to the single-phase output at the intersections.Fig.5 shows single phase matrix converter.

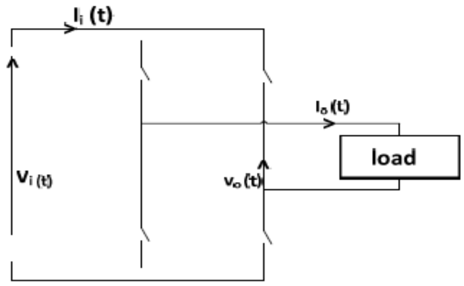

Figure 5 Representation of a single phase matrix converter [12].

2) Three Phase to Single phase matrix converter.

Figure 6 shows 3-phase to 1-phase matrix converter. The converter is composed of three bidirectional switch S1, S2, S3.Each switch connected the output line to an input phase.

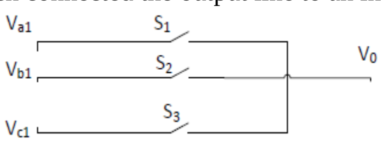

Figure 6 Representation of 3-phase to 1-phase matrix converter [12]

3) Three phase to Three Phase matrix Converter.

The structure of a three-phase to three Matrix converters is shown in fig.7.It consists of nine bidirectional switches whose operation are coordinated by a number of switching functions.

The Matrix converter can represent a symmetric electrical system, if a proper switching strategy is used.

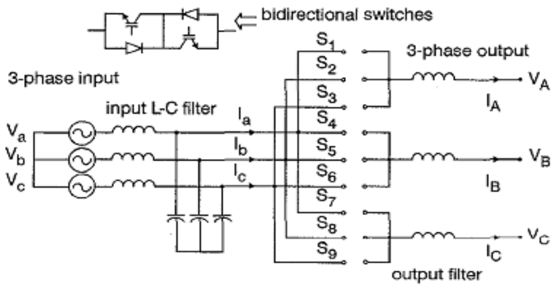

Figure 7 Representation of a 3-phase to 3-phase matrix converter. [12]

III GENERAL REQUIREMENT OF GRID INTERCONNECTION

Net metering programs have substantially improved the economy of small distributed resources (DR), including wind power. Although standards exist for large power plant connected to electric power system, they fail to address special requirement for distributed resources. To provide guidelines for all stakeholders including utilities. Independent power producers, users and equipment manufacturers, efforts are being made, both in Canada and internationally, to develop interconnection standards.

Supported by Natural Resource Canada and Industry Canada, Electro-Federation Canada is developing Canadian guidelines for connecting small distributed resources to grids.

A. General Requirements
1. Voltage Regulation: A DR shall not cause the voltage at the Point of Common Coupling(PCC)to go outside of range A specified by standard ANSI C84.1(or CSA CAN3-C235-83).For a 120/240V system, this specifies a maximum voltage of 126/252V and a minimum voltage of 114/226V[10].
2. Synchronization: When synchronizing, a DR shall not cause more than +/-5% of voltage fluctuation at the PCC.
3. Monitoring: A DR of 250 kW or large small have provision for monitoring connection status and real and reactive power output at the DR connection.
4. Isolation Device: A readily accessible, lockable, visible-break isolation device shall be located the DR and EPS.

B. Safety and protection Requirements
1. Frequency Disturbances: A DR shall cease to energize the EPS if the frequency is outside the range 59.3-60.5 Hz.
2. Voltage disturbances: At abnormal voltages, a DR shall cease to energize the EPS within the specified clearing time.
3. Loss of Synchronism: A DR of 250 KW or larger shall have loss of synchronism protection function.
4. Reconnection: A DR may reconnect to the power system 5 min.after the EPS voltage and Frequency return to Normal.
5. Unintentional Islanding: A DR shall cease to energize the EPS within 2sec.of the formation of an island.

C. Power quality Requirements

1) Harmonics: The total demand distortion of a DR, which is defined as the total rms harmonic current divided by the Maximum demand load current, shall be less than 5%.Each individual harmonics shall be less than the specified level[9].

2) Flicker: A DR shall not create objectionable flicker for other customers on the area EPS [10].
3) DC Current Injection: A DR shall have a dc current injection of less than 0.5% of its rated output current [9].

IV PROBLEMS RELATED WITH GRID CONNECTIONS

1. Poor grid stability - Economics exploitation of wind energy, a reliable grid is as important as availability of strong winds. The loss of generation for want of stable grid can be 10% to 20% and this deficiency may perhaps be the main reasons for low actual energy output of WEGs compared to the predicated output in known windy areas with adequate wind data [14].
2. Low-frequency operation - Low frequency operation affected the output of WEGs in two ways. Many WEGs do not get cut-in, when the frequency is less than 48Hz (for standard frequency of 50Hz) through wind conditions are favourable, with loss in output. This deficiency apart, the output of WEGs at low frequency operation is considerably reduced, due to reduced speed of the rotor. The loss in output could be about 5 to 10% on the account of low frequency operation.
3. Power quality - Flucations in wind power may have direct impact on the quality of power supply. As a result large voltage Flucations may result in voltage variations outside the regulation limits, as well as flicker and other power quality standards [10].
4. Short circuit - It is required to determine the impact of additional generation sources to the shot circuit current rating of existing electrical equipment on the network.
5. Power flow - It is to be ensured that the interconnecting transmission or distribution lines will not overloaded. This type of data required when additional generation will not overloaded the lines and other electrical equipment. Both active and reactive power requirements should be investigated.

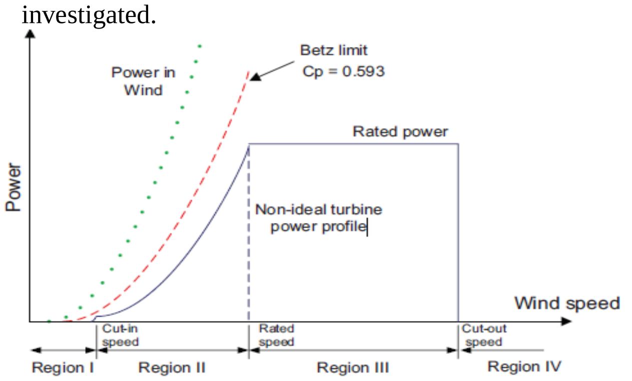

Figure 8. Power profile for a wind turbine [5].

- Cut-in wind speed: the speed at which the wind turbine starts to operate.
- Cut-out wind speed: is the wind speed where the wind turbine stops production and turns out of the main wind direction.
- Tip Speed Ratio: TSR is the speed of the blade at its tip divided by the speed of the wind.
- The design wind speed: when the windmill reaches its maximum efficiency.
- The rated wind speed: when the machine reaches its maximum output power.
- The furling wind speed: when the machine furls to prevent damage at high wind speeds. [2-7].

V MATHEMATICAL MODEL OF WIND TURBINE & SIMULATION

a) Principle of Wind Turbine:

There are two primary physical principles by which energy can be extracted from the wind; these are through the creation of either drag or lift force (or through a combination of the two). The difference between drag and lift is illustrated by the difference between using a spinnaker sail, in which fills like a parachute and pulls a sailing boat with the wind, and a Bermuda rig, the familiar triangular sail which deflects with wind and allows a sailing boat to travel across the wind or slightly into the wind. Drag forces provide the most obvious means of propulsion, these being the forces felt by a person (or object) exposed to the wind. Lift forces are the most efficient means of propulsion but being more subtle than drag forces are not so well understood.

$$P = \frac{1}{2}\rho C_p A V^3 \qquad (1)$$

$$T_{turbine} = \frac{1}{2}\rho A\, C_p\, \frac{V}{\gamma} \qquad (2)$$

Where,
P=Power developed by Wind turbine in (Watt)
Cp=The power co-efficient
ρ=Air density=1.225 kg/m^3
A=Area of wind turbine blades (m^2)
V=Velocity of Wind (m/s)
T=Output torque (N.m)
λ = Tip Speed Ratio.

b) Turbine Characteristic's Equation & Descriptions

The Mechanical power captured from the wind and the mechanical torque developed by the turbine shaft can be calculated using the well-known aerodynamic Equations are,

$$Pm = \frac{1}{2} * A * \rho * V^3 * Cp(\lambda, \beta) \qquad (3)$$

$$Tm = \frac{Pm}{wm} = \frac{1}{2} * A * \rho * V^3 * Cp(\lambda, \beta) * \frac{R}{\lambda} \qquad (4)$$

Where,
Tm = Mechanical torque (N.m)
Pm= Mechanical power (w)
A = Swept area by the turbine rotor (m^2)
R = Turbine rotor radius (m)
ρ = Air density (kg/m^3)
V = Wind speed (m/s)
C_p = Power coefficient (or performance coefficient)
λ = Tip speed ratio (ω*m*.r/v)
w_m = Angular speed of the wind turbine (rad/s)
β° = Blade pitch angle (degree)

c) Relationship Between tip speed ratio and power co-efficient at different β°

The power coefficient (*Cp*) indicates how efficiently the conversion of wind power to rotational mechanical power is performed by the wind turbine. The Betz limit is the maximum theoretic value reached by the power coefficient which is 0.59 for three blades horizontal axis wind turbine used to model the dynamics of the *Cp*. The values of C1–C9 presented in Table

1 were suggested by Slower to represent the aerodynamics of modern wind turbines,

$$C_p(\lambda,\beta) = C_1 * (\frac{C2}{\lambda i} - C3 * \beta - C4 * \beta^{C5} - C6) * e^{-C7/\lambda i} \quad (5)$$

$$\lambda i = \frac{1}{\frac{1}{\lambda + C8 * \beta} - \frac{C9}{\beta^3 + 1}} \quad (6)$$

Table 1 Optimized values of Cp curve equations presented. [8]

C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
0.73	151	0.58	0.002	2.14	13.2	18.4	-0.02	-0.003

At lower wind speed, the pitch angle is set to a null value, because, the maximum power co-efficient is obtained for this angle. Pitch angle control operates only when the value for wind speed is greater than the nominal wind speed. The *Cp* curves were calculated for different tip speed ratio (λ) and different blade pitch angle (β˚). For better visualization, they are shown in Figure 9.

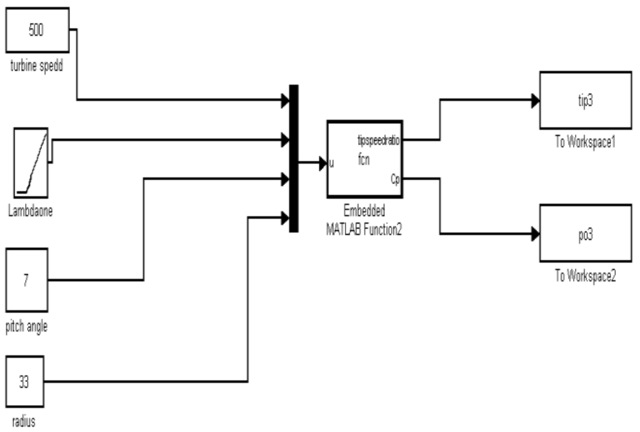

Figure 9 Matlab/Simulink Relationships between power & Wind speed at different β.

As the velocity increase, tip speed ratio decrease and power co-efficient must increase but here as velocity starts form zero tip speed ratio starts from zero tip speed ratio starts from its max so to obtain the range of graph from tip speed vs. Cp at different β.

>>plot(tip1,po1,tip2,po2,tip3,po3,tip4,po4,tip5,po5)

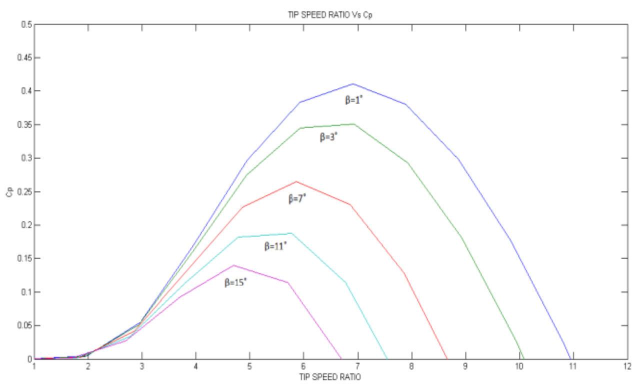

Figure 10 Graph between tip speed ratio Vs power coefficient at different β°

d) Relationship Between wind speed vs power & power coefficient

Power co-efficient Cp is dependent on the ratio λ, where λ tip speed ratio (TSR) is an important factor in wind turbine design. TSR refers to the ratio between the wind speed and the speed of the tips of the wind turbine blades.

TSR (λ) = Tip Speed of Blades (Wr) / Wind Speed (Vw)

The Ramp block generates a signal that starts at a specified time and value and changes by a specified rate. The ramp block Slope, Start time, and Initial output parameters determine the characteristics of the output signal. Here air density is constant take as 1.225 kg/.Air density has a significant effect on wind turbine performance. The power available in the wind is directly proportional to air density. As air density is increase the available power also increases. The turbine radius is taken as constant is 26.45m its square multiply with gain (pi=3.141) gives swept area.

Wind speed, power coefficient ,air density and radius all inputs gives to the Product block, performs multiplication of all inputs and then multiply with gain ,gives the power output in the scope. Turbine radius, swept area, and air density are taken constant from the Enercon E-53 Wind Turbine, rated power 800 kW. A wind turbine captures energy from moving air and converts it into electricity. The captured energy is affected by factors such as air density, turbine swept area, air velocity and power coefficient.A MATLAB/Simulink model fig 11 is developed to show how these factors affect the generated power from wind turbine.

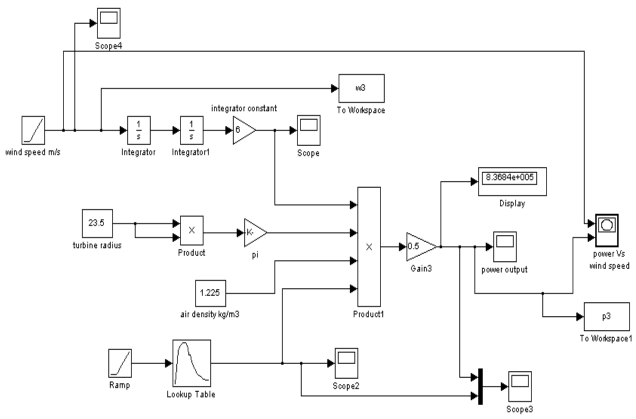

Figure 11 Matlab/Simulink model

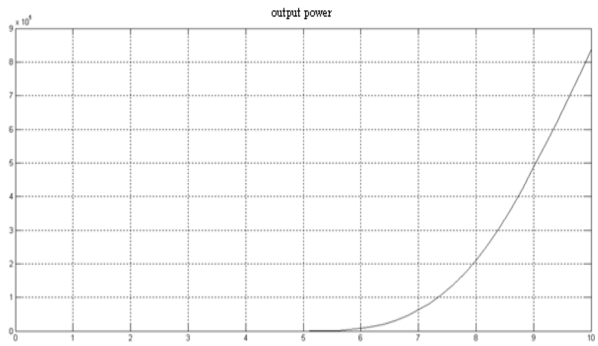

Figure 12 output of Torque

The fig.12 shows the relationship between Cp, wind speed and power. Based on the fluid mechanics we observe that the max value of Cp is 0.593 referred to as Betz limit. Cp is kept at maximum as long as the power or rotor speed is below its rated value. Wind speed change with change in power and power co-efficient, wind speed increase with increase in power co-efficient then Cp is decrease at Betz limit of 0.593.In power increase with increase wind speed after some time power reach its maximum value this point is called cut out speed then its constant, power co-efficient, and wind speed is varies.

Table 2 Relation of wind speed between power and power co-efficient [9]

Wind(m/s)	Power(kw)	Power coeffiecnt(Cp)
1	0.0	0.00
2	2.0	0.19
3	14.0	0.39
4	38.0	0.44
5	77.0	0.46
6	141.0	0.48
7	228.0	0.49
8	336.0	0.49
9	480.0	0.49
10	645.0	0.48
11	744.0	0.42
12	780.0	0.34
13	810.0	0.27
14	810.0	0.22
15	810.0	0.18
16	810.0	0.15
17	810.0	0.12
18	810.0	0.10
19	810.0	0.09
20	810.0	0.08
21	810.0	0.06
22	810.0	0.06

e) Basic Concepts and Wind Turbine Modelling.

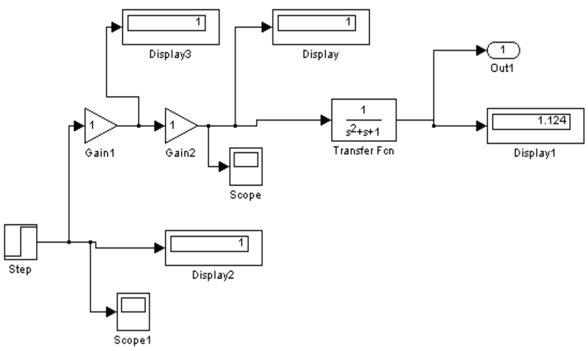

Figure 13 Mathematical Model of wind Turbine.

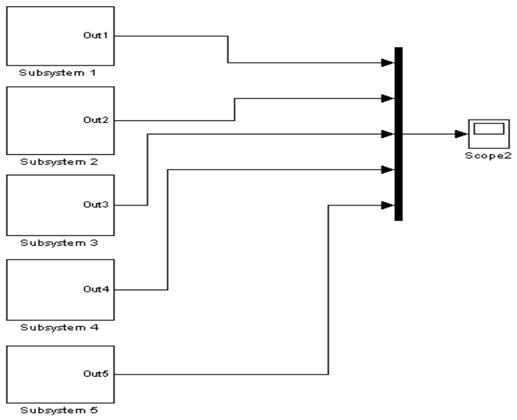

Figure 14 Mathematical Model of wind Turbine with Different wind speed

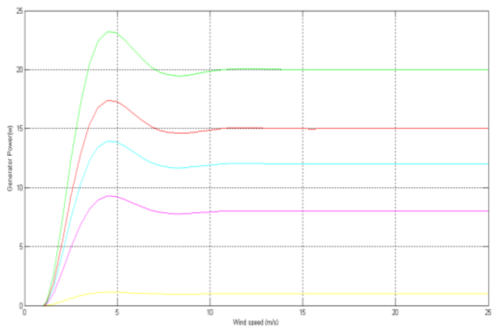

Figure 15 Power curve of wind Turbine with Different wind speed.

f) PSIM environment: with torque equation

Wind turbines cannot fully capture wind energy. The components of wind turbine have been modelled by the following equations. The wind turbine mechanical torque output Tm is given by beloved equation,

$$T_m = \frac{1}{2}\rho A C_p \frac{v^3}{\gamma} \qquad (7)$$

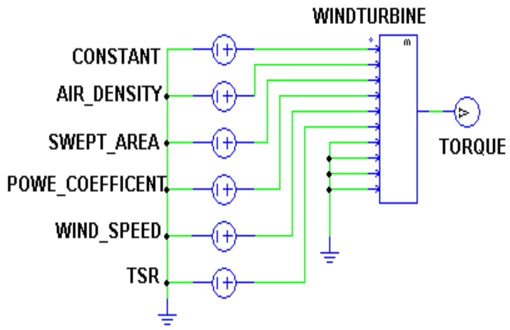

Figure 16 Wind turbines Model

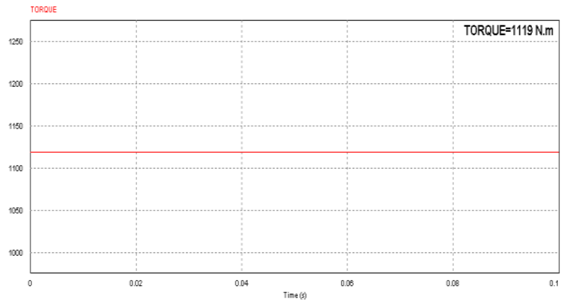

Figure 17 Torque Produced by Turbine (y axis-1 div. =50 N.m)

g) RPM model & TSR model:-

RPM model of wind turbine is given by below equation,

$$RPM = \frac{Wind\ speed * TSR * 60}{Dia.of\ rotor * pi} \qquad (8)$$

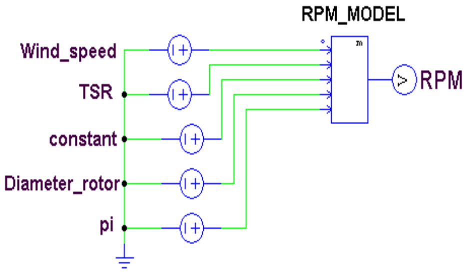

Figure 18 RPM model

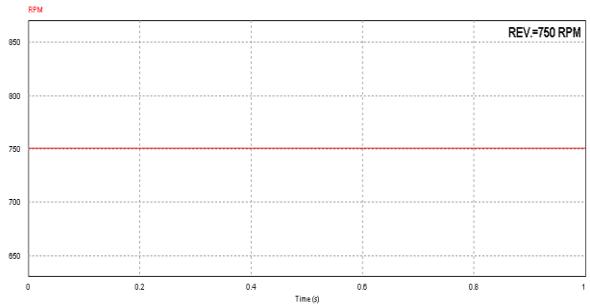

Figure 19 Result of RPM Model (y axis-1 div. =50 N.m)

TSR Model:-Tip speed ratio (TSR) of a wind turbine is given by below model,

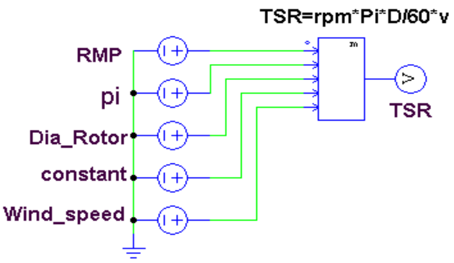

Figure 20 TSR Model

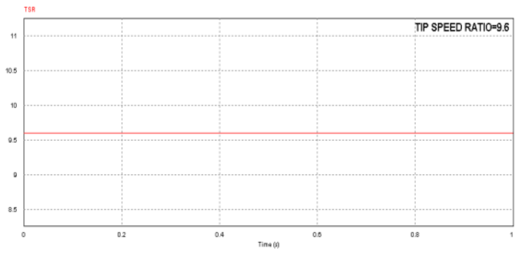

Figure 21 TSR at Rated Wind Speed(y axis-1 div. =0.5)

h) Wind Turbine Power Output:-

The power coefficient is a nonlinear function of the tip speed ratio λ and the blade pitch angle β (in degrees). If the swept area of the blade and the air density are constant, the value of C_p is a function of λ and it is maximum at the particular *λopt*. Hence, to fully utilize the wind energy, λ should be maintained at *λopt*, which is determined from the blade design.

$$P = \frac{1}{2}\rho C_p A V^3 \qquad (9)$$

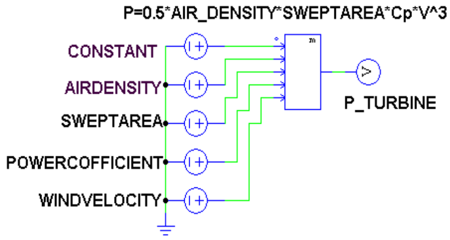

Figure 22 Power Output Model

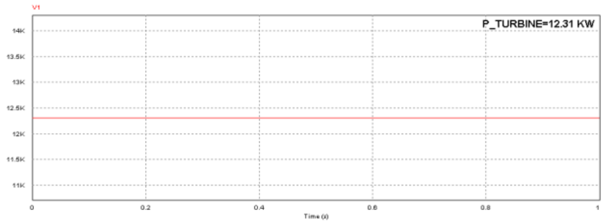

Figure 23 Value of Power Output(y axis-1 div. =0.5 KW)

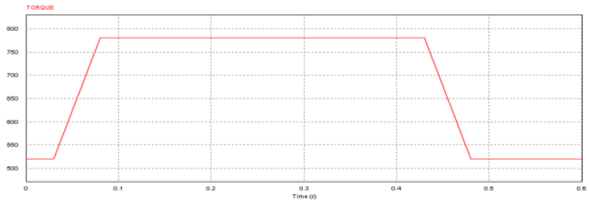

Figure 24 Torque (N.m) produced by Wind Turbine (y axis-1 div. =50 N.m)

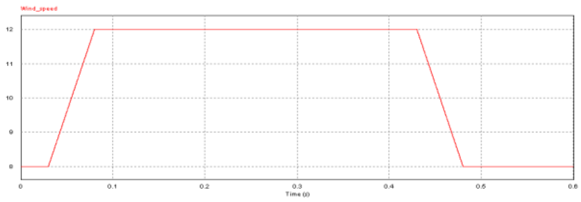

Figure 26 Wind speed under the variable condition.

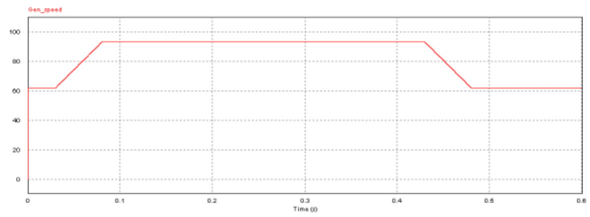

Figure 27 Generator speed under the variable condition.

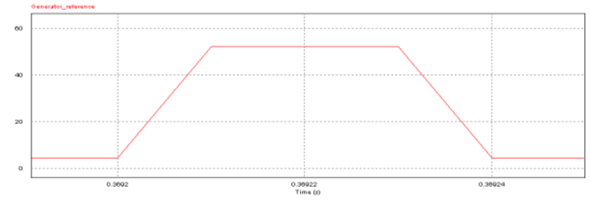

Figure 28 Generator reference speed under the variable condition.

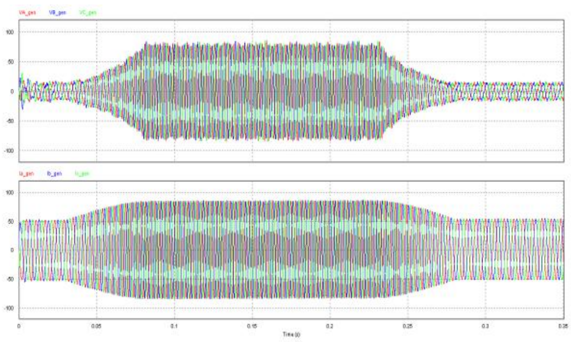

Figure 29 PMSG output voltage & current under the variable condition.

SIMULATION PARAMETER USED:

PARAMETERS OF THE TURBINE:-

P_t (Rated power): - 12 Kw
V(Base wind speed) 12 m/s
R(Rotor diameter): - 2.2 m
A(Swept area): - 31.98 m^2
ρ(Air density): - 1.08 kg/m^3
λ(Tip speed ratio)=9.6
C_p(Power co-efficient):-0.36

PARAMETERS OF THE POWER SYNCHRONOUS GENERATORS:-

Pr (Rated power): - 12 kW
R (stator resistance): - 3.85 Ω
L_d (stator d-axis inductance): - 0.001 H
L_q (stator q-axis inductance): - 0.001 H
λ_m (Permanent magnet flux): - 0.118 Wb
p_n (pole pairs):-4
p (Number of pole):-8
J(Moment of Inertia):-0.0025 $Kg.m^2$
B(Mechanical Time Constant):- 0.00186 Nm/rad/sec

VI CONCLUSIONS

This paper is focus on the wind energy conversion system from Electrical Perspective. Power electronic play very important role for the reliable operation of wind energy conversion system connected to the grid. For the Reliable operation of Grid Major Devices are WTGs, control strategies of PECs, and Power quality issues. New concepts of BDFIG, BDFRG for current Market and their Characteristic's Also Matrix converter and multilevel converter are increasing the wind turbine rating and it's Characteristic's with the Grid. Also Power quality issue is major for wind energy conversion system. It required Harmonics and Reactive power compensation capability at the common point coupling.In this Paper Mathematical Model of Enercon E-53 is developed in MATLAB & PSIM. The result shows the of Different kind of wind turbine characteristics like, power output, Turbine torque, Tip speed ratio, power co-efficient as a function of pitch Angle and blade tip speed.

Acknowledgment

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