Simulation of a Diode Clamped Multilevel Inverter in PMSG driven WECS

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Abstract: Wind energy conversion systems (WECS) include a variety of non-linear power electronic devices which have a significant contribution towards harmonic emissions. Harmonic emissions are threat for electrical power quality. Hence, harmonic analysis and mitigation has become an integral part of WECS. Multilevel invertershave been widely used for harmonic mitigation with the added benefits of low switching stress and high voltage capability. Diode clamped multi-level inverter utilizes the diodes as the clamping device to clamp the dc bus voltage so as to achieve steps in the output voltage.The validity of the proposed topology has been verified by simulation, which may provide possibility for the wind power system to be integrated with medium voltage power grid without a step-up transformer.

Keywords: Permanent Magnet Synchronous Generator (PMSG), Harmonics, Diode clamped multi level inverter, Phase disposition PWM, Total Harmonic Distortion (THD)

1. INTRODUCTION

Wind is the renewable source of energy available in plenty. Wind energy is harnessed by WECS comprising a wind turbine, a generator, power electronic converter, the corresponding control system and the load or grid. Permanent magnet synchronous generators (PMSG) alongwith variable speed variable frequency operation are being widely used in low power application. It is most efficient as compared to the other machines, highly robust and easy maintenance due to the absence of slip ring and exciter system.The most standard way of implementing a grid connected PMSG WECS with variable speed variable frequency is using a two stage conversion : the first one a rectifier that is, an AC-DC stage and the second one an inverter that is,a DC-AC stage [8-9] .

The AC-DC stage consists of three phase bridge diode rectifier or thyristorised converter, followed by dc capacitance filter. Second stage consists of IGBT based inverter, which involve several control techniques.AC-DC converters aremost suitable method to extract the AC power from the generator in variable speed operation. However, the use of these converters injects non-sinusoidal current with sinusoidal voltage into the system.In order to meet the demand for high voltage and high power, multilevel converters are used.

Multilevel converters reducing the output voltage and current harmonic content, increase the output voltage, make output waveform closer to the sine wave.Additionally, the reduction of low frequency harmonics from the ac voltages at the different levels reduces the size of the ac inductance, and hence decreases overall expense of the system. Multilevel converters control output frequency and voltage including the phase angle providing a fast response and autonomous control.This paper adopts double multi-level back-to-back converter structure,that is to say, generator side and load side converter.The maximum power tracking and generator stable operation is realized by using the phase disposition sinusoidal pulse width modulation.

2. MODEL OF WIND ENERGY CONVERSION SYSTEM.

The main components of a direct-drive permanent magnet synchronous generator (PMSG) wind turbine are the wind turbine and the PMSG. The wind turbine captures the power from the wind for the system, and the PMSG transforms the mechanical power into electric power. In this paper the basic principles of the electric power generation will be introduced, and the mathematical models of the wind turbine and the PMSG will be developed and analysed. Figure 1 shows the model of wind energy conversion system.

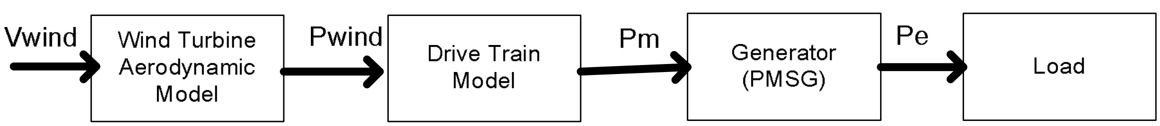

Fig1: Model of WECS

2.1 Modeling of Wind Turbines

In order to investigate the effectiveness of the energy conversion in wind energyconversion systems, first the available energy stored in the wind needs to be determined. Actually, the energy in the wind can be treated as the kinetic energy of a large amount of air particles with a total mass, m ,moving at a wind velocity V_W .Assuming that all the air particles are moving at the same speed and direction before impacting the rotor blades of the wind turbine, the potential available kinetic energy stored in the wind can be expressed as following:

$$E = \frac{1}{2} m V_W^2 \tag{1}$$

where, E, is the kinetic energy of the moving air particles, and m is the total mass of the air particles, while, V_W ,is the velocity of the air particles (wind speed) [1].

$$P_M = 0.5 \times \rho \times C_P(\lambda, \beta) \times A \times V_{Wind}^3 \quad (2)$$

Where P_m is Mechanical output power of the turbine (W), ρ is Air density (kg/m^3), A is Turbine swept area (m^2), V_{Wind} Wind speed (m/s), C_P is Power coefficient of the turbine[2-5]. λ Tip speed ratio of the rotor blade tip speed to wind speed. β is tip speed ratio.

The power coefficient, *Cp*is defined as-

$$C_P(\lambda, \beta) = C_1\left(\frac{C_2}{\lambda_i} - C_3 \times \beta - C_4\right) \times e^{\frac{-C_5}{\lambda i}} + C_6 \times \lambda \quad (3)$$

Where $$\lambda = \frac{R \times W_M}{V_{WIND}}$$

and coefficients $C1 = 0.5176$, $C2 = 116$, $C3 = 0.4$, $C4 = 5$, $C5 = 21$, and $C6 = 0.0068$.

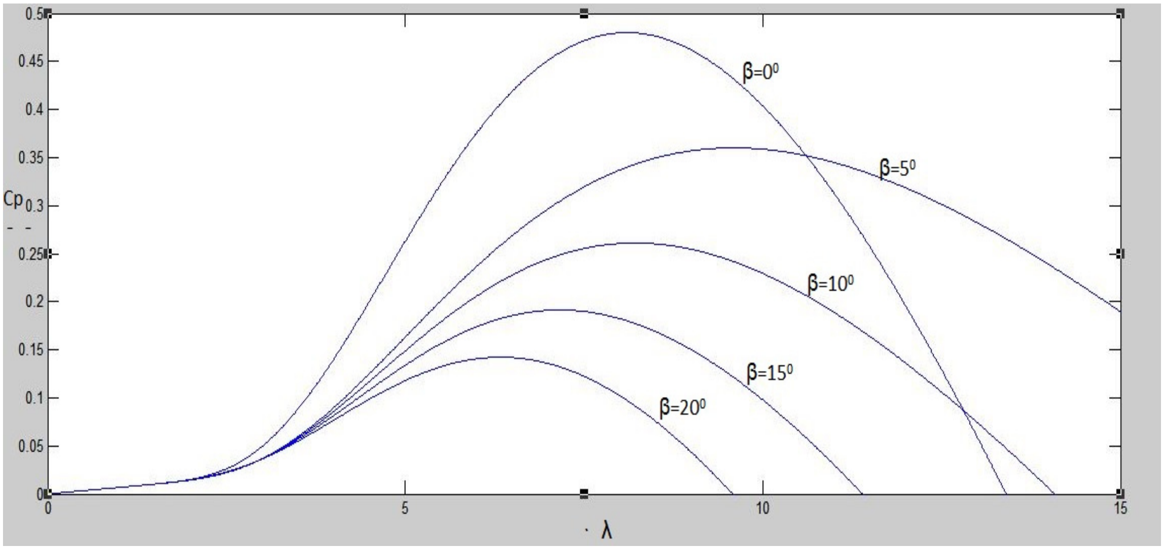

Fig 2: CpVs Tip speed Ratio Curve

Figure:2 shows the power coefficient with respect to tip speed ratio. It is observed that the $Cp\_max(\lambda,\beta) = 0.48$ i.e maximum power coefficient value for $\lambda = 8$ and for $\beta = 0^0$. This value of λ_{opt} results in optimal point where maximum power is captured from wind by the turbine.

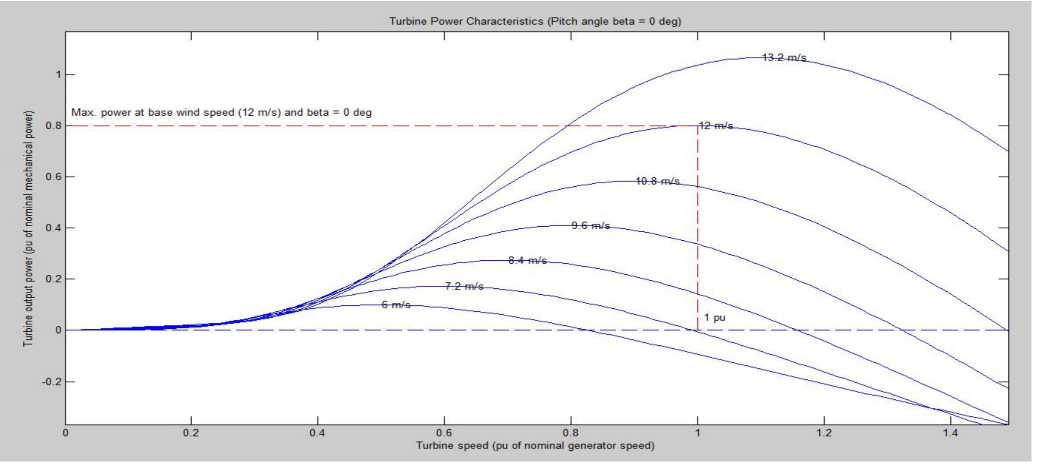

Fig 3:Wind Tyrbine Power Characteristic

Figure 3 shows the wind turbine power characteristics obtained for various values of the wind tangential speed [6].It is observed that maximum power (active) is achieved through optimal wind speeds and not at high wind velocity. The wind turbine does not operate when the wind speed is less than the minimum speed because the captured wind energy is not enough to compensate the losses and operation cost.

2.2 Drive train modeling.

This element converts the mechanical torque and the machine speed [7].

$$T_{aero} = g_r \times T_m \tag{4}$$

$$\Omega_m = g_r \times \Omega \tag{5}$$

$$J \times \frac{d\Omega}{dt} = T_m - T_e \times f \times \Omega_m \tag{6}$$

where,$T_{aero}$is the aerodynamic torque,$\Omega_m$is the machine speed,J is the mechanical inertia of the wind turbine and generator,T_e is the electromagnetic torque, and f is the friction coefficient.

2.3 PMSG modeling

The modeling of PMSG type electrical equipment is made through the following equations, represented by d-q reference frame [7]:

$$V_d = R_S i_d + L_d \frac{di_d}{dt} - w_e L_q i_q \tag{7}$$

$$Vq = R_S i_q + L_q \frac{di_q}{dt} - w_e L_d i_d + w_e \phi_m \qquad (8)$$

Where V_d and V_q are d and q components of stator voltages (V),i_d and i_q are d and q components of stator currents (A), *Rs* is stator resistance (ohms), L_d and L_q are machine inductances (H) is the electrical speed (rad/s) w_e is the magnetic flux (wb). ϕ_m

The electrical torque is obtained through the following equation-

$$T_e = \frac{2}{3} p\{\phi_m i_q + (L_d - L_q) i_d i_q\} \qquad (9)$$

$$T_m - T_e = B\omega_r + J \frac{d\omega_r}{dt} \qquad (10)$$

Where *B* is the rotor friction (kgm2/s),*J* is the rotor inertia (kgm2),*ωr*is rotor speed (rad/s) .*Tm* is the mechanical torque produced by wind (Nm).The machine dynamics can be simplified by assuming (Ld = Lq = 0).

3. SIMULATION AND RESULT:

The modeling of wind turbine and PMSG is carried out in MATLAB to determine its parameters. Harmonics generate due to Power electronic converters and non linear load should be reduced .Diode clamped multilevel inverter with for the wind energy system. Performance parameters are valuated for the proposed converter and the results are verified

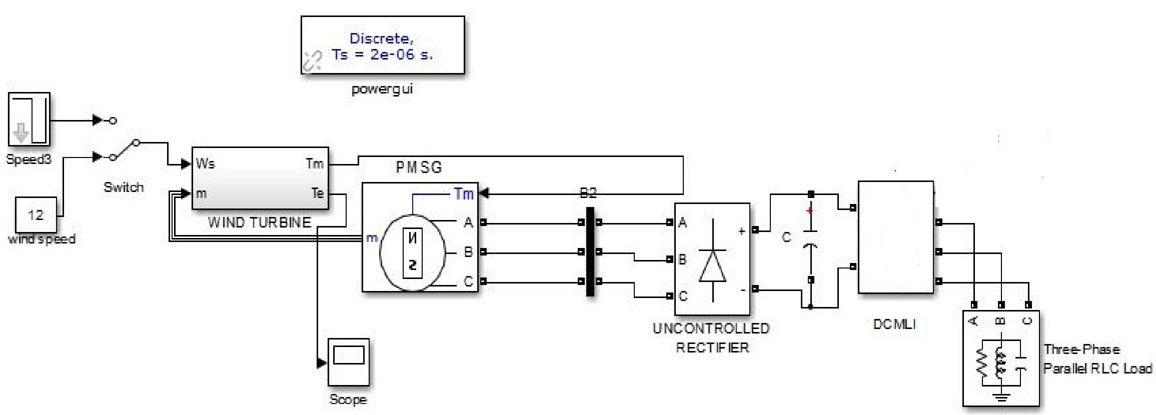

Fig 4: MATLAB Simulink model for Wind Energy Conversion System

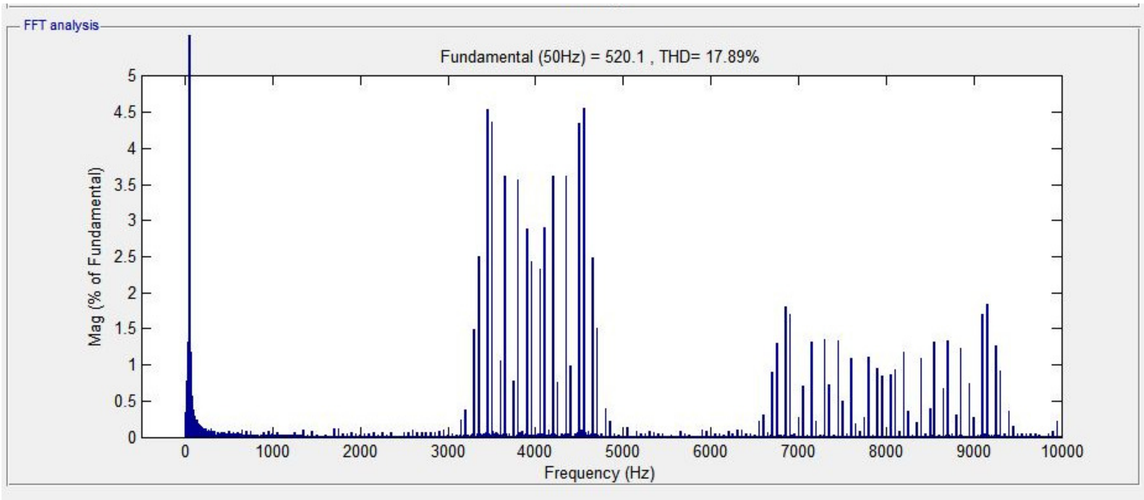

Fig 5: THD of 5 level inverter

Similar SPWM technique is applied for seven level,nine level and eleven level, For eleven level THD obtained is 3.89% according to IEEE Standards THD should be less than 5%, so desired reduction in harmonics obtained by connecting eleven level Inverter with Wind Energy Conversion System.

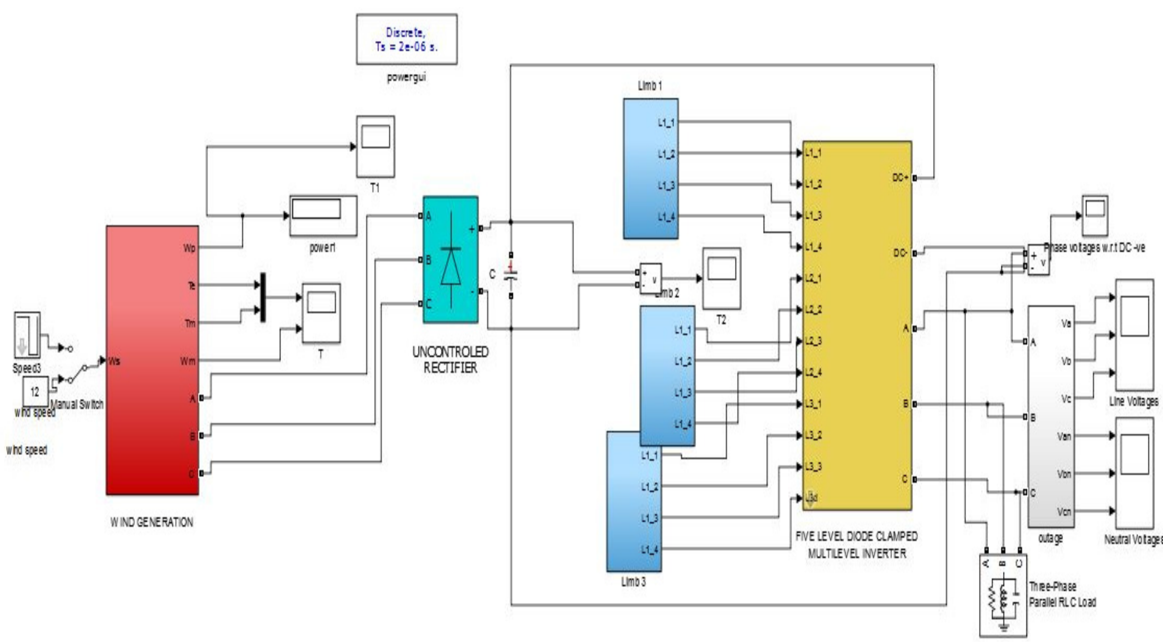

Fig 6: Complete MATLAB Simulink model for Wind Energy Conversion System.

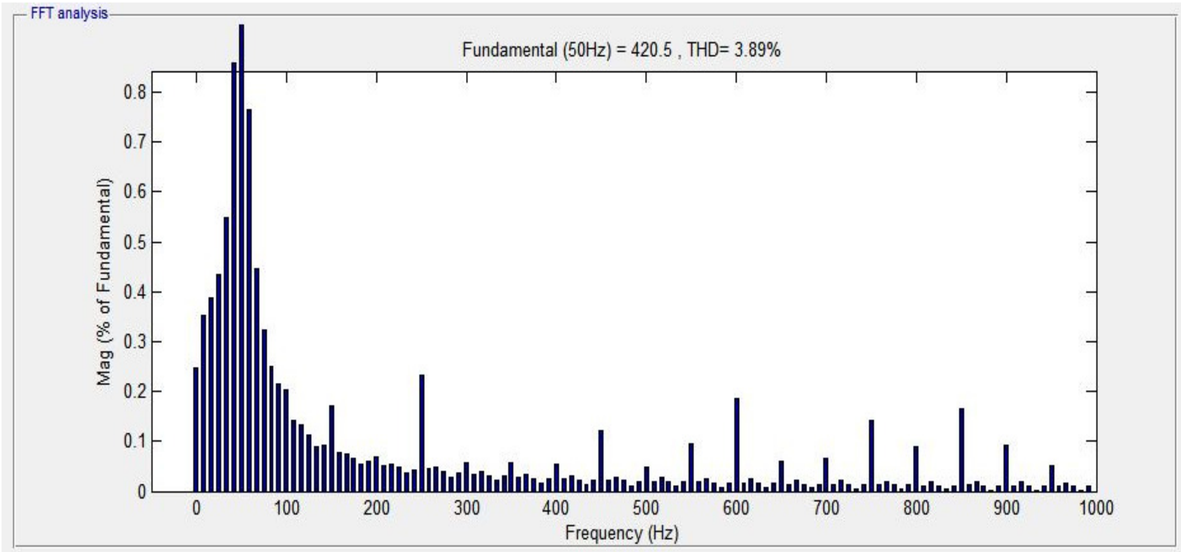

Fig 7:THD of eleven level inverter

Comparison among different levels of Inverters with Wind Energy Conversion System.

Table 1:THD of WECS at different levels of Inverter.

Diode Clamped Multilevel Inverter (PD PWM technique)	THD(%)
Three Level	23.43
Five Level	17.89
Seven Leven Level	13.56
Nine Level	7.23
Eleven Level	3.89

4. CONCLUSION

Eleven-level DCMLI was used to reduce the total harmonic distortion of the whole system effectively. Simulation was verified using MATLAB. DCMLI helps in reduction of voltage stress on switch and also improves the power capacity of the system.

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