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Modelling and Performance Analysis of Reactive Power controlled Wind Energy Conversion System

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ABSTRACT: The paper presents the performance analysis and modelling of a wind energy conversion system(WECS).The wind energy captured from the wind is converted to electrical energy using a frequency converter. Which incorporate a diode rectifier and a two level inverter. In order to maintain a good interaction with grid, a reactive power control strategy is also provided with the Two level inverter. The reactive power control will provide a grid interaction and power quality improvement for the system.

KEYWORDS: wind energy conversion system, permanent magnet synchronous generator, Two mass drive train, pitch angle controller, power quality, Two level inverter, THD

I.INTRODUCTION

The global electrical energy consumption is still rising and there is a steady demand to increase the power capacity. The production, distribution and the use of the energy should be as technological efficient [1].The environmental problems and shortage of traditional energy source in the near future increases the electrical power generation from renewable energy sources, such as PV, wind, etc. Among the renewable sources wind is one of the attractive source. Wind energy conversion systems will extract the kinetic energy and it holds great potential showing that in the future it will become the number one choice form of renewable source of energy along with power electronic devices [2].

Wind turbines may be designed to be fixed speed or variable speed (of rotation). Fixed speed turbines are easier to interface with the electrical grid, since the grid draws electricity at a particular frequency of 50 Hertz which can be transferred by a fixed speed turbine. However, variable speed turbines are able to extract around 2.3% more energy from the wind and require additional interface electronics to match the variable generator speed with the fixed grid frequency of 50 Hertz. The variable-speed wind turbines are more attractive, as they can extract maximum power at different wind velocities, and thus, reduce the mechanical stress on WECS by absorbing the wind-power fluctuations. Recently, PMSG-based directly driven variable-speed WECS are becoming more popular due to the elimination of gear box and excitation system [3][4][5]. Power electronic, being the technology of efficiently converting electric power, plays an important role in wind energy conversion systems. It is an essential part for integrating the variable-speed wind power generation system to grid and to achieve high efficiency and high performance in power systems. The power electronic converters are used to match the characteristics of wind turbines for grid connections, including frequency, voltage, control of active and reactive power, harmonics, etc [6].

But using the power electronic devices will decrease the power quality of the system. Some IEEE grid codes have been redefined to specify the requirements of a grid connected systems that to be met in necessary. Examples of such requirements include the frequency and voltage control by continuously adjusting active power and reactive power supplied to the transmission system, and the power regulation rate that a wind farm must provide, flicker, harmonics, etc. For that control techniques has to be provided along with the power electronic devices[7].

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II.PROPOSED SYSTEM

A diode rectifier with a dc link capacitor followed by inverter circuit is most widely used converter with PMSG based WECS as shown in fig. 1. It is economical and easy to control. It has a simple configuration in construction.

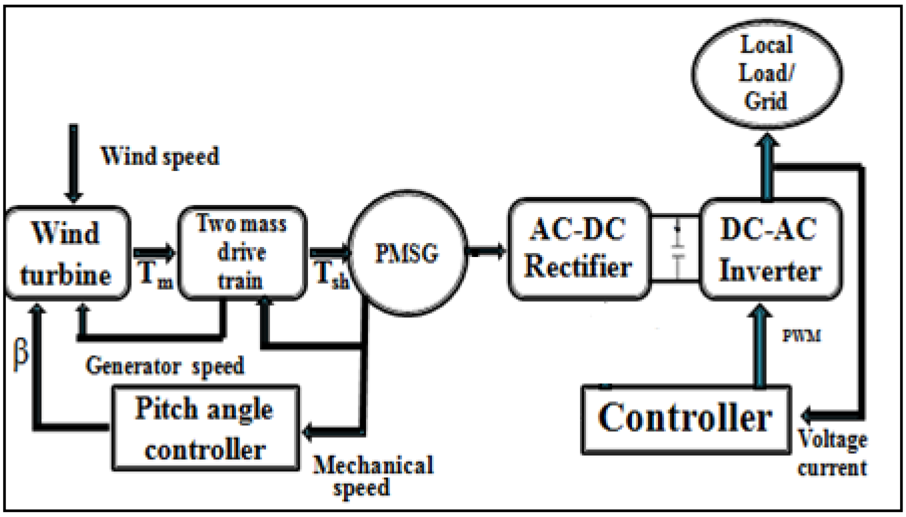

Fig. 1 Proposed wind energy conversion system

In this system on the machine side controllers are used in order to control the DC link voltage and reduce the vibrations in the system. The wind turbine collects the kinetic energy from wind and convert it into mechanical energy. The pitch angle controller will allow maximum power conversion. The two mass drive train over come the mechanical stresses and vibrations of wind turbine. The power electronic interface convert the electrical energy produced by the PMSG to what the grid requires. The presence of diode rectifier nd two level inverter may cause power quality issues. To overcome that reactive power control is used

III. MODELLING OF PMSG DRIVEN WIND TURBINE SYSTEM

The modeling of wind turbine is the most important part for a WECS. The turbine modeling should be done to capture maximum kinetic energy from the wind with less cost. The mathematical expressions for the modeling of wind turbine systems are given below.

The expression of the mechanical torque developed by a wind turbine *Tm* is given by the following [8, 10]:

$$T_m = \frac{1}{2}\rho\pi {R_t}^2 C_p(\lambda,\beta)\frac{v^3}{\Omega_r} \qquad (1)$$

Such that:

$$\lambda = \frac{R_t\Omega_r}{v} \qquad (2)$$

In order to simulate the wind generation system, expression of *Cp (λ , β)* has been considered , such that; [8]

$$C_P = [0.5 - 0.00167(\beta - 2)]\sin\left(\frac{\pi(\lambda+0.1)}{12-0.3(\beta-2)}\right) - 0.00184\,(\beta - 2)(\lambda - 3) \qquad (3)$$

The conversion of wind energy into mechanical energy over the rotor of a wind turbine is influenced by various forces acting on the blades and on the tower of the wind turbine. So this may change the pitch angle. According to bets concept maximum power can be captured when coefficient of performance value is maximum. Which is maximum when pitch angle is zero. So inoder to keep the pitch angle zero for all wind speed a pitch angle controller is also provided. There may be vibrations in the mechanical torque produced from the turbine due to sudden variation of wind speed. So that should be avoided by using a two mass drive train. The modeling equation for the drive train are given below.

The equation of the torque for drive train is given by

$$H_g \frac{d\omega_g}{dt} = T_e + \frac{T_m}{n} \qquad (4)$$

Since the wind turbine shaft and generator are coupled together via a gearbox, the wind turbine shaft system should not be considered stiff.

$$H_m . \frac{d\omega_m}{dt} = T_\omega - T_m \qquad (5)$$

The mechanical torque *Tm* can be modeled with the following equation.

$$T_m = K\frac{\theta}{n} + D\frac{\omega_g - \omega_m}{n} \qquad (6)$$

$$\frac{d\theta}{dt} = \omega_g - \omega_m \qquad (7)$$

where n is the gear ratio, θ is the angle between the turbine rotor and the generator rotor, ω m , ω g , H m and H g are the turbine and generator rotor speed and inertia constant, respectively .K and D are the drive train stiffness and damping constants, Tω is the torque provided by the wind and T e is the electromagnetic torque.

The modeling of PMSG system is also important for a WECS. The mathematical modeling equations based on d-q reference frame are given below [11,12].

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} r_s & 0 \\ 0 & r_s \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} \varphi_d \\ \varphi_q \end{bmatrix} + \omega_r \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} \varphi_d \\ \varphi_q \end{bmatrix} \qquad (8)$$

For a sinusoidal distribution of the back e.m.f, the flux and current phases are linked by the following expressions:

$$\varphi_d = L_d i_d + \varphi_r \qquad (9)$$

$$\varphi_q = L_q i_q$$

where φ_r is the rotor flux.

Substituting equation (5) on equation (4), we obtain the following system via *Laplace* transformation

$$\{\; v_d = (r_s + L_d \rho) i_d - e_d \qquad (10)$$

$$v_q = \left(e_s + L_q \rho\right) i_q + e_q$$

Such that the direct and the quadrature back e.m.f components are expressed as:

$$\begin{cases} e_d = \omega_r L_q i_q \\ e_q = \omega_r L_d i_d + \omega_r \varphi_r \end{cases} \qquad (11)$$

The stator active and reactive powers of the PMSG Machine are given by the equations (8):

$$\begin{cases} P_s = \frac{3}{2}(v_d i_d + v_q i_q) \\ Q_s = \frac{3}{2}(v_q i_d - v_d i_q) \end{cases} \qquad (12)$$

Under generator operation, the mechanical equation is expressed as follows:

$$T_m - T_{em} = J\frac{d\Omega_r}{dt} + K_f \Omega_r \qquad (13)$$

The electromagnetic torque can be expressed ,in (d, q frame)as follows:

$$T_{em} = \frac{3}{2} n_p \left(\varphi_r - (L_q - L_d) i_d\right) i_q \qquad (14)$$

IV.RESULTS AND DISCUSSIONS

The simulation study of the WECS using the controlled and uncontrolled rectifiers are done by choosing the following parameters. A four pole PMSG machine is used for the study. The parameters are given in table 1.

Table 1 Turbine and machine parameters

Parameters of machine		Parameters of turbine	
PARAMETER	VALUE	PARAMETER	VALUE
P_r, rated power	2.00 KW	Air density	1.08 kg/m^3
L_d L_q	0.01 H	A, area swept by blades	31.98 m^2
R_r , rotor resistance R_s, stator resistance	0.425 ohm	V, base wind speed	12 m/s
Pole pairs	4	C_{pmax}	0.48
Voltage constant	300 V_{pp}/rpm	Lambda	8.1
Torque constant Inertia constant Viscous	2.48 Nm/A 0.01197 kgm^2 0.001189 N.m.s	Pitch angle , β	0

The WECS using uncontrolled rectifier and controlled two level inverter is shown in Fig. 2. Here the uncontrolled rectifier will introduces a large amount of harmonic content in the switching system and since there is no control DC link voltage cant be maintained to constant. The wind turbine system is a variable speed one. So the variation in speed will also be there in the dc link voltage and obviously in the inverter output also. Since we are using a reactive power control in the inverter side, the control will reduce the reactive power control and THD component not the voltage amplitude.

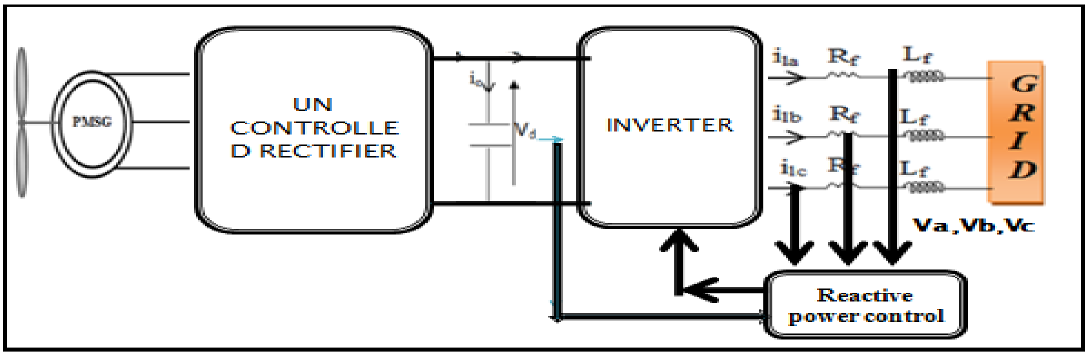

Fig. 2 PMSG driven WEC using reactive power control

The wind turbine modeled using above equations is shown in fig 3. Which is a simple model for wind turbines. Based according to Betz theorem.

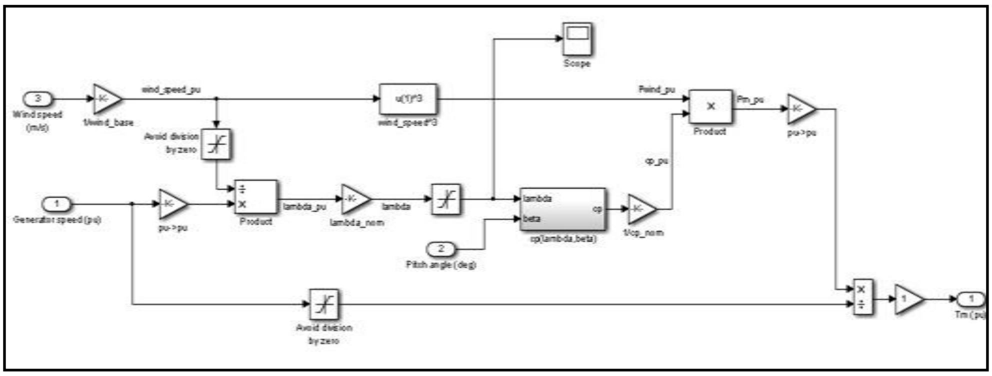

Fig. 3 Model For Wind Turbine System

PMSG modeled using mathematical equation described in chapter III IS shown in fig 4.The modeling is based on d-q axis theorem. The output of the system are torque, voltage and d-q axis components.

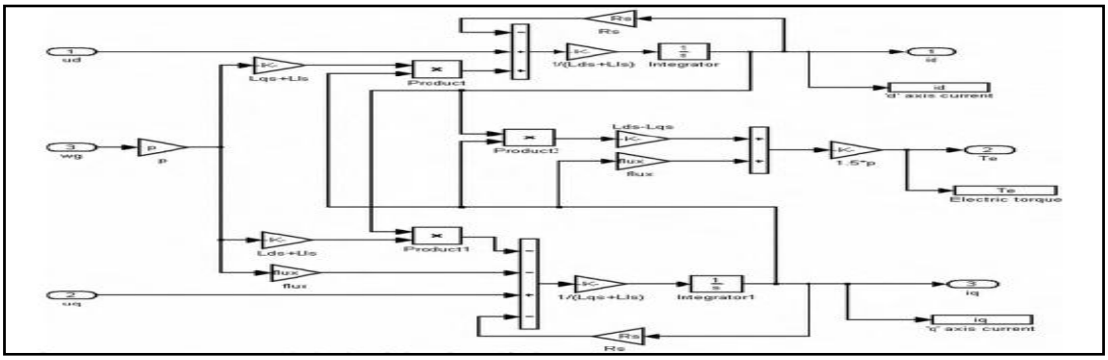

Fig. 4 Model For PMSG System

The simulation waveforms for wind velocity, torque produced from wind turbine system (T_m) and torque given to PMSG after two mass drive train (T_{sh}) are shown in below Fig. 5. It is clear that the sudden torque variations in the input side of a PMSG affects its performance.

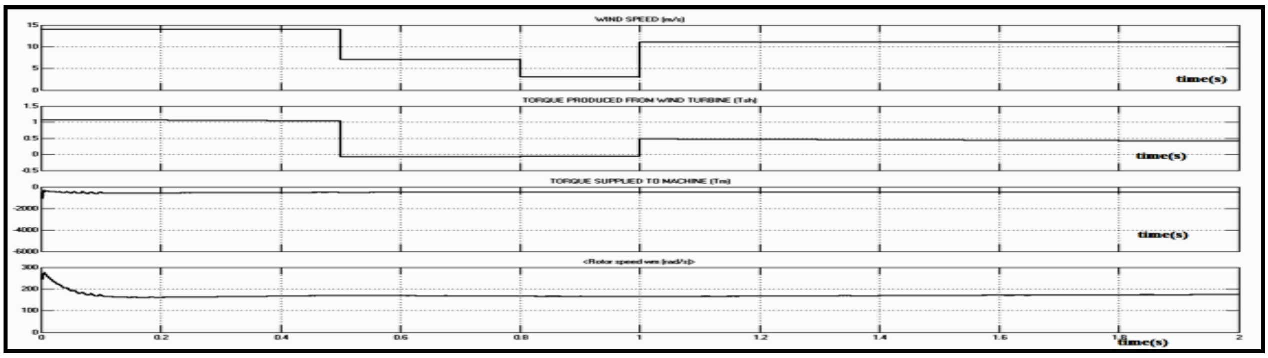

Fig. 5 Wind speed, Shaft torque, machine torque and rotor speed

The WECS using uncontrolled rectifier MATLAB model is shown in fig. 6. The system is having a diode rectifier and two level inverter with reactive power control

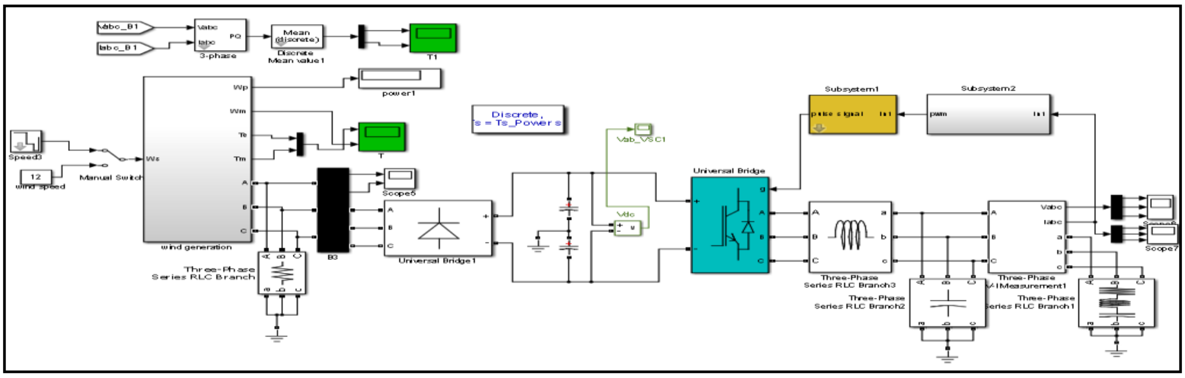

Fig. 6 Simulink model of WECS using uncontrolled rectifier and five level inverter

The generated voltage and current wave forms from PMSG of a WECS using uncontrolled rectifier is shown in Fig. 7.

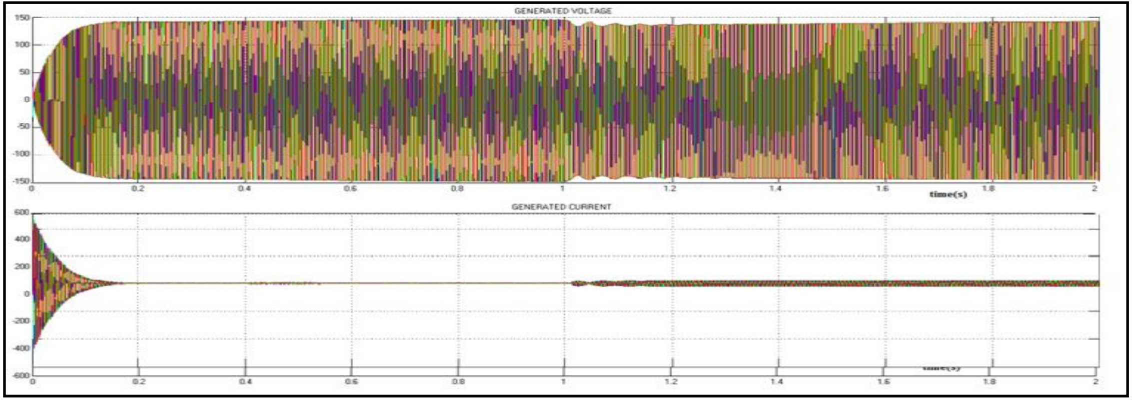

Fig. 7 Generated voltage and current from PMSG

The DC link voltages using an uncontrolled rectifier with variations are shown in Fig. 8. The dc link voltage waveform is having variation at some points where there is a large variation in wind

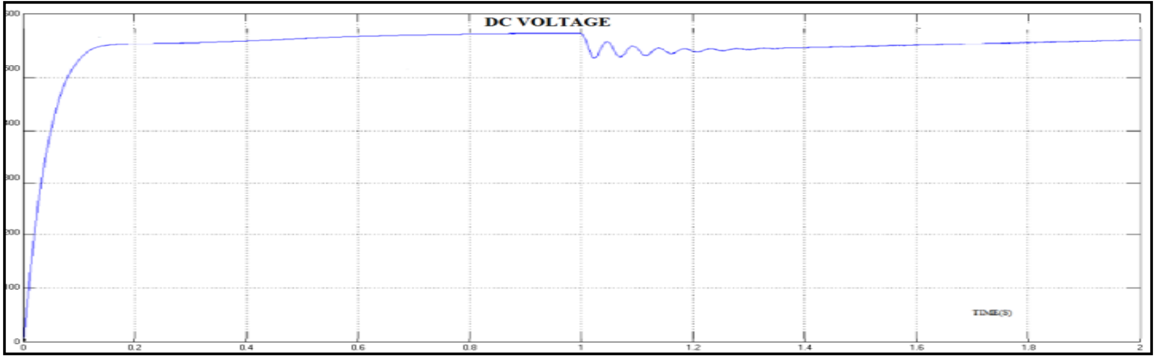

Fig. 8 Dc link voltage

The output voltage and current obtained from the Two level inverter using reactive power control is shown in Fig.9. Here due to the variations in dc link voltage, the output voltage also varies.

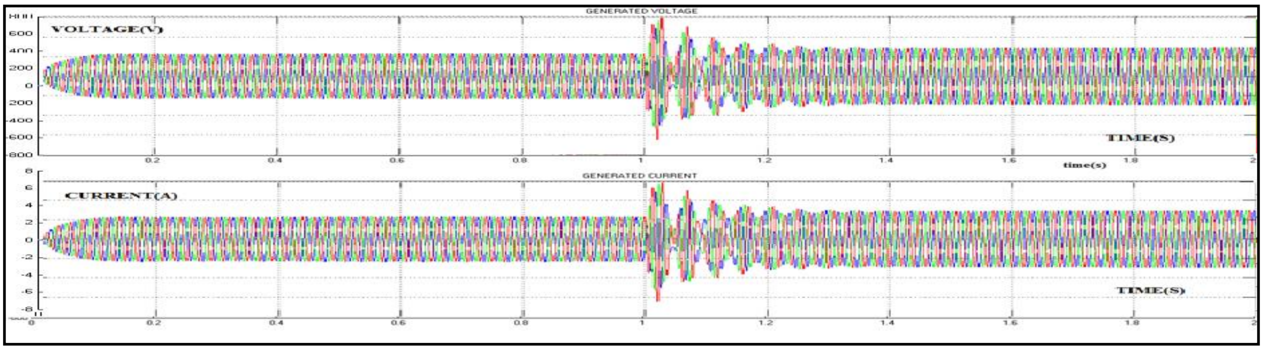

Fig. 9 Three phase output voltage and current from inverter

The THD analysis of the whole system is shown in fig.10 .It is noted that the THD values are less than the standard value.

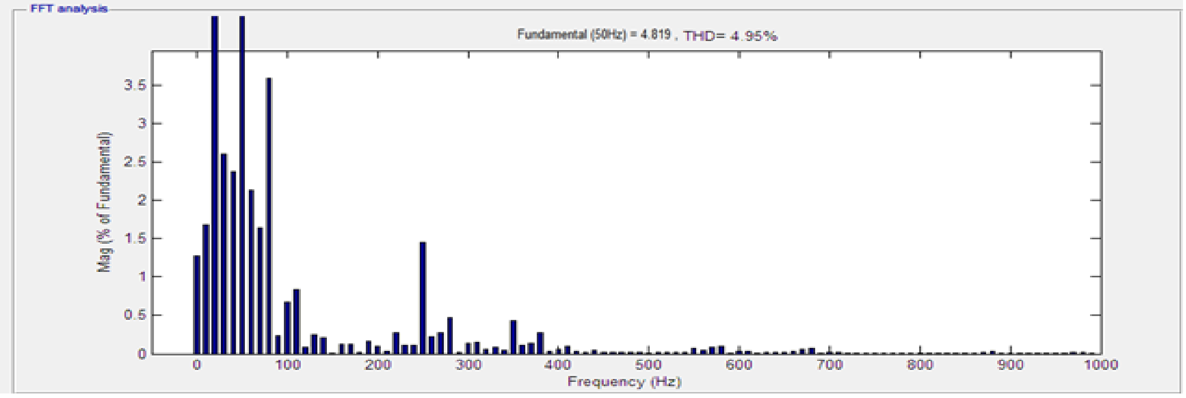

Fig. 10 THD analysis

VI.CONCLUSION

In this paper a wind energy conversion system with two level inverter using uncontrolled rectifier systems has been introduced . The performanance analysis of wind energy conversion system was done and analysis shows that vibrations of wind turbines are overcomed by two mass drive train and maximum power was obtained using pitch angle controller. The THD level and reactive power consuming for a local load were studied for both the systems. Using the reactive power control the reactive power consumption of the system were reduced. It is observed that the THD levels are below the IEEE standard. The simulated system using MATLAB/SIMULINK shows that using reactive power control system performance can be improved.

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