A PMSG Fed Wind Energy Conversion System Using3-Level NPC Inverter With Fuzzy Logic Based Pitch Control

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***Abstract*— This paper is mainly based on simulation to reduceharmonics which are found in a Permanent Magnet Synchronous Generator (PMSG) Wind Energy Conversion System (WECS) connected to a grid through a three-phase diode rectifier and a three-level Neutral Point Diode Clamped (NPC) inverter which together known as power electronics interface and also controllingthe pitch angle of the turbine based on Fuzzy Logic (FL) controller.**

Keywords— Wind turbine, Fuzzy logic, PMSG, Pitch angle control, NPC inverter

I. INTRODUCTION

The increase in wind energy installed in wind energy is considered as an important part of the total energy production. As a result, power system operators have introduced wind farm regulations to improve control of the entire power system. Therefore, wind power systems must meet the grid connection requirements specified by the power system operator. The need for electricity is growing day by day and renewable energy options such as wind power are emerging as an attractive alternative to fossil fuels. Among renewable energy sources, wind energy is the most popular and fastest growing and one of the most innovative and attractive ideas for generating electricity from renewable resources [1]. One of the most important requirements for building a power generation system related to wind farms is to maintain the operating frequency of the WT to reduce voltage and current fluctuations. Therefore, the tilt angle must be controlled. The pitch angle refers to the angle formed by the turbine blades in relation to the wind direction [2]. This allows the input power to be controlled to improve the conversion effect or to tune the turbine. An electronic circuit must be used to reduce voltage and electrical oscillation, but to achieve a constant frequency, a DC connection must first be made to convert the output of the generator from AC to DC and then to convert DC to AC. Voltage fluctuations can be reduced by controlling the reactive power value. Thus, efficient and advanced "air" production systems can be developed.

II. SYSTEM DESCRIPTION

The wind energy conversion framework mainly consists of four components, for example: wind turbine, generator, control transformer, which are related to the framework as shown in Figure 1. The winds passing over our heads must be captured and converted into a usable form of energy, and that should be conceivable with a turbine connected to an electric generator. Edge lift point control is also required for a wind turbine because it controls the torque and keeps the torque constant. PMSG is used to convert mechanical life force into electrical. The PMSG is an AC synchronous generator and is energized by a continuous DC current from the permanent magnet of the screen [3]. These generators are continuous during normal operation and no additional direct current is required for the excitation circuit [4]. Control Interface This user interface mainly consists of two control devices known as rectifier and inverter. First, the rectifier switches the wind turbine and PMSG from AC to DC, and the inverter again switches from DC to AC, which is fed into the grid. Area III covers the edge elevation controls in detail. Segment IV examines the arrangement of the NPC voltage source inverter. Section V examines the Results Occurs, and Section VI concludes the article.

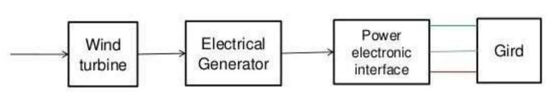

Fig. 1. Wind Energy Conversion System

III. Pitch Angle Control For Wind-Turbine

To produce more height, the blades should be positioned at right angles to the wind. The tips of the turbine blades move faster than points near the axis, and the angle of the wind seen by the blades depends on their radius. The greater the angle of the blades, the smoother the rotor. The maximum power that a wind turbine can extract from the wind is calculated using the Betz criterion. This is defined as (1):

$$P_T = C_P . P_O \qquad (1)$$

where P_T is the total available power, P_0 is the maximum power extracted and C_P is the called power coefficient and its value is 16/27 according to Betz criterion. The maximum torquedeveloped by the turbine occurs when maximum circumferential force acts at the tip of the blade with radius R and is given by (2)

$$T_M = F_{Cirmax} \cdot R \qquad (2)$$

$$T_M = P_0/u_0 \cdot R \qquad (3)$$

where u_0 = speed of incoming air According to the tip speed ratio relation (4)

$$\lambda = R \cdot \omega/u_0 \qquad (4)$$

where $R \cdot \omega$ = speed of the rotor blade

So, the equation for max torque derived in eqn. (3) now becomes (5)

$$T_M = P_0/\omega \cdot \lambda \qquad (5)$$

Shaft torque is given as (6)

$$T_{sh} = C_T \cdot T_M \qquad (6)$$

where C_T = torque coefficient Power developed by turbine

P_T which is given as (7)

$$P_T = T_{sh} \cdot \omega \qquad (7)$$

So,

$$C_T T_M \omega = C_P P_0 \qquad (8)$$

So, the above equation (8) can be rewritten according to the relation in equation (5) as

$$C_T\ P_0 \lambda = C_P P_0 \qquad (9)$$

Hence from the above relation (9) it can be derived that

$$C_T = C_P/\lambda \qquad (10)$$

The relation of blade pitch angle (β) with CP and λ

$$C_p(\lambda,\beta) = C_1\left(\left(\frac{C_2}{\lambda_i}\right) - C_3 . \beta - C_4\right) e^{-\frac{C_5}{\lambda_i}} + C_6\lambda \qquad (11)$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \qquad (12)$$

For wind turbines, edge point control is additionally essential to control torque and keep up torque at all times. Constant torque is imperative to attain steady yield torque to preserve solidness in wind turbines. In this case, a fuzzy rationale controller is utilized to control the pitch point of the edges.

A. Fuzzy Controller

Fuzzy control is based on its logic. Its formulation is a real-time expert diagram that realizes some of the aptitude of a human manager or process designer, which is not easily communicated to any controller parameters or differential conditions, but instead to conditions or operating rules. This control differs from the standard computer update in a number of aspects [5]. The basic structure of the FL controller is shown in Figure 2.

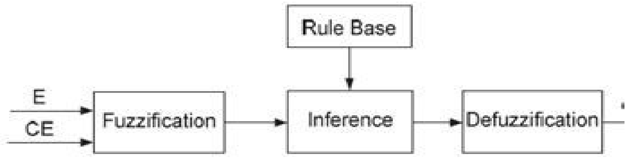

Fig. 2. Block diagram of Fuzzy Logic Controller

In this project the two inputs are error (e) and change of error (ce) and are defined as (13) & (14),

$$e(k) = T_{ref}(k) - T_{actual}(k) \quad (13)$$

$$ce(k) = e(k) - e(k-1) \quad (14)$$

where the e is the difference between reference and actual torque and result is change in the blade pitch angle which is denoted as $d\beta$. The fuzzy rule base which are used in this paper, are shown in Tab. I

TABLE I. RULE BASE OF FL CONTROLLER

E/CE	**NB**	**NS**	**ZE**	**PS**	**PB**
NB	NB	NB	NS	NS	ZE
NS	NB	NS	NS	ZE	PS
ZE	NS	NS	ZE	PS	PS
PS	NS	ZE	PS	PS	PB
PB	ZE	PS	PS	PB	PB

For the fuzzy logic controller designing, the inputs are error (e) and change of error (ce) in torque of the WT and output is the change in pitch angle (dβ). This generated pitch angle targets the WT to produce the optimal torque. The membership functions for both inputs and output are shown in Fig. 3, 4 & 5

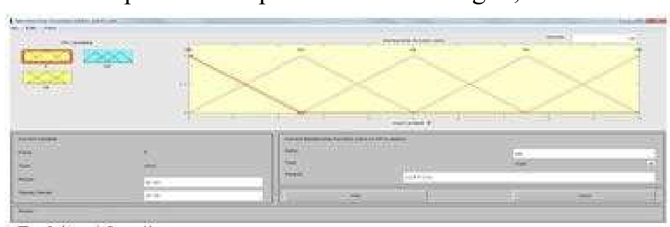

Fig. 3. Input Function e

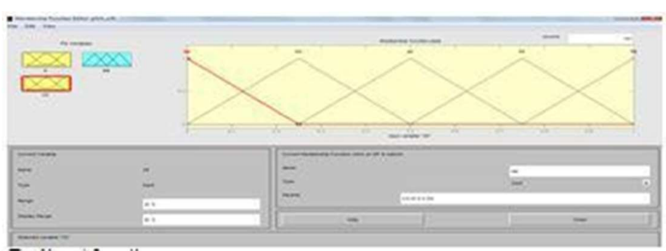

Fig. 4. Input Function ce

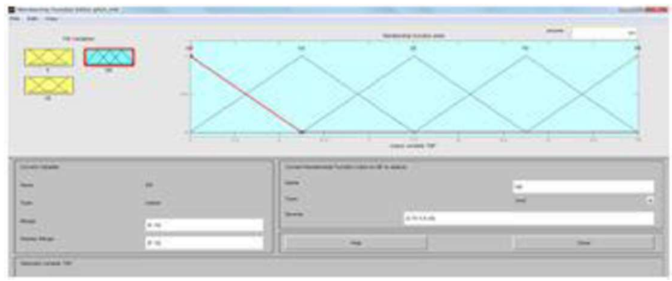

Fig. 5. Output Function $d\beta$

IV. NEUTRAL POINT DIODE CLAMPED 3-LEVEL INVERTER

The 3-phase 3-level diode clamped multilevel inverter is a common multilevel inverter used in various applications. This paper uses a three-phase 3-level diode clamped multilevel inverter as shown in Figure 6. As high-efficiency power electronics and semiconductor technologies develop, variable-speed drive (VSD) systems are increasingly used in residential, commercial, and industrial applications. Due to the advantages of higher power classes, the three-level neutral-point-clamped (NPC) voltage source inverter (VSI) is used in industrial and traction applications [6], static VAR compensation systems, active filters, and electronic device interconnection applications.

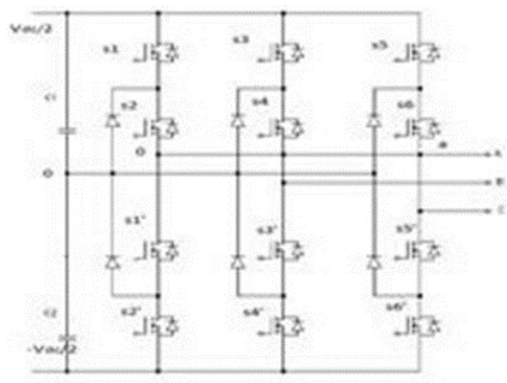

Fig. 6. Neutral Point Diode Clamped 3-Level inverter

It is obtained from a configuration of twelve switching devices and six clamping diodes as shown in figure 2. The pairs $S1S1'$, $S2S2'$, $S3S3'$, $S4S4'$, $S5S5'$ and $S6S6'$ are complementary. Therefore, $S1' = 1 - S1$, $S2' = 1 - S2$, $S3' = 1 - S3$, $S4' = 1 - S4$, $S5' = 1 - S5$ and $S6' = 1 - S6$. There are twelve active combinations were taken using these switching states which produce twelve active voltage vectors. A 3-level diode clamped converter typically consists of 3-1 capacitors on the dc bus and which produces 3 levels of phase voltage. The diode clamped converter produces (3-1)/2 levels above and below the zero level [7].
Assuming that the value of the diodes is much more equal to the nominal value of the main switches of the converter, then a problem arises in a diode-clamp converter, and the number of diodes required in the circuit increases with the number of diodes. levels. Assume that the switch chain from the positive upper bus to the output terminal, which has half the total number of switches, is in the upper or lower half of the switch chain, as it corresponds to m-1 switches. If someone has a chain of 3-1=2 switches, then there are 3-2=1 connections between the switches. Diode chains are connected to each of these connection points. All of these diode chains terminate at the switch junction at the bottom of the inverter totem pole. Each diode chain must carry the total capacitor voltage, for example if the diode voltage rating is the same as the switch rating, this would mean that each diode chain must consist of 3-1 = 2 diodes. In this circuit, the DC bus voltage is divided into three levels by two series capacitors, C1 and C2. The center n of the two capacitors can be defined as the zero point. Verification diodes. The function of the circuit is to prevent a voltage transfer across a single switching device that exceeds the voltage across a single capacitor. The output voltage Van has three states which are: Vdc/2, 0 and Vdc/2. At voltage level Vdc/2, switches S1 and S2 must be on; -For Vdc/2, switches S1' and S2' must be on; and at level 0, S2 and S1 must be on.

The main key component that decides this circuit is a normal two-level converter is D1 and D1. These two diodes clamp the switch voltage to half the DC bus voltage level. When both S1 and S2 are on, the voltage between a and 0 is Vdc, ie. Va0 = Vdc. In this case, D1" balances the voltage division between S1' and S2', while S1' blocks the voltage between C1 and

S2' and blocks the voltage at C2. Note that the output voltage Van is AC and Va0 is DC. Between Van and Va0 is C2 voltage, which is Vdc/2. When the output is removed from a to 0, the circuit becomes a DC-DC converter with three output voltage levels: Vdc, Vdc/2, and 0.

A. Grid side converter control strategy

In this work, adjustment of the pitch of the wind turbine blade, which takes the maximum power of the turbine, was carried out. Then after a generation comes the rectifier part. Since the rectifier is considered a three-phase diode rectifier, no control strategy is required. The implemented control strategy is voltage control of a three-level NPC (neutral point diode clamped) inverter, which is a grid-side control strategy [8] [9].

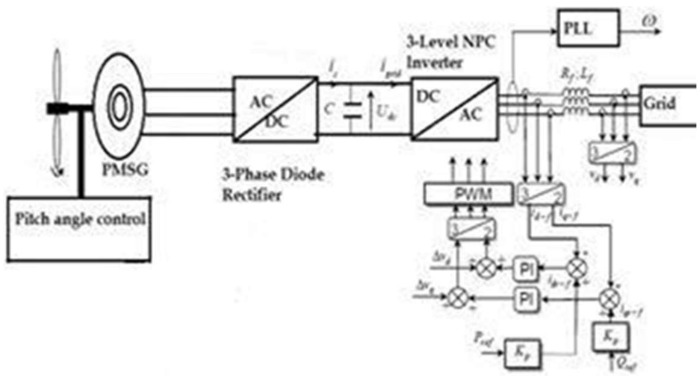

Fig. 7. Complete Control Strategy of PMSG based WECS

The grid-side converter delivers power from the PMSG side to the grid, regulates the DC bus voltage, and adjusts the amount of reactive power and active power delivered to the grid as the wind changes to achieve a unity power factor (UPF). for everyone wind speeds. He got used to it. As a result, vector control and PI control loops are used. The controller is shown in Figure 7. Next, in the inner control loop, a PI controller is used to control the forward and current components, respectively, in the second loop, determined by the DC voltage PI to the DC voltage at the reference value [10]. Additionally, an isolation voltage is added to the output of the current controller to compensate for cross-coupling effects due to the output filter of the inverting synchronous reference frame.

According to Fig. 7, the relationship between the line currents and the grid inverter voltages is given by (15):

$$\begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} = R_f \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + L_f \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (15)$$

where:

e_a, e_b, e_c are voltages at the inverter system output;

v_a, v_b, v_c are grid voltage components;

i_a, i_b, i_c are line currents;

L_f filter inductance;

R_f filter resistance

Transferring Eq. (15) in the reference frame rotating synchronously with the electrical grid voltage vector as shown in Fig. 8, the model for the grid-side converter is given by (16) & (17):

$$v_q = e_q - R_f i_q - L_f \frac{d}{dt} i_q - \omega L_f i_d \quad (16)$$

$$v_d = e_d - R_f i_d - L_f \frac{d}{dt} i_d - \omega L_f i_q \quad (17)$$

where,

e_d, e_q are inverter d-axis and q-axis voltage component;

v_d, v_q are grid voltage components in d-axis and q-axis;

i_d, i_q are d-axis and q-axis grid currents;

ω is the angular frequency

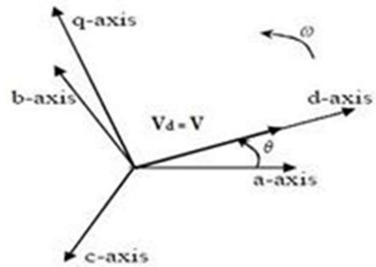

Fig. 8. d q axis transformation

The VC scheme used is based on a rotating reference frame as shown in Fig. 8. The instantaneous powers are given by eqn. (18) & (19)

$$Q = \frac{3}{2}\left(v_d i_q - v_q i_d\right) \qquad (18)$$

$$P = \frac{3}{2}\left(v_d i_d - v_q i_q\right) \qquad (19)$$

The Vector Control scheme used is based on a rotating synchronously reference frame as shown in Fig. 8, then

$$v_d = V \qquad (20)$$

$$v_q = 0 \qquad (21)$$

Thus, Eqs. (16-17) may be expressed as:

$$L_f \frac{d}{dt} i_d = e_d - R_f i_d + \omega L_f i_q - V \qquad (22)$$

$$L_f \frac{d}{dt} i_q = e_q - R_f i_q + \omega L_f i_d \qquad (23)$$

Then, using (20) & (21), the reactive power and active power in eqns. (18) & (19) can be expressed as

$$Q = \frac{3}{2} V i_q \qquad (24)$$

$$P = \frac{3}{2} V i_d \qquad (25)$$

As a result, reactive and active power control can be controlled by quadrature and direct current components, respectively. Then

$$i_{qr} = \frac{2}{3V} Q_{ref} \qquad (26)$$

$$i_{dr} = \frac{2}{3V} P_{ref} \qquad (27)$$

where i_{qr} and i_{dr} are the reference signal of q-axis and d- axis current, respectively. Q_{ref} and P_{ref} are the reference of reactive and active power, respectively. Inverters are also used to obtain UPF by sending all the active power produced by the WTG to the power grid without generating reactive power. As a result, the DC link voltage must be constant. The grid-side inverter control mechanism is shown in Figure 7. The principle is to use two closed-loop controls to control the DC bus voltage and the transmission line current.

Figure 7 shows the control block diagram of a network-side PWM converter based on the above strategy. There are two closed-loop controllers, which use PWM to generate a control signal that controls the step-by-step inverter. In addition, decoupling voltages, Δv_d and Δv_q are added to the output of the current controller to compensate for cross-connection effects.

V. RESULTS

The complete system is simulated in MATLAB/Simulink environment. In this section pitch control using both PI and FL controller and 3-level NPC inverter scheme WECS was proposed.

A. System performance with FL Controller

When the wind speed drops below the rated value, the pitch angle is reduced from high to help accelerate the turbine. When the wind speed increases above the specified speed, which is about 25 m / s, which is called the cutting speed, the pitch angle is reduced to reduce the angle of the blades to maintain the output power at the decisive power. Also, pitch angle control is important to keep the turbine above its rated speed. The power is taken at a wind speed of 10-18 m/s and an angle of inclination 0˚- 10˚.

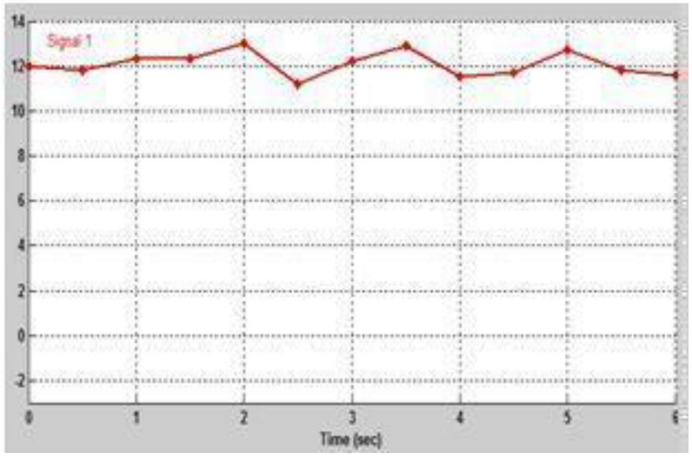

Fig. 9. Wind Speed Input

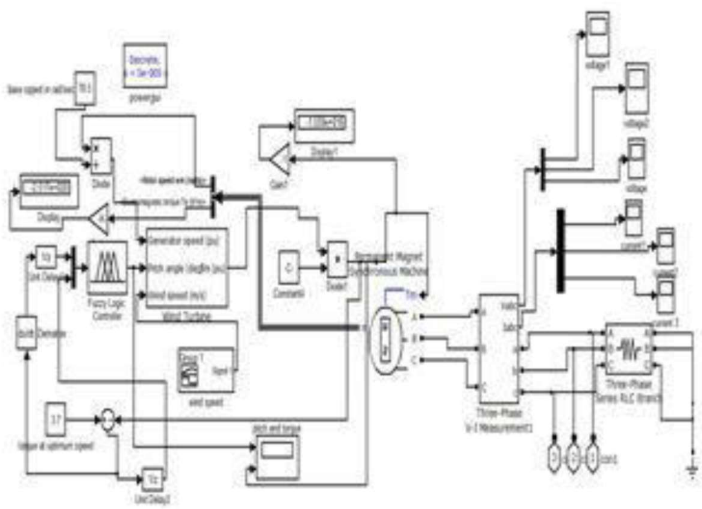

Fig. 10. Simulation of Pitch control with FL controller

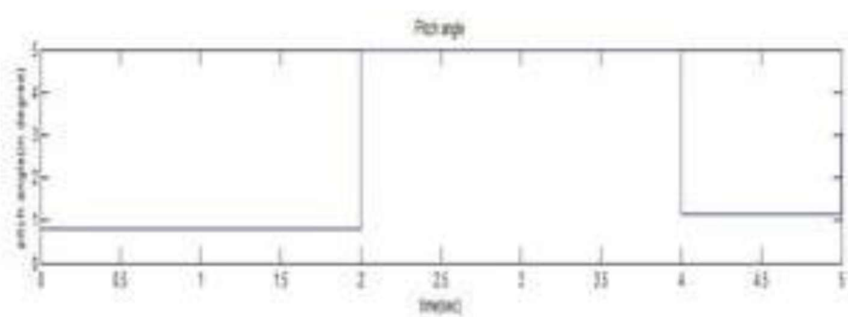

Fig. 11. Pitch angle variation

B. System performance with Rectifier-inverter module

In this work, MATLAB simulation of bridge diode rectifier and 3-level NPC inverter using voltage control technology was implemented as shown in Figure 12 according to grid side inverter equation and related voltage waveforms and the current after implementing the control technology shown in Figures 13 and 14.

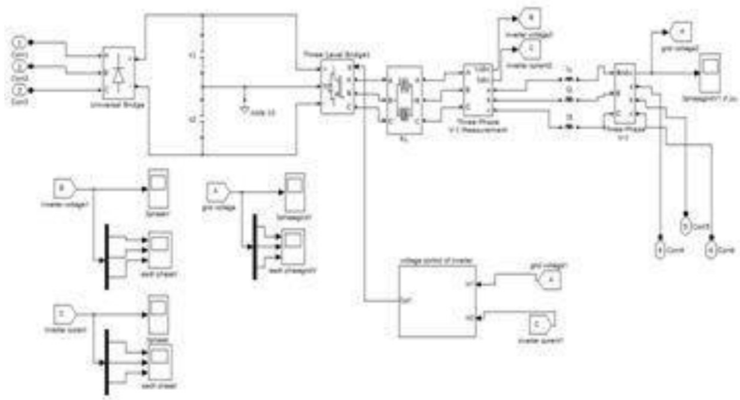

Fig. 12. Simulation diagram of converter controller technique

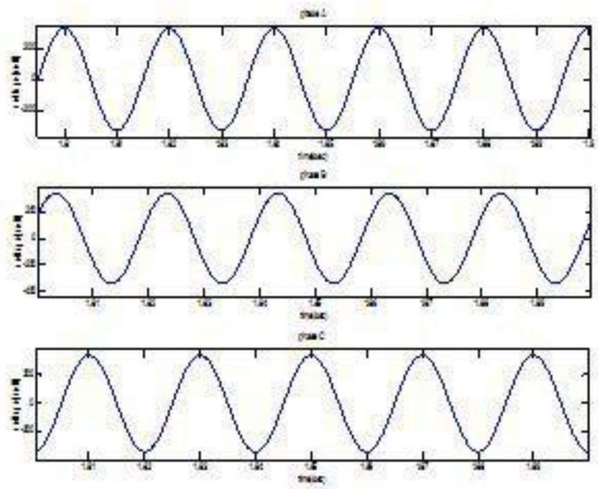

Fig. 13. Inverter output wave form-Voltage

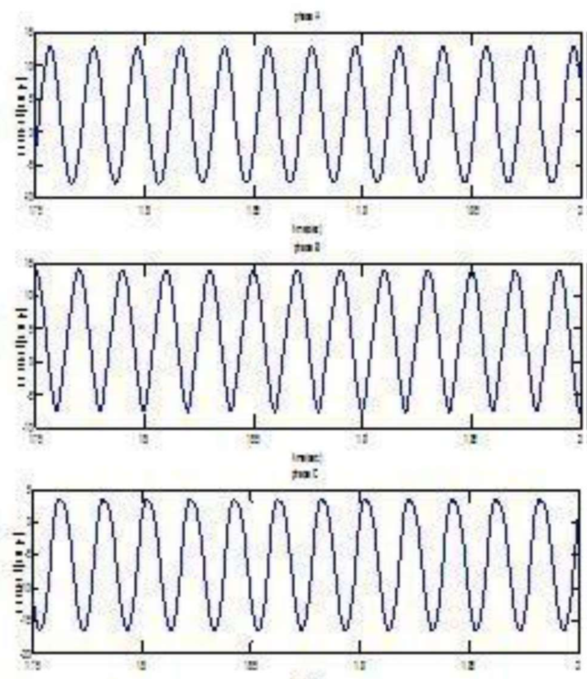

Fig. 14. Inverter output wave form-current

The harmonic analysis after implementation of the control strategy was performed and the results showed a decrease in the harmonic level in both current and voltage are within the tolerable range of operation. The FFT analysis of the output voltage and current waveforms are shown in Fig 15 & 16. The Harmonic analysis is given in Tab. II.

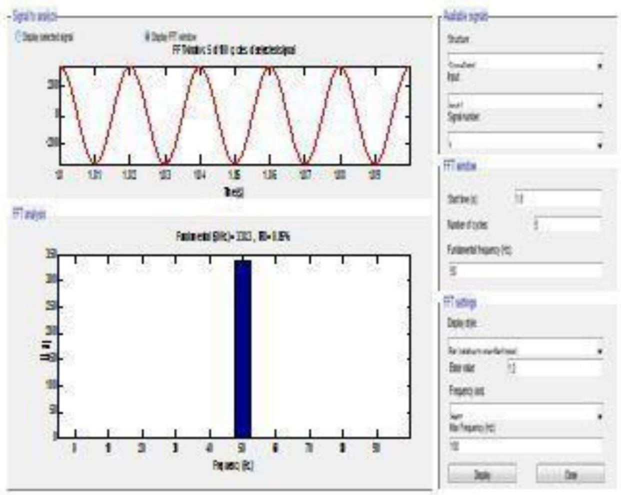

Fig. 15. Voltage waveform FFT analysis

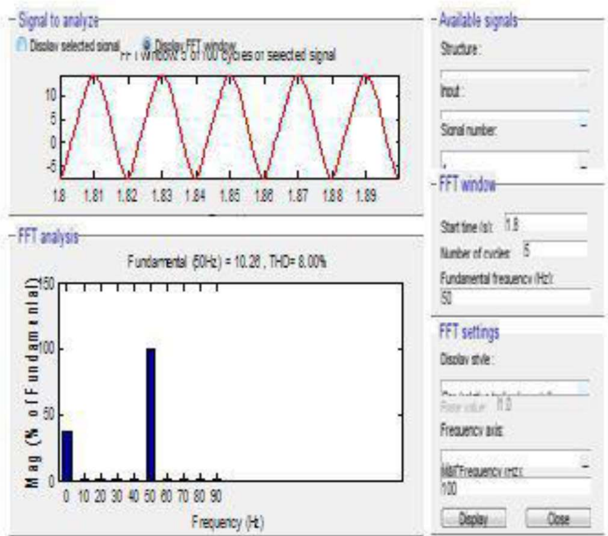

Fig. 16. Current waveform FFT analysis

TABLE II. HARMONIC ANALYSIS OF VOLTAGE AND CURRENT

Electrical parameters	Total harmonic distortion (%) of inverter	Total harmonic distortion (%) of PMSG
Voltage	0.05	27.26
Current	8.00	37.22

VI. Conclusion

The current scenario uses a different speed technology to generate electricity from wind. Whenever the wind speed reaches a value higher than the nominal wind speed, which is about 25 m/s, called the cutting speed, the blade angle to the wind is controlled to lower the blade angle to maintain the output power. Therefore, this slow control scheme is suitable for keeping the turbine above rated speed. The proposed topology with the NPC inverter module is a significant advance in inverter technology to reduce power consumption.

Appendix

TABLE III. PARAMETER SPECIFICATION OF WIND TURBINE

Parameters	Values
Nominal mechanical output power	8500MW
Base wind speed	12m/sec
Pitch angle(Beta)	0°
Base rotational speed	1.2
Maximum power at base wind speed	0.73

TABLE IV. PARAMETER SPECIFICATION OF PMSG

Parameters	Values
Base Electrical i/p power	9444.5MW
No. of phases	3
Torque base value	120.25NM
Rotor base speed	750RPM
No. of pair of poles of machines	4
Flux linkage	0.433Wb

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