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POWER ANALYSIS FOR A VARIABLE SPEED WIND ENERGY CONVERSION SYSTEM UNDER VARIABLE LOAD CONDITIONS

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ABSTRACT

The use of fossil fuels such as Coal, Gas, Diesel, Nuclear etc., in the power generation sectors are of major concerns. These power generation techniques increase the pollution across the globe due to their wide usage developing environmental unbalance. Also they are getting depleted. Hence giving high alerts for environmental unbalance. To quash these effects, the usage of natural resources for the generation of power like solar, wind, tidal power etc., should be utilized. Among all renewables, solar and wind has gained a lot attained due to their abundance in nature.

In this paper, Variable Speed Wind energy Conversion system, consisting of Wind Turbine, PMSM (Permanent Magnet Synchronous Machine) connected a standalone system is implemented. This model presents the back to back PWM converter where the generator voltage will be stabilized using DC link between the two converters. Here the PWM inverter is under the control of SPWM (Sinusoidal Pulse Width Modulation). The main objective is to analyze the power quality and harmonic distortions for various loads such as R, RL, LC, and RC. The entire model is implemented using MATLAB/SIMULINK.

Keywords: Variable Speed Wind Energy Conversion System (VSWECS), wind turbine, PMSM(Permanent Magnet Synchronous Machine), PMSG (Permanent Magnet Synchronous Machine, PWM converter, SPWM technique, FFT analysis.

I. INTRODUCTION

Inorder to secure the future for ourselves and for coming generation, it is widely accepted that we must act now to reduce energy consumption through conventional sources. So, we have to go for renewable sources, which are reliable and plenty. Among the various energy sources, wind and solar can be considered as viable options for future electricity. In 1986, the usage of wind power was started in the coastal areas like Maharashtra (Ratnagiri), Gujarat (Okha), and Tamilnadu (Tuticorin) with 55 kW Vestas wind turbines and these projects were supported by Ministry of New and Renewable Energy (MNRE). Recently MNRE is implementing a programme to promote the installation of small wind energy system with the aim to provide uninterrupted power supply to uneletrified areas[1]. It was the first time to implement pilot-cum-demonstration project of 25 kWcapacity installed at the wind turbine test station of National Institute of Wind Energy at Kayathar, Tamilnadu. Until the day 31st march 2016 the total installed capacity is 2.69 MW. Still 6 wind turbine manufacturers and 9 models empanelled under this programme.

In this paper, modeling of the Wind Energy Conversion System (WECS) was studied along with PMSG (permanent magnet synchronous generator) integrating to the grid via converter and inverter station.

The wind energy conversion system can be classified into two types:

1. Fixed Speed (WECS) and
2. Variable Speed (WECS)

Variable Speed wind energy conversion system is preferable than Fixed speed wind energy conversion system because of the following advantages:

- It can capture maximum efficiency.
- Improves dynamic behavior.
- Improves power quality.

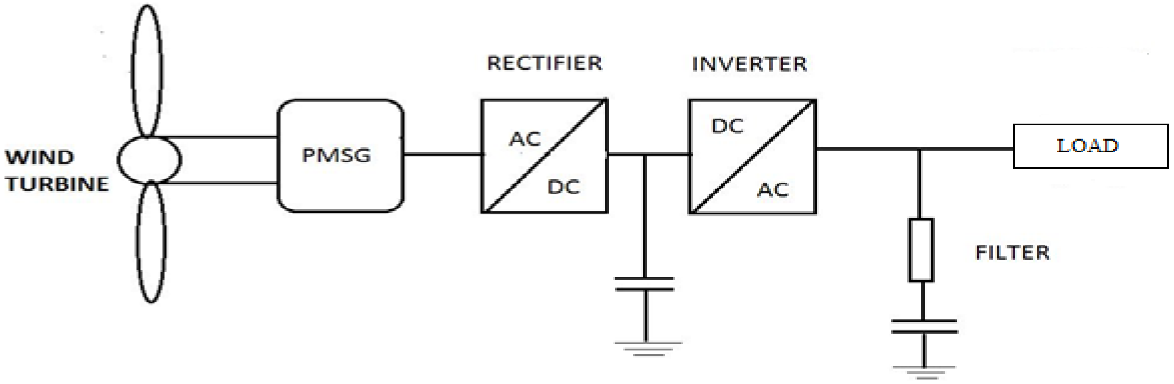


Fig. 1: Main Fig. of WECS with PMSG

In fig.1 we can observe the main Fig. of WECS which contains the components like a generator, a power electronic system, and a transformer for grid connection. The function of the wind turbine is to capture the power from the wind with help of its blades and then convert it to mechanical power.

With the help of either stall or pitch control power limitation can be done during higher wind speeds.

II. DESIGN OF WIND TURBINE

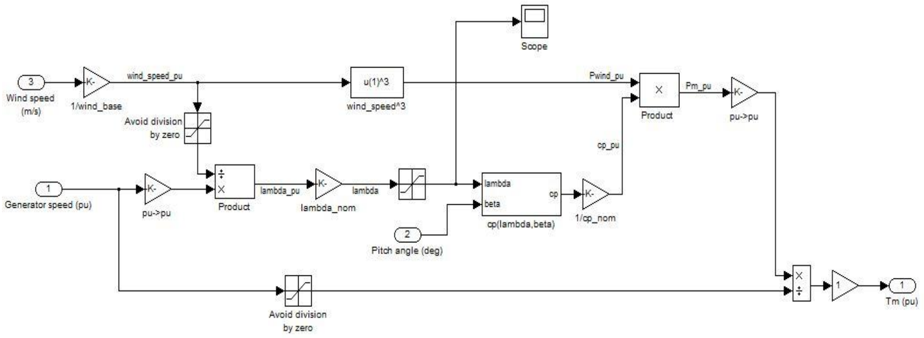


Fig. 2: Layout of wind turbine

The wind energy is captured by the blades and then converts it to mechanical power.

The power equation for wind

Power=work/time

= kinetic energy/t

The Kinetic energy can be written as $=\frac{1}{2}mv^2$therefore,

Power $= \frac{1}{2}mv^2/t$Where m= mass (kg) = ρAd (1)

Power $= \frac{1}{2}\rho Ad\,(v^2/\mathrm{t}) = \frac{1}{2}\rho Av^2(d/\mathrm{t})$ (2)

Therefore, power in the wind$Pw=\frac{1}{2}\rho Av^3$ (3)

Taking into consideration, the power of the actuator disc can be written as:

Power $= \frac{1}{2}\rho Av^3 4x(1-x)^2$ Where $x=\frac{1-v}{v_u}$(4)

Mechanical torque of wind turbine $T_m = \frac{P_W}{W}$Where $W = \frac{2\pi N}{60}$

N is representing the speed of the wind turbine

Deriving the power extraction efficiency,

$C_P = \frac{P}{P_W} = \frac{0.5\rho Av^3 4x(1-x)^2}{0.5\rho Av^3}$ (5)

Where C_p is the power coefficient, P is the power of actuator disk, P_w is the power of the wind, ρ is the air density, A is the circular area, and v is the wind speed.

2.1 Performance of The Wind Turbine

A wind turbine can be known as a power extracting device. With the help of indicators like power Vs wind speed, torque and thrust performances the wind turbine performance can be known.

The *tip speed ratio* (λ) is defined as the ratio between blade speed and wind speed therefore,

$\lambda = \frac{R\Omega_t}{v}$ (6)

Where R is the blade length, Ω_t is the rotor speed and $v$is the wind speed. The tip speed ratio characterizes the power conversion efficiency and used to define acoustic noise levels.

The power extracted by wind turbine,

$P = 0{,}5\rho\pi R^2 v^3 C_p(\lambda)$ (6)

The conversion efficiency is always below the Betz limit (0.59), since it assumes perfect blade design. A typical two – bladed wind turbine represents the $C_p(\lambda) - \lambda$ curve as shown below[4].

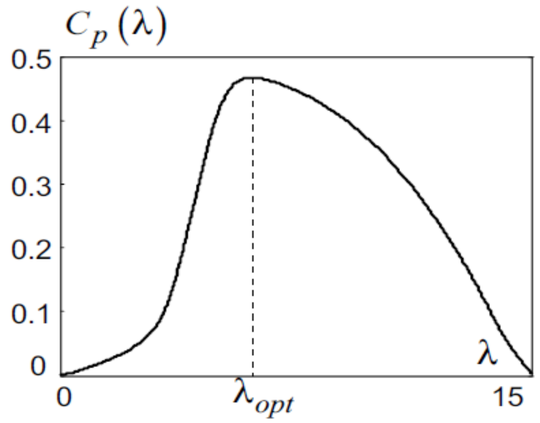


Fig. 3: *Cp*(λ) performance curve

From the Fig.3 it can be known that, for a particular tip speed ratio power conversion efficiency will be maximum. Depending upon the various values of λ and β, the*Cp*family ofcurve is observed as follows:

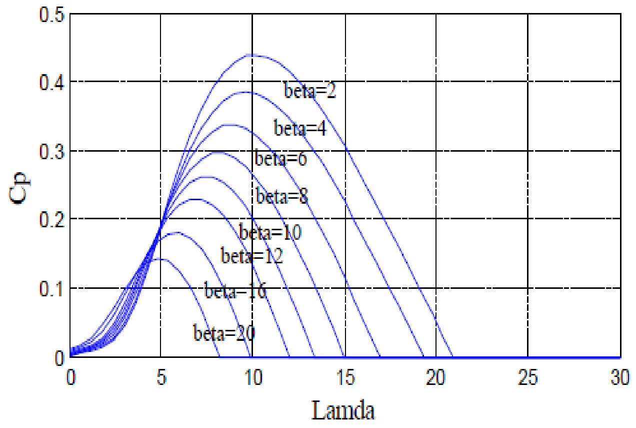


Fig. 4: *Cp* family curve Vs β and λ

III. MODELING OF PMSG

Basically, the synchronous generator will have better efficiency and power factor over induction machines. Therefore several types of generators can be used in wind turbines. Among them PMSG (Permanent Magnet Synchronous Generator) is preferred for gearless applications.

In variable speed wind energy systems, usually the synchronous generator is connected to the load/grid via a power converter station. Compared to WRSG (Wound Rotor Synchronous Generator) PMSG is more efficient because of its self-excitation and also elimination of rotor copper losses. It does not need any external supply as WRSG, thus it requires less maintenance. However, the materials used for producing permanent magnets are expensive, and shows difficulty in their working while manufacturing them. The frequency of the induced voltage to the grid frequency will be adapted by the generator through a converter therefore, it regulates the output voltage and the power factor is determined by the load/grid.

3.1 Mathematical Equations of PMSG

According to rotor d-q reference frame the mathematical modeling of a PMSM drivegiven below

$$V_d = RI_d + L_d\frac{dI_d}{dt} - L_q W_e I_q \qquad (7)$$

$$V_q = RI_q + L_q\frac{dI_q}{dt} + L_d W_e I_d - W_e Y_{af} \qquad (8)$$

With $Y_d = L_d I_d + Y_{af}$ (9)

$$Y_q = L_q I_q \qquad (10)$$

$$-T_e = J\frac{d}{dt}W_r + BW_r + T_l \qquad (11)$$

$$T_e = -\frac{3}{2}P\left(Y_{af}I_q + \left(L_d - L_q\right)I_d I_q\right) \qquad (12)$$

Where $W_r = \frac{2}{p}W_e$

$$W_e = \int \frac{1}{W_r}\,[\frac{1}{J}\frac{P}{2}(T_e - T_m - B\frac{2}{p}W_e)] \qquad (13)$$

Here V_d, V_q =dand q axes stator voltage

$I_d,. I_q$= d and q axes stator current

L_d, L_q=d and q axes inductances

R = stator resistance

T_e, T_l = electromagnetic and load torque

J = moment of inertia of motor and load

B = friction coefficient of the motor

P =number of pole pairs

W_e = rotor speed in angular frequency

Y_{af} = rotor magnetic flux linking the stator

IV. DESIGN AND IMPLEMENTATION OF PMSG BASED VARIABLE SPEED WECS IN MATLAB

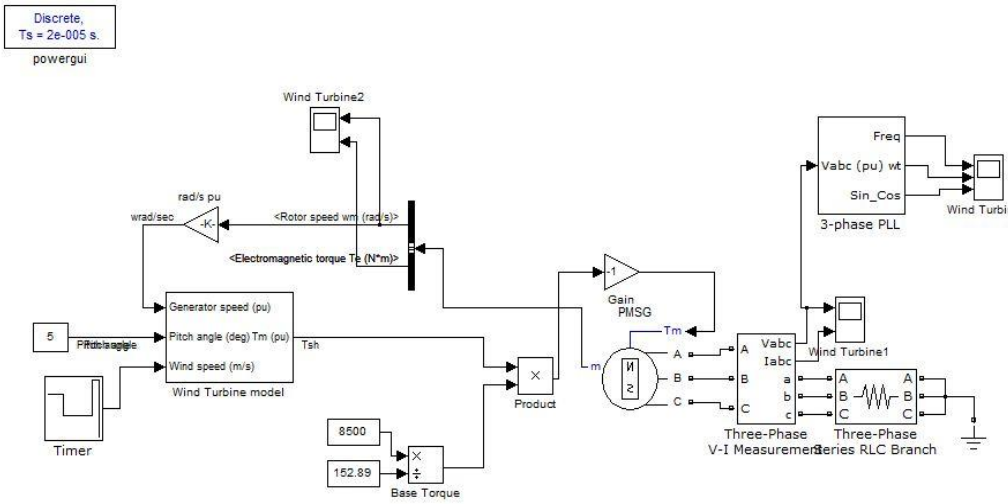


Fig.5: PMSG with WECS

In the method[7] PMSG based variable speed wind energy conversion system, the wind turbine provides the negative torque this torque will helps to run the PMSM as a generator when it will be coupled to the wind turbine. The voltage, FFT and power analysis can be done with the help of connecting load to the PMSG.

V. BACK TO BACK PWM CONVERTER

In general, back to back PWM converter is known as two level converter because it consists of two levels such as generator side rectifier as well as grid side inverter. A DC link is connected between the two PWM-VSI(voltage source inverter) it is also named as decoupling capacitor which gives separate control in the inverter on generator side and on load side.

It has the Advantage like less cost and

Some Disadvantages like

- reducing the life of the system,
- switching losses and,
- High frequency harmonics.

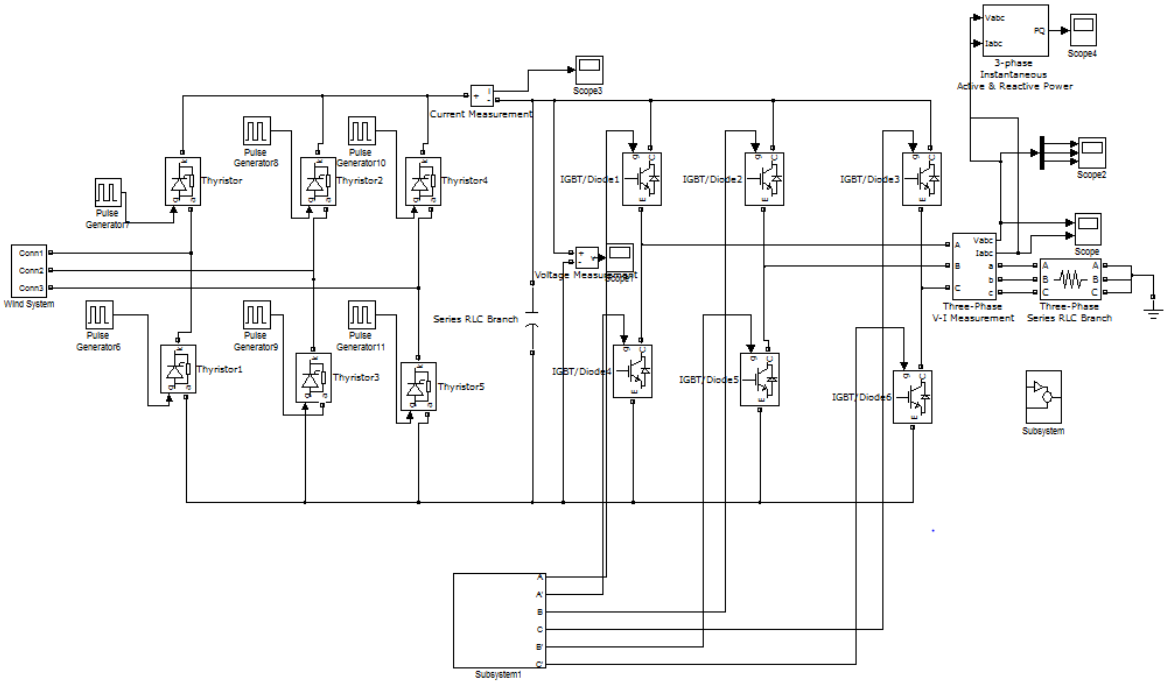


Fig. 6: Back to Back PWM converter

VI. IMPLEMENTATION OF SPWM TECHNIQUE:

The DC-AC inverters usually operate on pulse width modulation technique (PWM). In PWM technique,widths of the gate pulses are controlled by several mechanisms. In order to maintain the output voltage as rated voltage PWM inverter is used irrespective of the output load. In this method SPWM (Sinusoidal pulse width modulation)technique ischosen as it provides the advantages like low switching losses, fewer harmonics in the output and also easy to implement.

In SPWM technique, the width of the pulses are not constant ,they change for every half cycle therefore the pulse width varies in proportion with amplitude of sine wave. The gating signals are generated by comparing sinusoidal reference with triangular signal.

VII. RESULTS AND DISCUSSIONS:

Analyses on R load with LC filter:

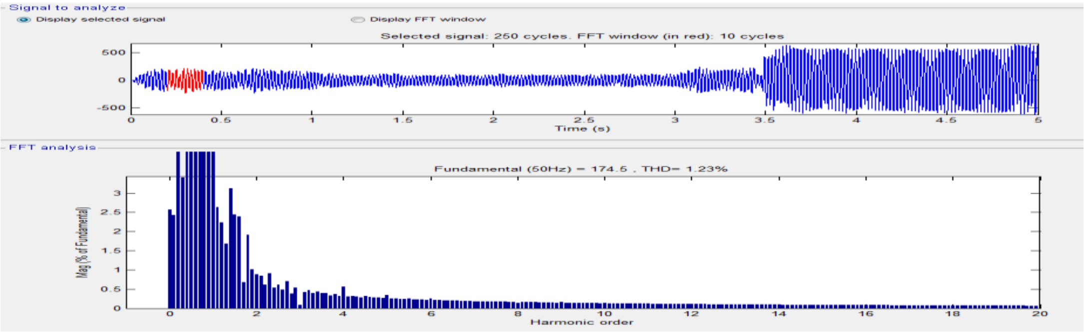


Fig. 7: FFT analysis on r load with filter

In this paper, FFT analysis can be done with filter and without filter for various loads such as R, RL, LC, and RC. The voltage, current, and power waveforms can also be evaluated in this work.

In fig 7, by using LC filter it is clear that the total harmonic distortion occurred is very less and better,along with the THD the Three phase voltage has also been observed here.

Analysis on RL load with LC filter:

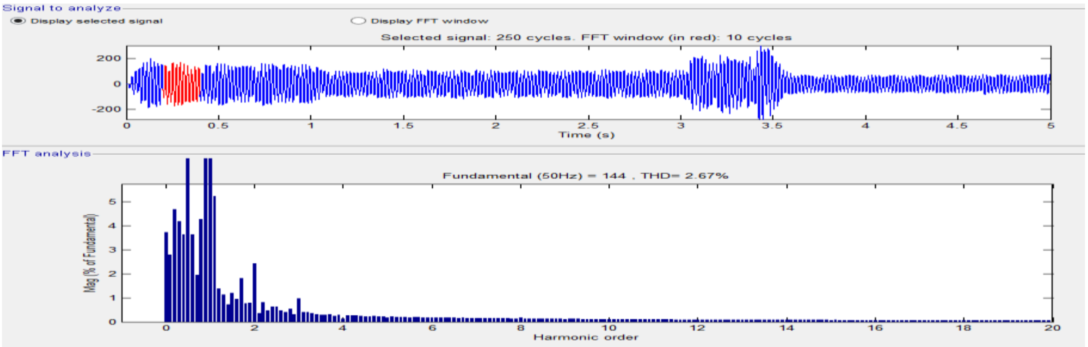


Fig. 8: FFT analysis on RL load with filter

The FFT analysis for RL load is little more than R load (see Fig. 8) therefore the voltage can also be observe here same as in fig 7.

Analysis on LCload with LC filter:

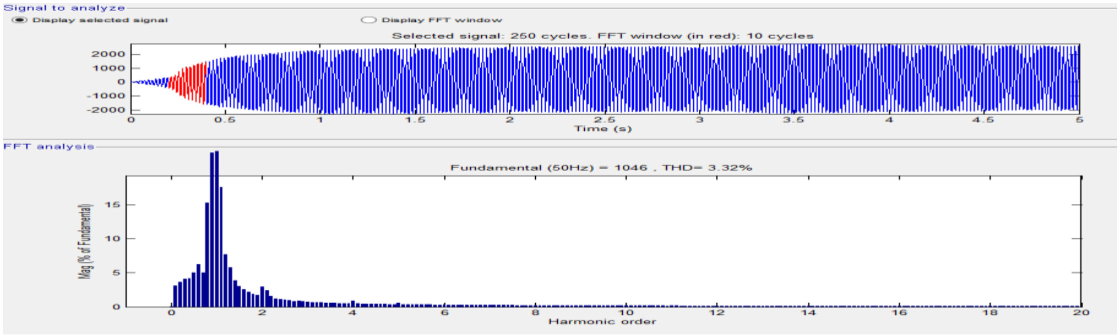
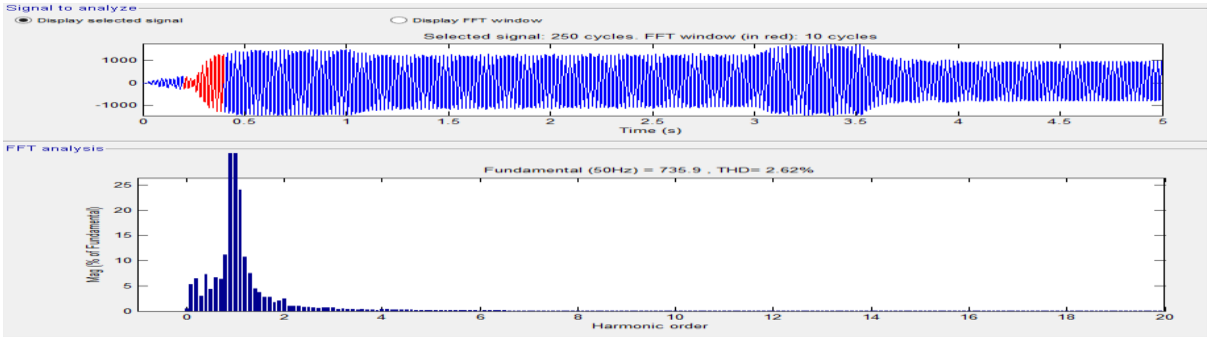


Fig. 9: FFT analysis on LC load with filter

The percentage of THD is increased in the above shown fig 9 because of the presence of LCload. Since the LC load completely can consumes or produces the reactive power, in similar to that the harmonic distortions are more/less.

Analysis on RC load with LC filter:



Selected signal: 250 cycles. FFT window (in red): 10 cycles

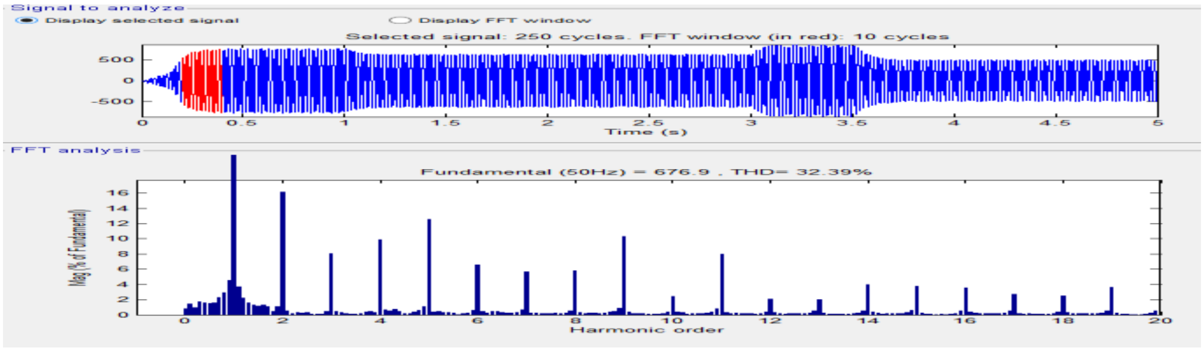
Fundamental (50Hz) = 735.9 , THD= 2.62%

Fig. 10: FFT analysis on RC load with filter

In fig 10, both the THD percentage and Three phase voltage is represented with the frequency can be set for 50Hz for all the loads. After the using of R load the THD is again better for this RC load with slight changes.

Analysis on R load without filter:

All above mentioned analysis can be done by using the LC filter. Now, here it can be seen that the voltage and power analyzation along with the FFT analysis without using the filter.

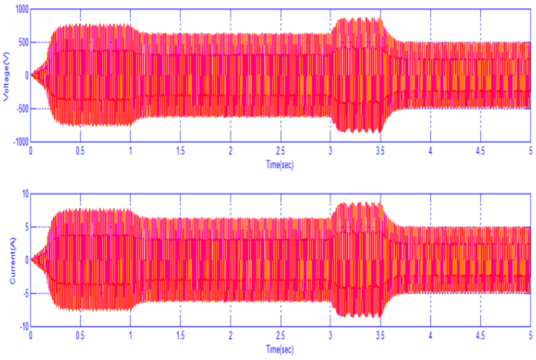


Selected signal: 250 cycles. FFT window (in red): 10 cycles

Fundamental (50Hz) = 676.9 , THD= 32.39%

Fig. 7: FFT analysis on R load

The complete waveform can be taken for 10 cycles in the above shown Fig. and based on wind speed the voltage changes proportion to it.



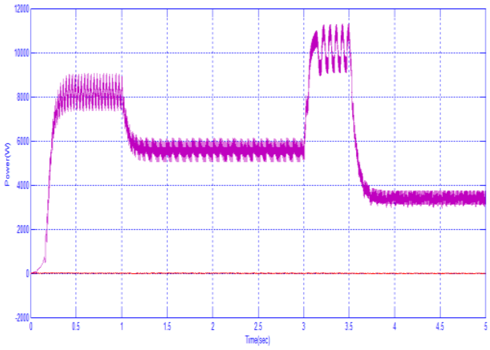


Fig. 8: Vand I of R loadFig. 9: Activeand ReactivePower of R load

From the above Fig. 8, it can be easily known that for various wind speeds the voltage and current changes accordingly. Hence using the R load, fig 9 shows the active power only whereas the reactive power becomes zero.

Analysis on RL load without filter:

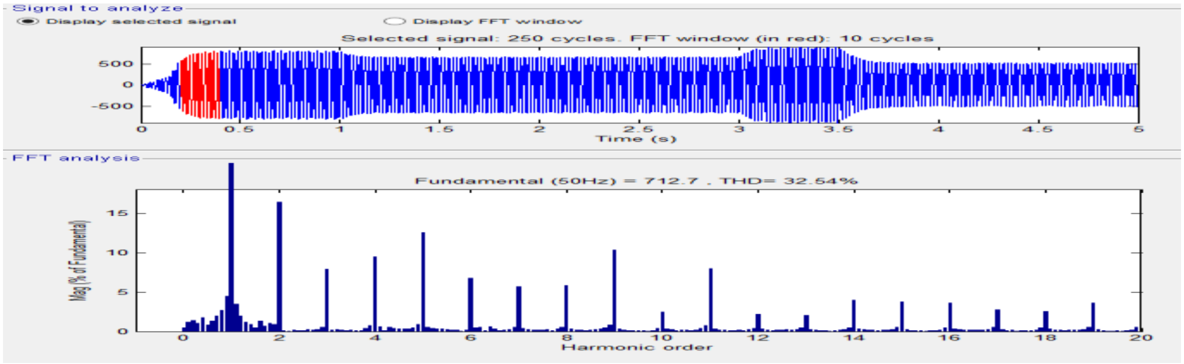
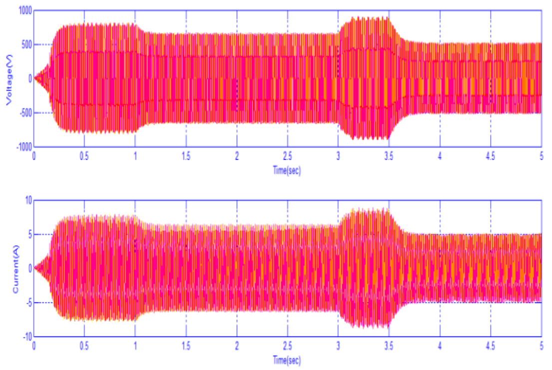


Fig.10: FFT analysis on RL load

In fig 10, the entire analysis can be done for RL load, here three phase voltage can be observed for different wind speeds and the total harmonic distortion also changes for various loads.



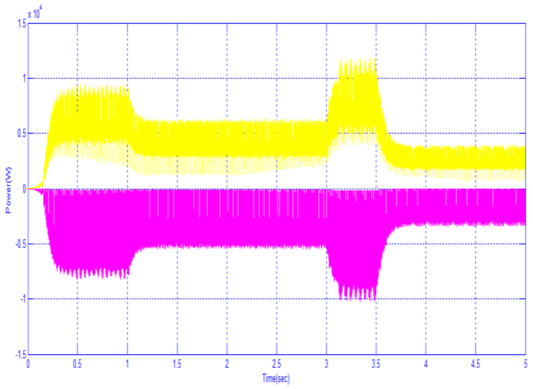


Fig. 11: Vand I of RL loadFig. 12:Active and Reactive Power of RL load

Compared to the R load it can be observed that the distortions are more in current waveform for RL load in fig 11. The active and reactive power for RL load is shown in fig 12.

Analysis on LC load without filter:

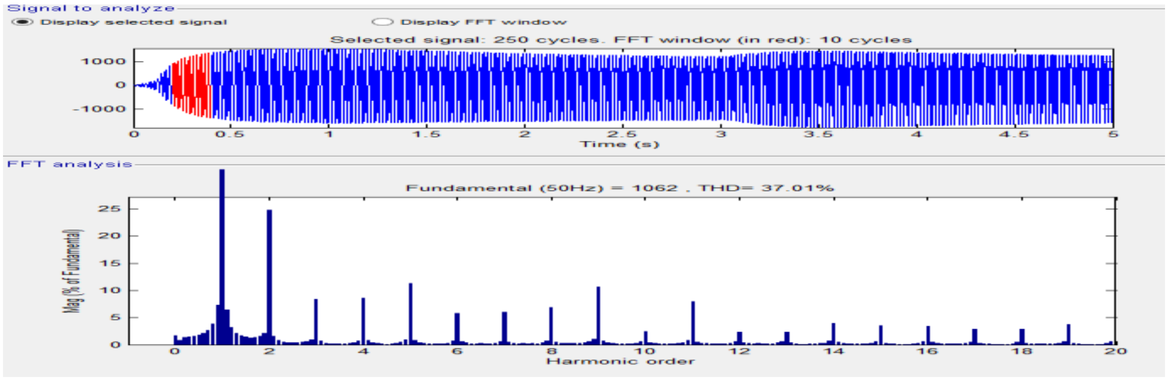
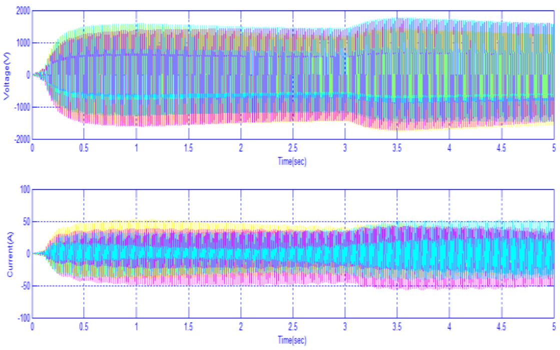


Fig. 13: FFT analysis on LC load

For the various loads the percentage of harmonic distortion is changing and the voltage also changes because of inappropriate wind speeds and also for different loads.



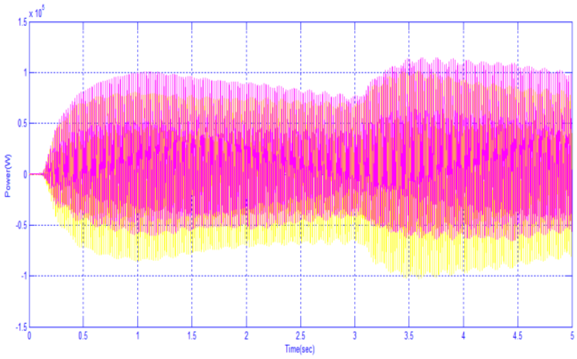
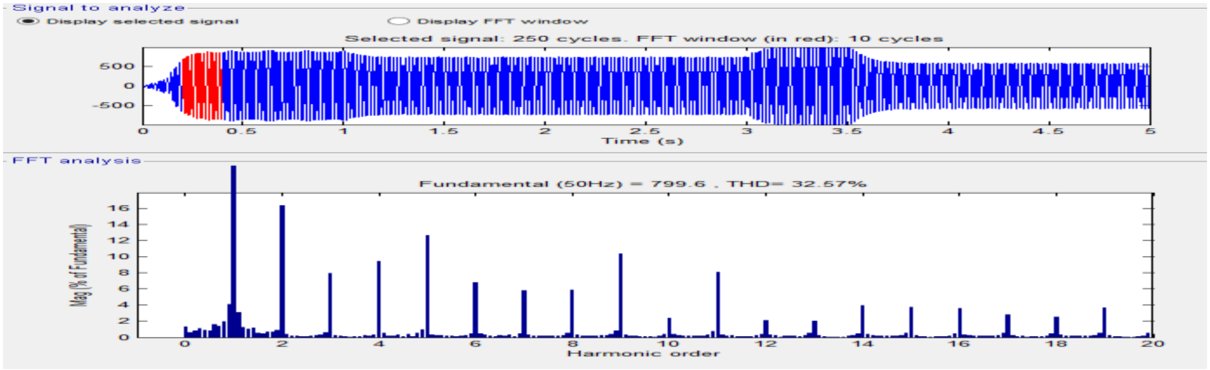


Fig. 14: V and Iof LC loadFig. 15: Active and ReactivePower of LC load

In fig 14, the voltage and current waveforms are varies differently compared to the previous loads and here it can be known that distortions are less and in fig 15, the reactive power is negative whereas active power is positive for the LC load.

Analysis onRCloads without filter:

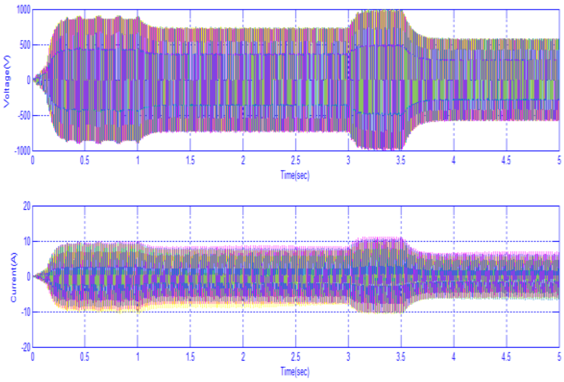


Selected signal: 250 cycles. FFT window (in red): 10 cycles

Fundamental (50Hz) = 799.6 , THD= 32.57%

Fig. 16: FFT analysis on RC load

In fig 16 as like other loads the level of harmonic distortion can also be known here with RC load and observed as similar to previous loads with slight changes.



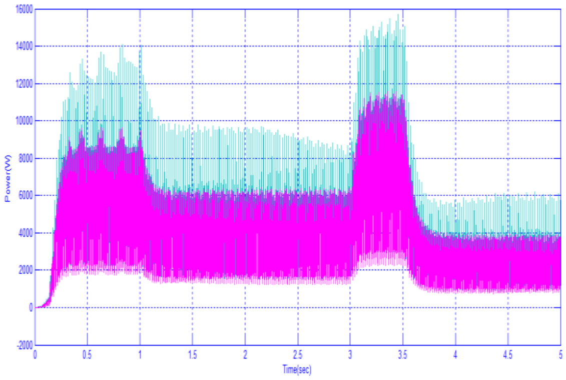


Fig. 17: Vand I of RC loadFig. 18: Power of RC load

TheActive and Reactive power both can be observed on the positive cycle in fig 18 for RC load. The voltage and current waveforms are shown in fig 17 with some slight changes compared to the other loads.

VIII. CONCLUSION

In this paper, the SIMULINK model of a Variable Speed Wind Energy Conversion System (VSWECS) with PMSG has been implemented via using a PWM converter station. The two converters are linked by a DC voltage bus. The first one used in this work is Diode Bridge Rectifier and the other one is thyristor bridge rectifier. Here,for the inverter operation SPWM technique is developed and evaluated the active and reactive power along with the voltage, current and harmonic distortion waveforms for various loads. Using various loads the FFT analysis also presented in this paper with LC filter and without filter.The performance of this work had done using MATLAB/SIMULINK.

Table 1: Percentages of THD for different loads

FFT ANALYSIS		
LOAD	**% OF THD WITH FILTER**	**% OF THD WITHOUT FILTER**
R	1.23%	32.39%
RL	2.67%	32.64%
LC	3.32%	37.01%
RC	2.62%	32.57%

Comparing the values of THD (total harmonic distortion) for different loads such as R, RL, LC, and RC using with filter and without filter is mentioned in table 1. The harmonic distortion is less for R load in both conditions i.e. with LC filter and without filterand it can be observed that the distortion value is again better for RC similarly for RL and LC loads but among all loads the distortion is little bit high for LC load it will be clearly shown in fig 9, 13 and in above table. Therefore, besides the THD values of PMSG, the voltage and current waveforms also evaluated. Up to this method, work had done for Open loop Control Strategy further approach regarding this work is to implement the same work with PI controller and to complete this method in Closed loop Control Strategy.

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