Pitch Control Strategy by Using Fuzzy-PID Control for Output Optimization in Wind Turbine

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Abstract

As we know the Energy demand is growing everyday and the main source of power generation is by using coal and other non-renewable energy resources but global warming is one of the most serious issues in the world .So it's the social as well as moral responsibility for every individual as well as countries also to promote the Nonrenewable Energy based Power Generation. Wind Energy and Solar Energy has great potential to generate Energy. In this work the Wind Energy is used to generate power and wind flow is nonlinear so it's a major challenge to get the constant outputs and for this purpose conventionally PID control system is used to get the maximum power point tracking from the wind flow. The control of pitch angle should be designed in such a manner to get nominal rotational speed and it is achieved normally by PID controller. This controller has a good response when the wind is stable. The fuzzy controller has an optimal response when the statistics of wind analysis and the dynamic response of wind is available and can be used in the design of Fuzzy control system rules and membership functions. In this field lots of research is going on and the electrical output increased with good percentage.

Index Terms- Fuzzy logic, Pitch angle controller, PSO (Particle swarm optimization), ZN (Ziegler Nichols), PID (Proportional integral derivative).

1. Introduction

The amount of electricity generation has been increasing day by day to meet the essential growing demand through renewable source of energy. In the clean energy, wind and solar energy has found to be great potential in recent years. The council of wind energy reported 60.4 GW of new installations in year 2019 and global capacity recorded 651 GW and expected growth of near about 100GW and more in the next decade. [1]

As per the technological point of view for the development and construction of large wind turbines., the highest capacity wind turbine was produced by Siemens that generates about 14

MW of power and has a swept area diameter of 222 m and has the requirement of an annual average wind speed of 10m/s. [2]

As per the energy efficiency goals, controlling of wind turbine is the main challenge for the engineers. From the point of view of control system has to meet certain requirements and objectives simultaneously. The control system should be well designed to obtain power of nominal value. [3]

Furthermore, the fatigue and mechanical vibrations should be reduced since the control system influences stability of wind turbine. [4].Our work is based on the pitch of the blades a lot of solutions has been proposed as the nonlinear wind is a major challenge, its heavy dynamics and complexity in various control signals.

Data analysis of wind is very important factor to develop a better wind turbine controller. In this work we develop a wind turbine pitch control using fuzzy logic algorithm along with the PID control system and the outputs analyzed. The main points of our work are summarized as follows.

The development of a wind turbine model along with the two mass drive train and synchronous generator connected to the grid. A fuzzy control system has been designed along with the PID control system and the rule based on the future prediction of wind. Various control system constants can be varied as per the rule based on fuzzy set and membership functions to receive much better results.

2. Related Works

A model has been designed and proposed for the hybrid control system and simulation done for the comparison of conventional PID control system and advanced intelligent fuzzy logic controller accomplished with deep learning module and without deep learning module. The results show the improvement with deep learning module and improvement in control performance of system. For low and medium wind speed the improvement of 21% is obtained as compared with the conventional controller and 7% with respect to normal standard fuzzy control system. An intensive study has been carried out in deep learning configuration. [5]

A pitch control system based on reinforced learning is designed and implemented on the wind energy conversion system model. This control system has four algorithm a state estimator, a reward strategy, a policy table and policy update algorithm. They are designed to improve the wind turbine efficiency. Two reward categories only positive and positive negative strategies are proposed and linked to the wind turbine control. The controller is then compared with the conventional controller PID regulator for the small wind turbine and obtains a better performance. The results show how the positive negative rewards improve the performance of the controller and reduce error time. [6]

The pitch angle controller is an adaptable technique for the nominal rotational speed with a PID controller. This controller has a good response when the wind is stable and not well with the changes in speed of the wind. To solve this issue our work proposed a control system based on PID with adjustment of gain parameters automatically by fuzzy system. The membership functions defined from the strategy that is wind speed measurements, statistical analysis of wind variations and wind path analysis. This system is implemented on a 14 KW wind turbine where the difference in comparison with the conventional controller is measured. The output seems to be increased by approximately near 7% and the rotor damage risk and fatigue reduced by 20%. [7]

The maximum power generation from the wind energy requires control of various parts of the system. This article presents a pitch angler control system for the wind turbine by using PID controller in addition to the ant colony optimization and particle swarm optimization. For tuning the PID control Ziegler Nichols and particle swarm optimization has been used for the production of rated stable output power in variable and fluctuating wind. This model is simulated in a fast wind speed variations and the results compared with PID-ZN and PID-PSO to verify the output and its effectiveness. This approach has many advantages of easy implementation; robust control of output power with fluctuating wind speed is also an advantage of this strategy. Various analysis for the simulation results has been done and found satisfactory performance in the fluctuating wind speed locations. The wind turbine system and two different control systems like PID-ZN and PID-PSO has been compared at different wind speed. The hybrid PID-ACO is found to be much suitable as compared to PID-PSO and conventional PID. [8]

Wind parameters forecasting plays very important role in wind energy conversion system. Due to its nonlinear and unpredictable behavior it's a difficult task. This work is based upon the new approach of component analysis and hidden patterns of wind, this algorithm is applied to wind data to identify the hidden and meaningful information, an optimized deep learning algorithm with a tensor flow framework is used to forecast wind power from the various significant features. This proposed idea has been applied to the three different database hourly, monthly and yearly gathered from national renewable energy laboratory energy database. The results show that the proposed research can accurately predict wind power using a span ranging from hours to years. [9]

3. Modelling of Wind Turbine

The wind turbine modelled for the variable speed and the mechanical power versus rotor speed characteristics is shown in the below graph. The point for the optimum power is pointed accordingly.

The power of the wind turbine can be illustrated as

$$P_r = 1/2 \rho \pi R^2 Cp\,(\lambda)\, v^3 \qquad \ldots \qquad (1)$$

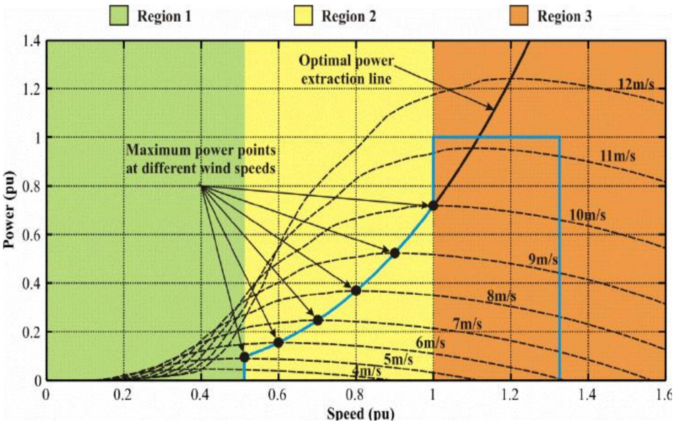

Fig -1: Mechanical power versus rotor speed with optimum power shown

When optimum value is maintained by rotor to obtain maximum power can be expressed as

$P_{rmax} = kopt\omega 3$ .... (2)

Where K_{opt} is decided by

$K_{opt} = \rho\pi\ R5Cpmax2\lambda 3opt$ .... (3)

$T_{mopt} = K_{opt}(\omega_{opt})2$ (4)

It can be seen from above fig that there is an optimum rotor speed to produce maximum optimum power from the wind. The main function of the control system is to keep the turbine operates in this curve. If the control system will follow this optimum curve, the turbine will produce maximum power from the wind available at that time.

The output ac voltage amplitude can be controlled at rated voltage. The ac voltage output and dc voltage relation of a three phase PWM inverter can be expressed as

$V_{LL1} = \frac{\sqrt{3}}{2\sqrt{2}}\, k\, V_{dc}$ …… (5)

4. Wind Energy Conversion System

In our work a wind energy conversion system is designed and connected to grid. In this modelling firstly a wind turbine has been designed and pitch control system is attached to the wind turbine. The whole system comprises of turbine, two mass drive train, inverter, converter, control system and grid. The research work is done on the pitch control system by using a fuzzy control system with predefined inputs and outputs to get the desired output.

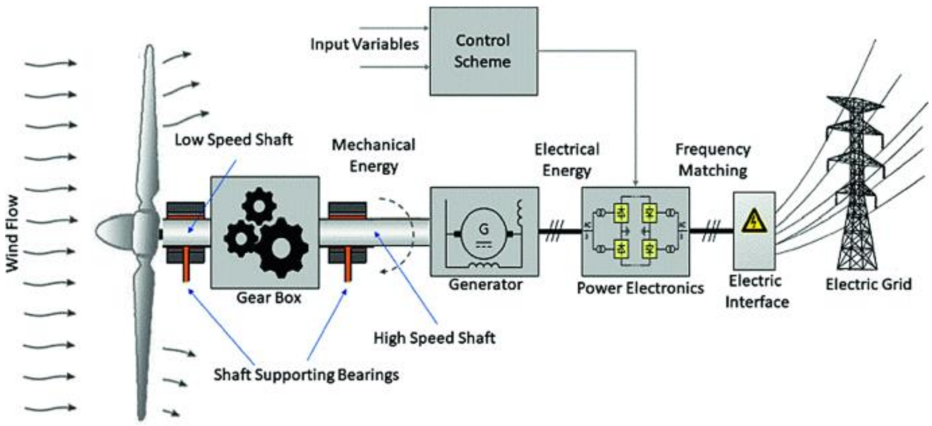

Fig -2: Wind Energy Conversion System

5. Two mass drive train

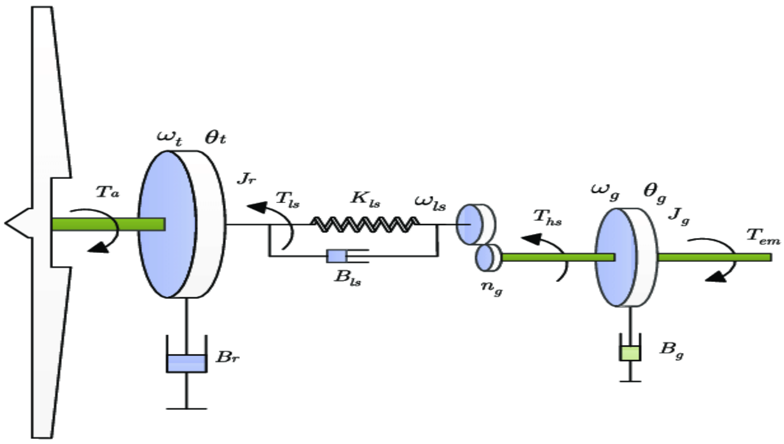

Fig -3: Wind turbine with two mass drive train

The two mass drive train has effects on variable speed wind turbine has been described below in the form of equations. The simulation results shows that the control systems capability to control both active and reactive powers so that the system will be stabilized during transient condition. It is found that for high speed wind turbine and generator inertia parameters of the two mass shaft model could lead to a longer time in recovery to its steady state after a network disturbance. It is also found that lower shaft stiffness parameters of two mass model could also lead to the longer time for the steady state after the network disturbance. [5]

$$T_T - K_{sh}(\theta_T - \theta_G) - D_T\omega_T = J_T\frac{d\omega_T}{dt}$$

$$K_{sh}(\theta_T - \theta_G) - T_G - D_G\omega_G = J_G\frac{d\omega_G}{dt}$$

$$T_{sh} - K_{sh}(\theta_T - \theta_G)$$

Where, T_T, T_G, T_{sh} are turbine , generator and shaft torques(N/m), ω_G is the generator angular speed (rad/sec), θ_T and θ_G are turbine and generator angular position (rad).

The differential equation with its dynamics of a two mass drive train of wind energy conversion system is expressed as:

$$2H_t\frac{d}{dt}\omega_t = T_m - T_{sh}$$

$$\frac{1}{\omega_{elb}} * \frac{d}{dt}\theta_{tw} = \omega_t - \omega_r$$

$$2H_g\frac{d}{dt}\omega_r = T_{sh} - T_g$$

Where H_t represents inertia constant of the turbine, H_g represents inertia constant of the synchronous generator , θ_{tw} is the shaft twist angle , ω_t represents angular speed of the turbine, ω_r is the rotor speed Synchronous Generator , ω_{elb} is the electrical base speed and shaft torque T_{sh} is

$$T_{sh} = K_{sh}\theta_{tw} + D_t\frac{d}{dt}\theta_{tw}$$

Where K_{sh} represents shaft stiffness and D_t is the damping coefficient.

6. Fuzzy Control System

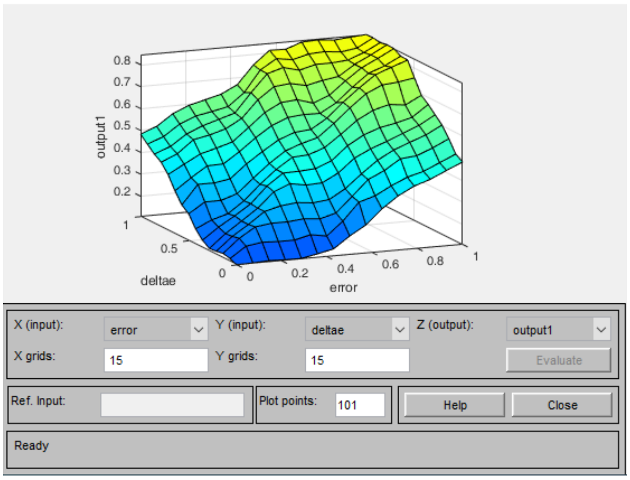

Fig -4: Surface View of control system

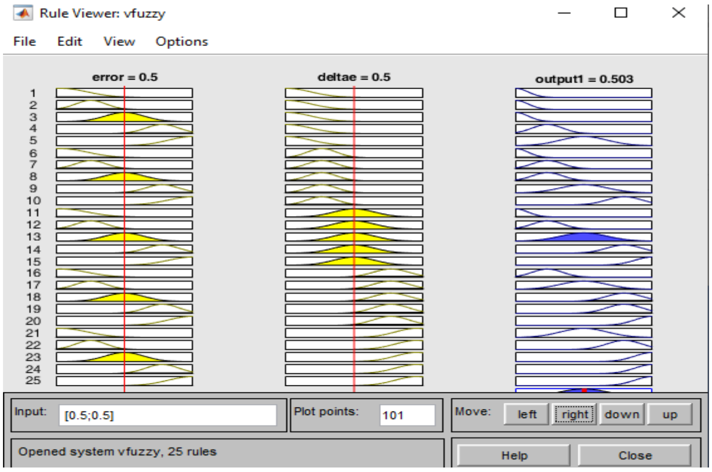

Fig -5: Rule View of control system

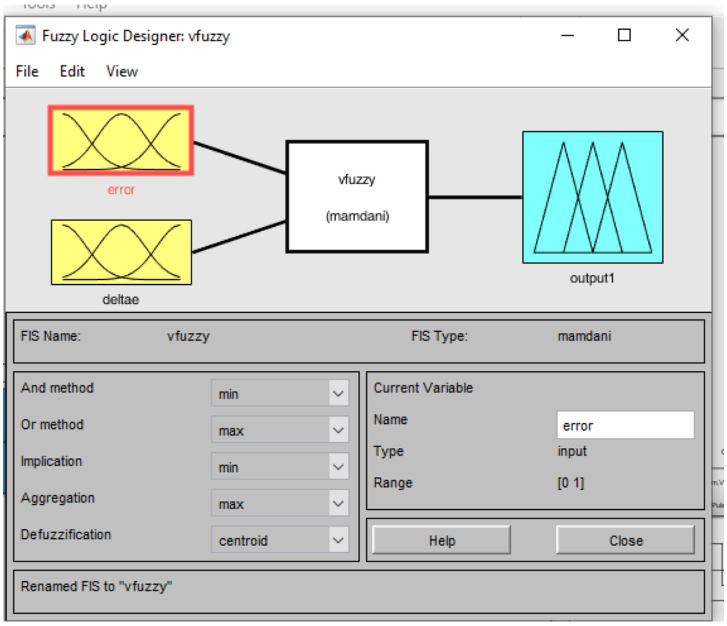

Fig -6: Fuzzy logic designer

The fuzzy controller designed in this work taken by a reference paper has two inputs and one output by using takagi sugeno structure.

Two inputs, Perr and VDL, and one output, href. The input Perr is assigned 3 fuzzy sets, the output is a singleton that can take 3 values: - $\pi/4$, 0, and $\pi/4$ (rad). This configuration of fuzzy system obtained by trial and error. Figure above shows the fuzzy sets of the inputs. [6]

• If Perr = Neg and VDL = Low then out = 0

• If Perr = Neg and VDL = Med then out = - $\pi/4$

•If Perr = Neg and VDL = High then out = - $\pi/4$

•If Perr = Zero and VDL = Low then out = Zero

•If Perr = Zero and VDL = Med then out = Zero

•If Perr = Zero and VDL = High then out = Zero

•If Perr = Pos and VDL = Low then out = $\pi/4$

•If Perr = Pos and VDL = Med then out = $\pi/4$

•If Perr = Pos and VDL = High then out = Zero

7. Results

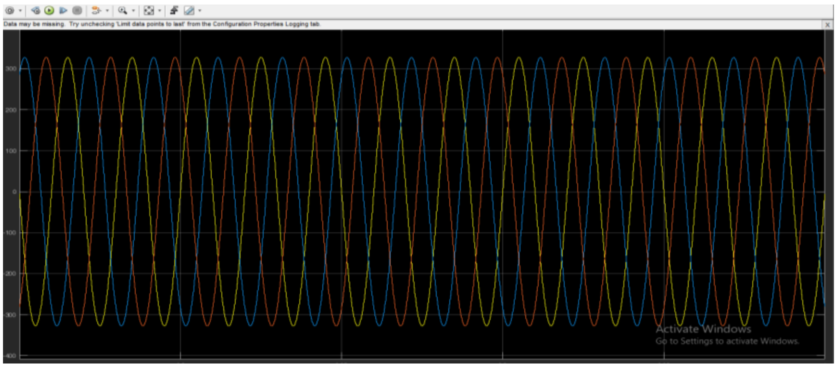

Fig -7: Voltage output from fuzzy system

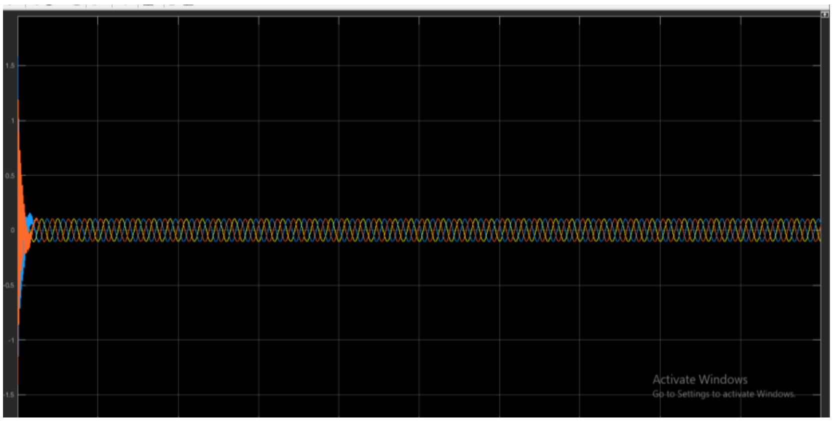

Fig -8: Current output from fuzzy system

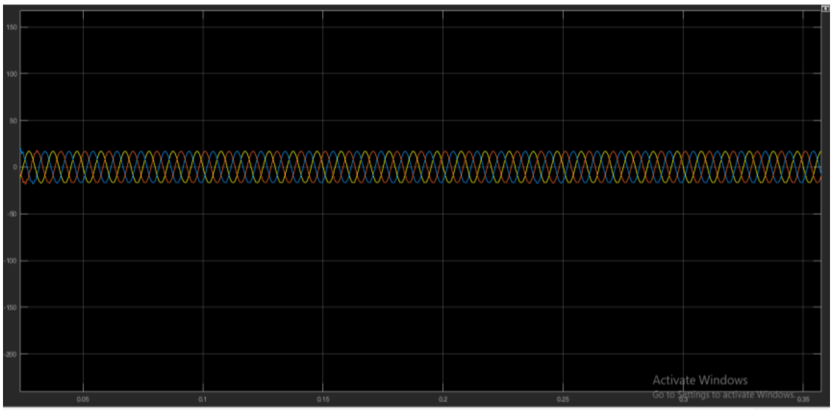

Fig -9: Power output from fuzzy system

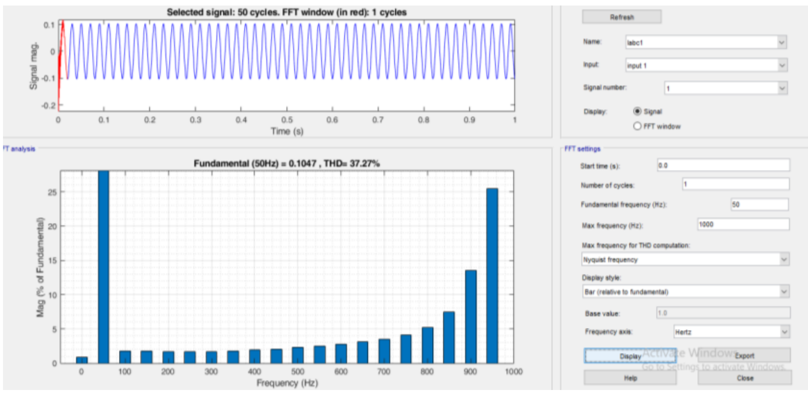

Fig -10: Current harmonic distortion of PID

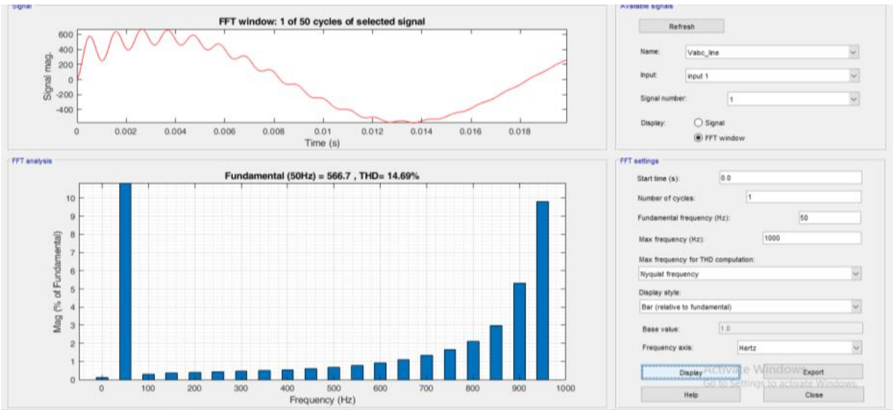

Fig -11: Voltage THD of PID

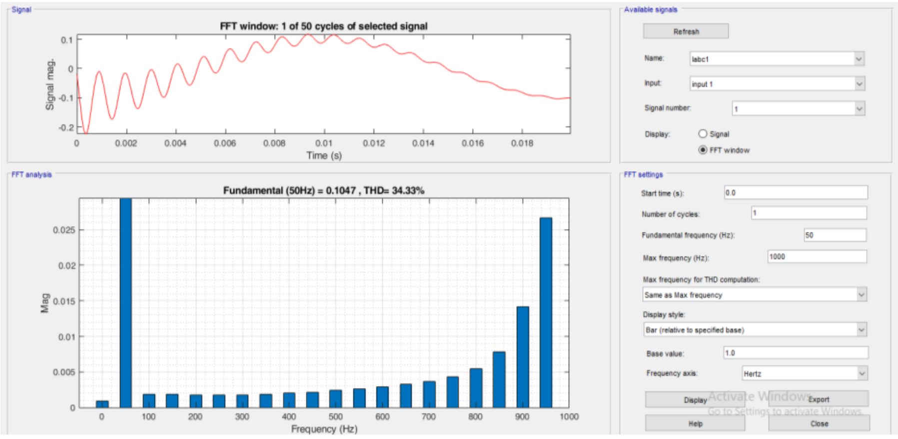

Fig -12: Current THD of Fuzzy system

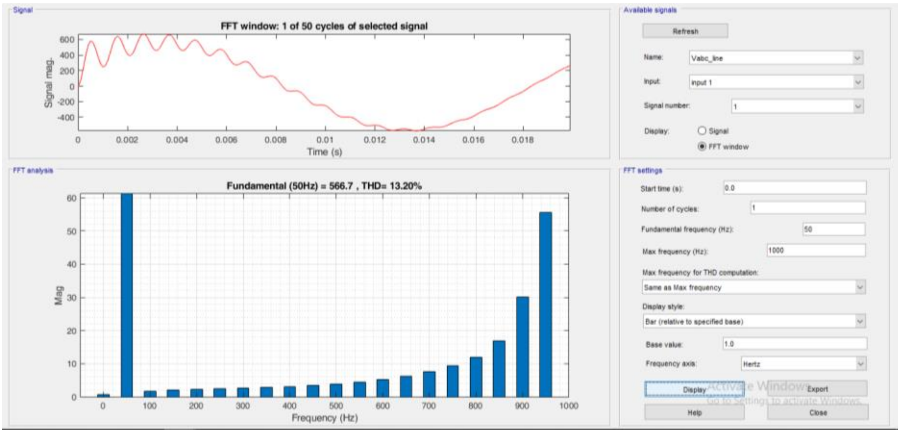

Fig -13: Voltage THD of Fuzzy system

8. Conclusion

A wind energy system has been modelled and simulation has been done in Matlab Simulink software. Two different control system has been developed a PID control and next is Fuzzy control strategy. Three phase output voltage obtained at output and waveform is found to be smooth. ID controller when connected with the conversion system and current harmonics values found to be near 37% and voltage harmonics is near 14%. In fuzzy control strategy the harmonics in current and voltage is found to be reduced up to 34% and 13% respectively that increases power quality of system. Harmonics filter of suitable values needs to be installed to reduce the harmonics to the desirable value.

9. Future Scope

In the next work a model with the fuzzy control system be designed in such a way that after finding details of weather data of that particular location and climate analysis will be done. Wind rose diagram methodology will be used in this analysis and the wind speed along with the direction pattern average data will be taken yearly or monthly basis and pitch controller will be designed according to that data and wind direction to get the possible maximum output from the wind and energy conversion system with this smart methodology of deep analysis.

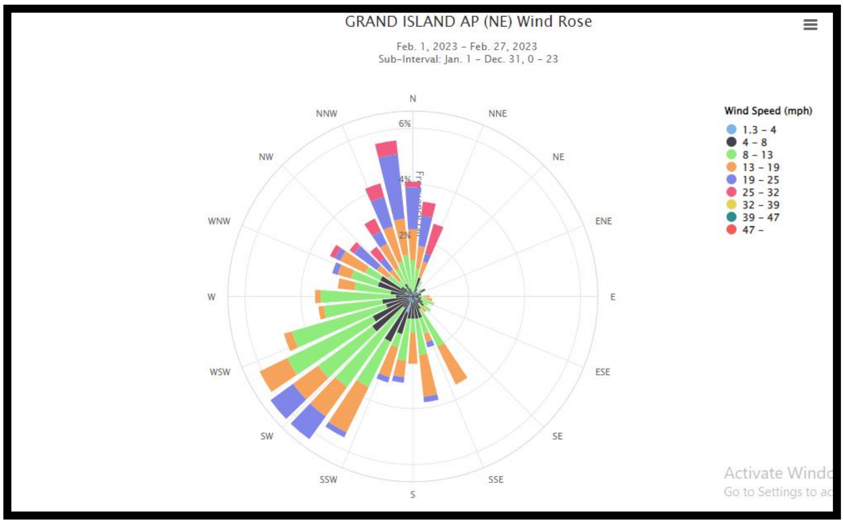

Fig -14: Wind rose diagram of Grand Island for analysis

Sub-Daily Data Between Two Dates
GRAND ISLAND AP (NE)
14935
Lat/Lon/Elev: 40.9611/-98.3136/1840 ft

Date	Time	Temp (F)	RH (%)	Dewpt (F)	Wind Spd (mph)	Wind Direction (deg)	Peak Wind Gust(mph)	Atm Press (hPa)	Precip (in)
2023-02-01	00:53	12	63	2	13	250	m	956.00	0.00
2023-02-01	01:53	11	66	2	14	240	m	955.30	0.00
2023-02-01	02:53	10	66	1	9	240	m	955.70	0.00
2023-02-01	03:53	10	66	1	11	240	m	955.00	0.00
2023-02-01	04:53	11	66	2	10	240	m	954.70	0.00
2023-02-01	05:53	11	66	2	9	240	m	954.70	0.00
2023-02-01	06:53	10	69	2	6	230	m	954.40	0.00
2023-02-01	07:53	10	66	2	8	230	0	955.00	0.00
2023-02-01	08:53	13	66	4	9	230	0	955.30	0.00
2023-02-01	09:53	18	57	5	10	230	0	955.30	0.00
2023-02-01	10:53	22	52	7	8	240	m	955.70	0.00
2023-02-01	11:53	28	48	11	9	250	m	955.00	0.00
2023-02-01	12:53	32	47	14	9	250	0	954.40	0.00
2023-02-01	13:53	34	47	16	11	250	m	954.00	0.00
2023-02-01	14:53	33	48	16	16	250	m	953.70	0.00
2023-02-01	15:53	32	51	16	14	240	0	953.70	0.00
2023-02-01	16:53	30	58	17	9	250	m	954.00	0.00
2023-02-01	17:53	26	65	16	8	260	m	954.40	0.00
2023-02-01	18:53	22	74	15	8	250	m	954.70	0.00
2023-02-01	19:53	20	77	14	8	230	m	954.70	0.00
2023-02-01	20:53	20	73	13	8	220	m	954.40	0.00
2023-02-01	21:53	20	79	14	7	240	0	954.70	0.00
2023-02-01	22:53	20	73	13	9	250	0	954.70	0.00
2023-02-01	23:53	20	73	13	9	260	0	954.70	0.00

Fig -15: daily data between two dates and various details

A government website and its supporting software climate.gov developed with the help of research institute and government bodies for the deep analysis of wind speed and direction for the analysis and many more details can be used for the research method, major field of experiment is wind direction, speed, temperature, humidity and moisture etc.

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