OPTIMIZATION OF OFFSHORE WIND POWER STABILITY WITH FUZZY LOGIC

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Abstract: *Power system stability is a critical aspect ensuring equilibrium among its elements amidst disruptive forces. Disturbances in power systems, arising from various sources, necessitate careful management for system reliability. This study focuses on offshore wind energy systems, pivotal in global energy landscapes. Harnessing wind power demands strategic turbine placement based on wind speed. Presently, Permanent Magnet Synchronous Generators (PMSGs) offer advantages, albeit with challenges like variable speeds. Advanced controllers, integrating Maximum Power Point Tracking (MPPT) and Pulse-Width Modulation (PWM), enhance efficiency. Full Converter Wind Turbines (FCWTs) are pivotal in grid stability, adapting to variable wind conditions. Their accurate modeling aids performance optimization. Transformers amplify or reduce voltages for consumers, ensuring compatibility with grid standards. This study proposes a MATLAB/Simulink model for an offshore wind energy system employing DC transmission. Fuzzy Logic-based Unified Power Flow Controllers (UPFC) enhance power output and stability. Comparative analysis demonstrates improved active and reactive power outputs with the UPFC-based controller, ensuring a reliable system.*

Keywords: *Power transformers, evolution, challenges, emerging trends, electrical power systems,*

I. INTRODUCTION

In the context of power systems, stability refers to a critical attribute that empowers the system to establish counteracting forces among its elements, capable of equaling or surpassing the disruptive forces. The ultimate goal is to reestablish an equilibrium state among these elements within the system. When a power system operates smoothly in a constant state, any abrupt alteration from this state is regarded as a disturbance [1]. Disturbances within power systems can vary in magnitude, and their origins can be diverse. Some disturbances are substantial, characterized by their significant impact on the system, while others are more modest in scale. To illustrate this, let's examine two distinct categories of disturbances.

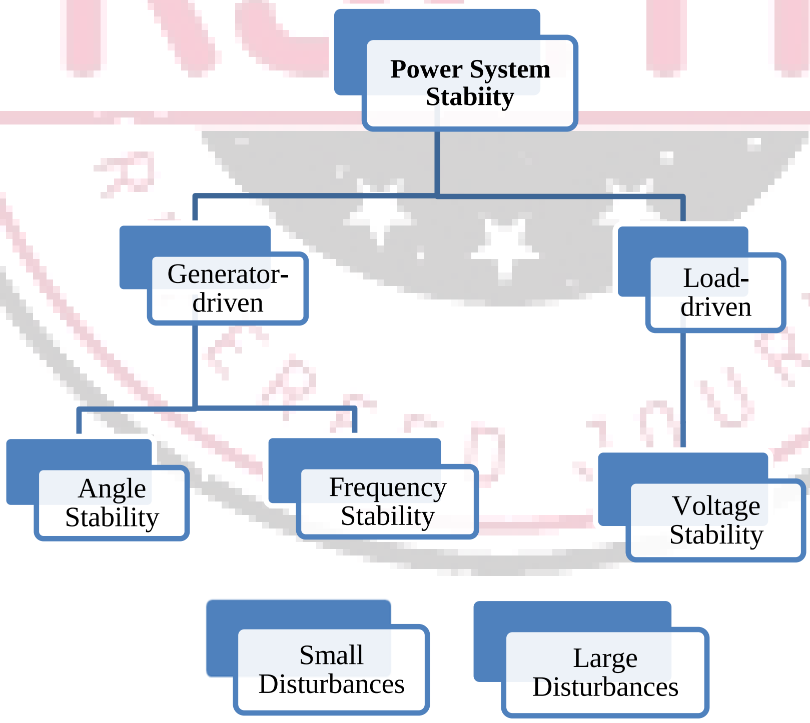

Figure 1 Types of Power System Stability [2]

Although the incorporation of wind power is advantageous for addressing energy shortages and environmental issues, careful consideration and management of these dynamic factors are required to maintain the stability and reliability of the power system.

A. Energy Harvest from the Wind

The electricity produced by wind turbines can either be used locally or sent to the electric grid for distribution to more consumers. Currently, wind turbines have developed into enormous multimegawatt generators with rotor diameters greater than 100 meters. As a result, selecting locations with high wind speeds becomes essential for the strategic placement of wind turbine installations. This emphasis on high winds helps to increase the production of electrical energy [3]. According to the most recent data from the global wind report [4], 2021 marked a significant turning point for the world's wind power industry, with a total wind power capacity reaching a staggering 733 GW. With 282 GW of installed wind capacity, China stood out visibly and became a major player in this renewable energy market. With installed capacities exceeding 10 GW, it should be noted that a number of other nations also made sizable contributions to the wind energy landscape. Among them are the United States (118 GW), Germany (62 GW), India (39 GW), Spain (27 GW), the United Kingdom (24 GW), France (17 GW), Brazil (17 GW), Canada (14 GW), and Italy (11 GW).

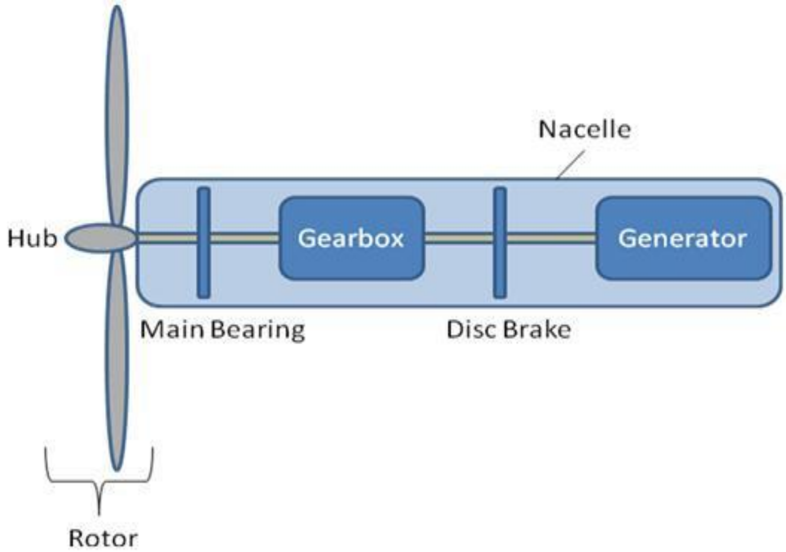

Figure 2 Major Components of a Wind Turbine *(Source: Google)*

Wind turbines are essential components of the global renewable energy landscape, harnessing the kinetic energy of wind to generate electricity. These turbines are available in various types, each designed to cater to specific environmental

B. Wind Turbine Basics

A wind turbine consists of several key components:

- Rotor Blades: The primary function of the rotor blades in a wind turbine is to efficiently capture the kinetic energy contained in the moving air, which is commonly referred to as wind, and then transform this captured energy into rotational motion.
- Hub: The hub in a wind turbine serves as a critical component that connects the rotor blades to the main shaft. This connection is essential for the effective conversion of wind energy into rotational motion and, ultimately, electrical power.
- Generator: The main shaft in a wind turbine is a pivotal component responsible for the crucial task of transmitting the rotational energy generated by the turning rotor blades to a generator, where it is converted into electrical power.
- Tower: The tower of a wind turbine is a fundamental and essential component that fulfills multiple critical functions in the overall operation and performance of the system.

C. Structure of PMSG Wind Turbine

Various types of variable-speed generators are utilized in wind turbines. While doubly fed induction generators (DFIGs) are more commonly employed than permanent magnet synchronous generators (PMSGs) presently, PMSGs offer distinct advantages recognized by experts. PMSGs are characterized by their direct-drive nature, slow rotational speed, absence of rotor current, and the potential to operate without a gearbox. These features contribute to high efficiency, lower maintenance requirements, and cost reduction, addressing significant investment concerns. Nevertheless, PMSGs also exhibit certain drawbacks. They require an electromagnetic field with a flexible structure, imposing stringent production and operational standards. Additionally, the variable speed of the generator needs to be managed by a power inverter.

In the context of ongoing wind power technology advancements, the efficiency of inverter devices is crucial for enhancing wind power generation system performance. To achieve this, they must be equipped with innovative controllers. One such controller, as highlighted in previous studies, integrates Maximum Power Point Tracking (MPPT) with back-to-back space vector Pulse-Width Modulation (PWM). This controller method is employed to measure rotor speed and compare it with the calculated optimal rotor speed, contributing to efficiency improvements. Additionally, pitch angle control plays a significant role in wind turbine operation. It is integrated to adjust the aerodynamic torque of the wind turbine, particularly when the wind speed exceeds the rated speed.

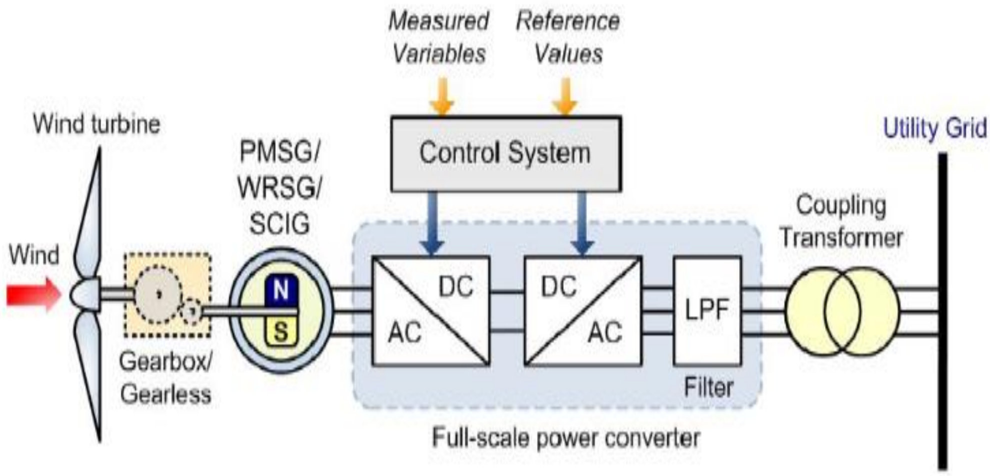

Figure 3 General wind turbine PMSG system with control schemes [5]

D. Modeling of Full Converter Wind Turbines

Wind energy's rapid growth as a renewable power source is significantly driven by Full Converter Wind Turbines (FCWTs), which excel in advanced control capabilities and grid support functions. These turbines adapt their rotor speed for optimal energy capture in varying wind conditions, unlike fixed-speed counterparts. FCWTs play a vital role in enhancing power grid quality, providing reactive power support, and strengthening grid stability. To comprehend and optimize their performance, modeling FCWTs is essential. These models replicate real turbines, enabling engineers and researchers to explore their behavior, assess performance, and develop control strategies [6]. This complicated modeling encompasses various components, including rotor, generator, converters, control systems, and mechanical elements, with mathematical equations describing their relationships. As FCWT technology advances, challenges like intricate system interactions are addressed, resulting in refined models that contribute significantly to the sustainable energy landscape's future success.

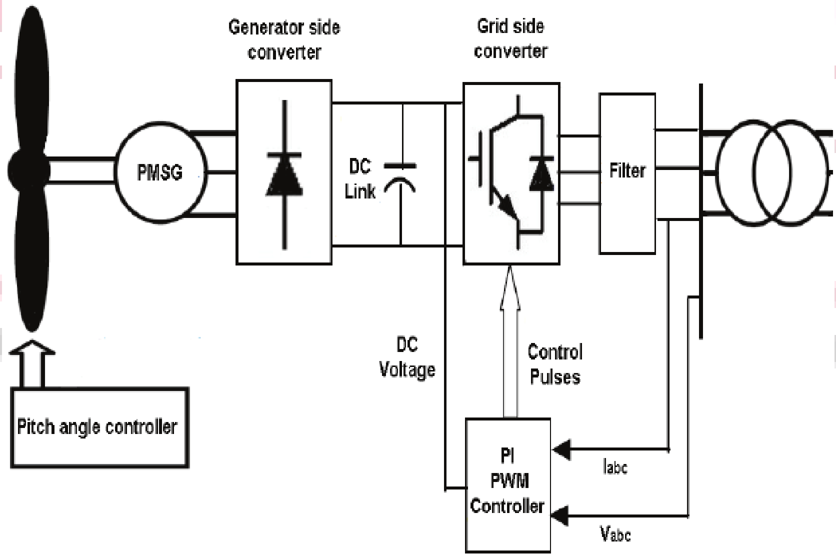

Figure 4 Block diagram of the wind turbine model [7].

E. Transformer

A transformer or substation assumes a pivotal role in the energy distribution system connected to the grid, primarily responsible for regulating the AC voltage from the inverter to align with the mains voltage standards [8]. These transformers possess the capability to amplify line voltages or reduce the supplied voltage to cater to the specific needs of individual consumers. The fundamental operation of a transformer is rooted in the principles of electromagnetic induction. It commences with an electric current coursing through the primary windings (input), generating a magnetic field characterized by a distinct magnetic flux [9].

II. LITERATURE REVIEW

Lucas Lima Rodrigues et al. (2020) [10] introduces a Generalized Predictive Control (GPC) approach tailored for Doubly Fed Induction Generation (DFIG) systems within wind energy applications. The controller utilizes a state-space formulation as the prediction model and incorporates vector control techniques to regulate stator active and reactive power. To address voltage limitations and prevent voltage values from surpassing rated levels, constraints are introduced. Additionally, a parameter selection methodology for GPC is proposed, based on the analogous closed-loop transfer function. The predictive controller, complete with constraints, is then implemented on a Digital Signal Processor (DSP) in a practical test environment, and the results from experiments provide empirical validation of the proposed methodology.

Prasad, et al. (2020) [11] explores the speed control of a three-phase induction motor through the application of the Switching-Table-Based Direct Torque Control (ST-DTC) technique. The study involves MATLAB/SIMULINK simulations and assesses the motor's performance under load torque variations. Parameters such as electromagnetic torque response, speed tracking capabilities, and stator flux trajectories are analyzed across different speed and torque settings. The simulation outcomes demonstrate enhanced dynamic performance of the induction motor when employing the proposed ST-DTC method compared to a conventional fixed PI controller. Furthermore, ST-DTC exhibits superior speed control across a wide range of operational scenarios.

Li, Shuhui & Haskew et al. (2012) [12] The doubly-fed induction generator (DFIG) wind turbine, a prominent variable speed wind turbine in the modern wind power industry, has primarily relied on a decade-old technology in commercial applications. However, this paper highlights limitations in conventional vector control methods. It introduces a novel direct-current vector control approach for DFIG wind turbines, leading to the development of an integrated control strategy encompassing wind energy extraction, reactive power management, and grid voltage support. A transient simulation system employing Sim Power System is constructed to validate this innovative control methodology. Comparative assessments are made between the conventional and proposed control techniques for DFIG wind turbines, considering both steady-state and gusty wind conditions. The study demonstrates that the DFIG system, operating under the DC vector control configuration, exhibits superior performance across various parameters.

Abdelhak Dida et al. (2020) [13] focuses on the comprehensive analysis, modeling, and control of a doubly-fed induction generator employed in variable-speed wind turbine systems. It establishes the wind turbine's startup procedure, including grid synchronization. The research introduces novel sensorless control schemes, one for standalone operation and grid synchronization known as "direct voltage control," and another for grid-connected mode known as "direct power control." To enhance system robustness in the face of machine parameter variations, a fuzzy logic controller is incorporated. The study encompasses various operational scenarios, such as wind turbine acceleration, braking, limited power and speed operation, power maximization, and standalone operation with variable load supply. The complete startup procedure is meticulously simulated using Matlab/Sim Power Systems, and the results across various transient conditions underscore the efficacy of the proposed control strategy.

Alshbib, M. M., et al. (2022) [14] introduces an enhanced and robust approach to direct torque and rotor flux control (DTRFC) for an induction motor (IM) to eliminate uncontrollable angles (UCAs) across the entire speed spectrum. The method ensures that each voltage vector (VV) generates the desired torque and flux effects without any counteractive influence. Initially, the DTRFC algorithm's behavior was assessed at low and high speeds to identify UCAs, revealing issues at medium and high speeds. Consequently, a specialized strategy with 18 sub-sectors (SSs) was proposed for medium and high speeds, while retaining the basic 6-sector strategy for low speeds. The transition speed between these strategies was determined to guarantee the absence of UCAs throughout all speed ranges. Simulation results were obtained using the MATLAB/Simulink environment, and the effectiveness of the approach was validated through experiments using a dSPACE-based induction motor DTRFC drive system.

III. OBJECTIVE

- To create a MATLAB SIMULINK model of off shore wind energy system having power being transmitted through DC transmission system. The first model will have no power flow controller and second model will have artificial intelligence based controlling technique.
- To design a controller for enhancing the power output from the wind energy system using UPFC. This will be made to feed DC transmission system.
- The fuzzy logic set of rules is to be implemented for controlling the power enhancement device off the DCWT system
- Finally integrating the system with long distance DC transmission system and then to the grid so as to make it more reliable and efficient.

IV. METHODOLOGY

The model has been developed in MALAB/SIMULINK environment. This is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It has following key features:

- High-level language for computation in science and engineering

- Graphics for displaying data and tools for making custom plots. Apps for curve fitting, data classification, signal analysis, control system tuning, and many more tasks.
- Desktop environment designed for iterative exploration, design, and problem-solving.
- Toolkits for a variety of engineering and scientific applications;
- Instruments for creating applications with unique user interfaces
- Royalty-free deployment options for sharing MATLAB programs with end users

The modeling of Dual Voltage Source Inverter system is done which is capable of feeding the load with either solar or wind resources depending on the availability thus making the system more reliable

A. Wind Energy System Modeling

Model of wind turbine with PMSG Wind turbines cannot fully capture wind energy. The components of wind turbine have been modelled by the following equations.

Output aerodynamic power of the wind-turbine is expressed as:

$$P_{Turbine} = \frac{1}{2}\rho A C_p(\lambda, \beta) v^3$$

where, ρ is the air density (typically 1.225 kg/m3), A is the area swept by the rotor blades (in m2),CP is the coefficient of power conversion and v is the wind speed (in m/s).

The tip-speed ratio is defined as:

$$\lambda = \frac{\omega_m R}{v}$$

where$\omega_m$and R are the rotor angular velocity (in rad/sec) and rotor radium (in m), respectively.

The wind turbine mechanical torque output m T given as:

$$T_m = \frac{1}{2}\rho A C_p(\lambda, \beta) v^3 \frac{1}{\omega_m}$$

The power coefficient is a nonlinear function of the tipspeed ratio λ and the blade pitch angle β (in degrees).

Then Power output is given by

$$P_{Turbine} = \frac{1}{2}\rho A C_{p_{max}} v^3$$

A generic equation is used to model the power coefficient $C_P$based on the modeling turbine characteristics described in [2], [7-9] and [11] as:

$$C_p = \frac{1}{2}\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right) e^{-\left(\frac{21}{\lambda_i}\right)}$$

For each wind speed, there exists a specific point in the wind generator power characteristic, MPPT, where the output power is maximized. Thus, the control of the WECS load results in a variable-speed operation of the turbine rotor, so the maximum power is extracted continuously from the wind.

This mechanism uses the variable torque output $w_m$and tries to optimize the output current and voltage waveform to its maximum value.

B. UPFC Working

UPFC consists of two back to back GTO based voltage source converters (shunt and series) via a common DC link as shown in Fig. 5. The main objective of series converter is to produce an ac voltage Vc of controllable magnitude and phase angle and inject this voltage at the fundamental frequency in series with the transmission line, exchanging the real and reactive powers at its ac terminals through the series connected transformers.

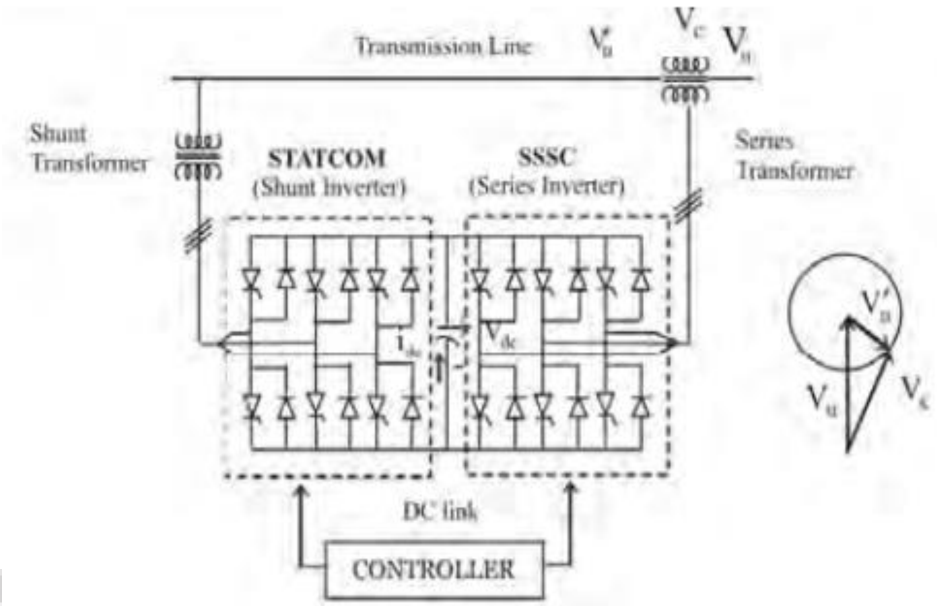

Figure 5 Basic Circuit Configuration of the Unified Power Flow Controller.

The shunt converter regulates the real power or it controls the capacitor's DC voltage by providing the required real power at the DC terminals. It also provides the voltage regulation of the shunt connected point through adjusting reactive power (generating or absorbing the reactive power). The two converters can generate or absorb the power independently without flowing through the DC link. Thus, UPFC can fulfill the functions of reactive shunt compensation, series compensation and phase shifting and meet multiple control objectives by adding the voltage Vc with appropriate amplitude and phase angle to the terminal voltage Vu

The power system is composed of a synchronous machine connected to the grid via a transmission line. The UPFC is connected to the bus near the machine and its model is given as ideal transformer model shown in Fig. 3.2. The power system model including UPFC is also shown in Fig 6.

To obtain the simplified block diagram, it is necessary to obtain the dynamic rotor equation and its parameters based on the parameters of Fig. 7. The dynamic rotor equation is.

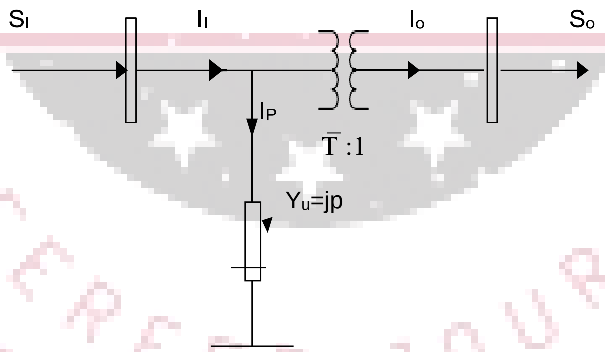

Figure 6 Ideal transformer model of UPFC

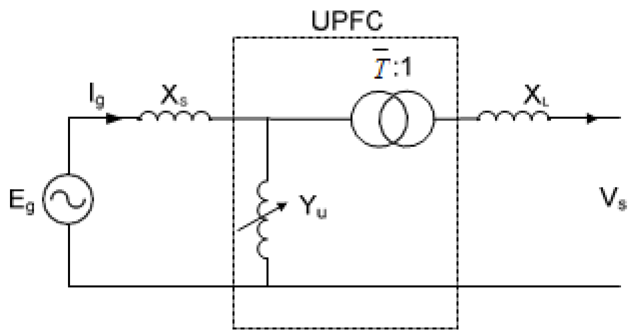

Figure 7 Power system model including UPFC

It is necessary to calculate Pg based on UPFC and network parameters. Pg is Eg times Ig, therefore current generator must be calculated.

$$\begin{bmatrix} E_g \\ I_g \end{bmatrix} = \begin{bmatrix} 1 & \frac{1}{Y_s} \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \bar{T} & 0/1 \\ \bar{T}Yu & \dot{\bar{T}} \end{bmatrix} \begin{bmatrix} 1 & \frac{1}{Y_s} \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_s \\ I_s \end{bmatrix}$$

$ABCD_i$ $ABCD_u$ $ABCD_k$

Eg:Internal voltage of generator

ABCD: Transmission matrix

T: Complex ratio of transformer

Yu: UPFC admittance

Ys:Generator admittance

YL: Line admittance

Equation (2) can be written as (3).

$$\begin{bmatrix} E_g \\ I_g \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_s \\ I_s \end{bmatrix}$$

A= $\frac{\bar{T}\, Y_s + \bar{T} Y_u}{Y_s}$

B= $\frac{\left| |\bar{T}|^2 Y_s + |\bar{T}|^2 Y_u + Y_L \right|}{\dot{\bar{T}}\ Y_L\, Y_s}$

C= $\bar{T}\ Y_u$

D= $\frac{\left| |\bar{T}|^2 Y_u + Y_L \right|}{\dot{\bar{T}}\ Y_L}$

And generator current is:

$I_g = V_s \left(C - \frac{DA}{B}\right) + \frac{D}{B} E_g$

The basic modeling of the UPFC is done in the manner stated above by utilizing the equations.

The upfc is being created in the model as shown below

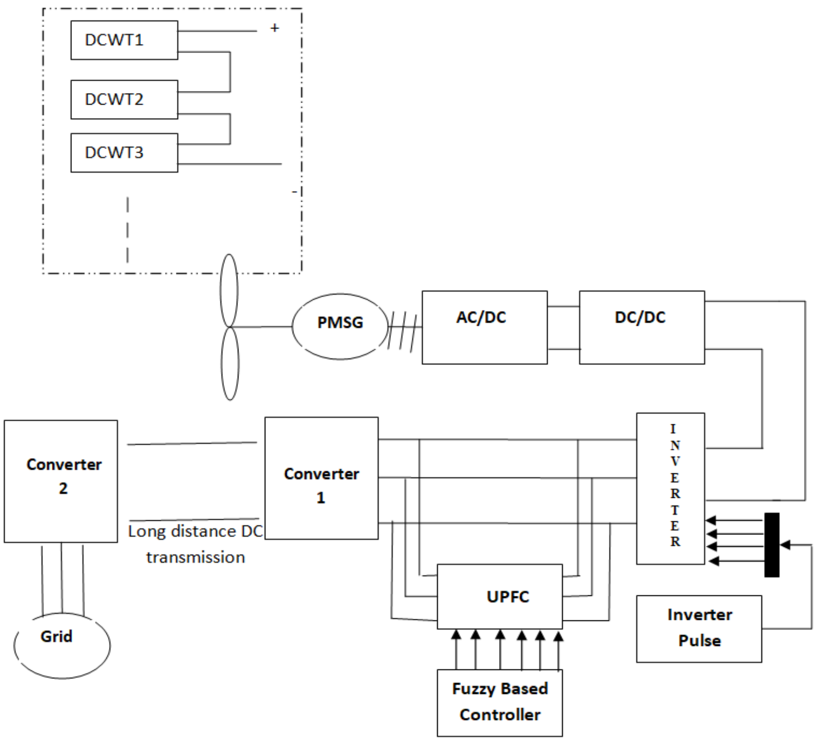

Figure 8 Long Distance DC transmission of Wind turbine system

C. Fuzzy based UPFC

Fuzzy logic works on the concept on deciding the output on the basis of assumptions. It works on the basis of sets. Each set represents some linguistic variable defining the possible state of the output. Each possible state of the input and the degrees of change of the state are a part of the set, depending upon which the output is predicted. It basically works on the principle of If-else-the, i.e. If A AND B Then Z.

Suppose we want to control a system where the output can be anywhere in the set X, with a generic value x, such that x belongs to X. Consider a particular set A which is a subset of X such that all members of A belong to the interval 0 and 1. The set A is known as fuzzy set and the value of $f_A(x)$ at x denotes the degree of membership of x in that set. The output is decided based on the degree of membership of x in the set. This assigning of membership depends on the assumption of the outputs depending on the inputs and the rate of change of the inputs.

Every Fuzzy Logic block consists of two inputs and one output. The first input is the error and the other input is error-rate which is one-sampling before error values. For all the transmission line parameters the input and output membership functions are named similar. Traditional controller is replaced by a fuzzy controller. Input variables for the fuzzy controller are the error signal and the change of this error.

The following seven fuzzy levels are chosen for each input and output variables as NB (-ve Big), NM (-ve medium), NS (-ve Small), Z (zero), PL (+ve low), PM (+ve medium), and PH (+ve high).

Table 1 shows the rules formed on the basis of the fact that control output should be high and low error. Figure 3.4-3.6 shows the input variables and output variable membership functions.

Table 1 Fuzzy Rule Table for UPFC

error/coe	**NM**	**NS**	**Z**	**PL**	**PM**	**NB**	**PH**
NM	NH	NH	NH	NL	PH	NH	PL
NS	NM	NL	PL	Z	PL	NH	PM
Z	NL	NH	NL	PL	PM	NH	PH
PL	NL	Z	PM	PM	PH	NM	PH
PM	Z	PL	NM	PH	Z	NL	PH
NB	NH	NH	Z	NM	NL	NH	Z

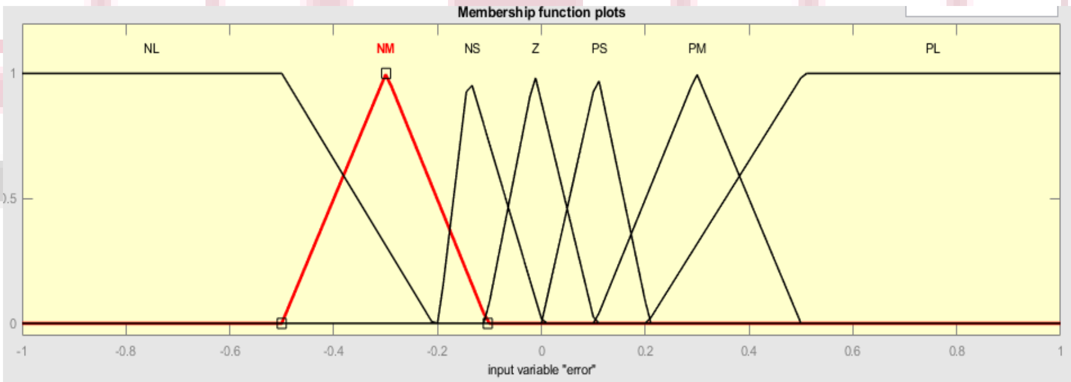

Figure 9 Input Variable (error) Normalized Membership Function

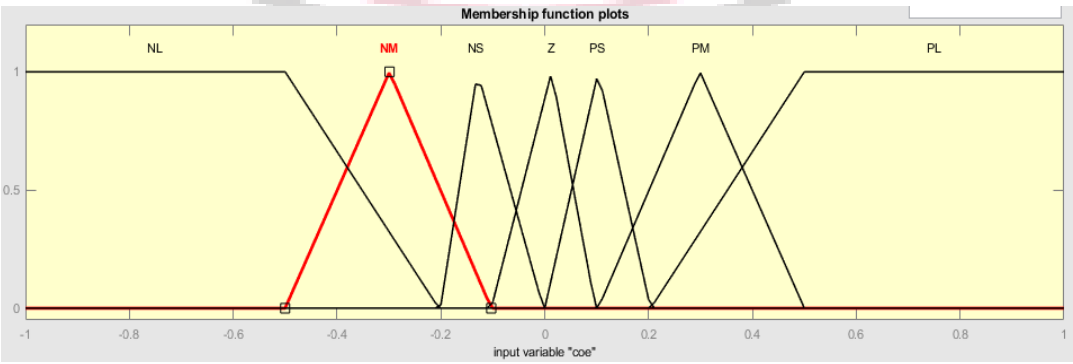

Figure 10 Input Variable (coe) Normalized Membership Function

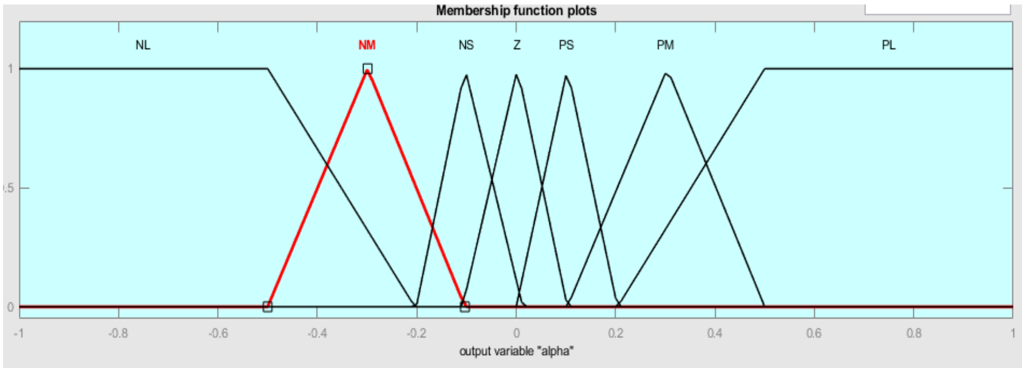

Figure 11 Output Variable Normalized Membership Function

Simulation is carried out for a fixed RES generation, which is greater than the load demand. The result of both scenarios are compared.

V. SIMULATION AND RESULT ANALYSIS

A. Implementation Details

In this work, a coordinated control based on fuzzy logic for UPFC for a cluster of offshore WPPs connected to the same HVDC connection is constructed and assessed. The study aims to control the voltage of the offshore AC grid while coordinating the flow of reactive and active power between the WPP cluster and the HVDC converter. The chapter discusses the results in two following cases:

Case 1: Offshore wind energy system integrated with the grid without any power controller

Case 2: Offshore wind energy system integrated with the grid having power enhancement fuzzy based controller

The wind speed of each DCWT is random wind speed with the average value of 12m/s. The simulation is also made to adjust the speed variations from 0 to 12 m/s. The three phase output of the wind system is transferred to the long distance via DC transmission system.

B. Modelled offshore wind energy system

The modeling of wind energy system has been done using a permanent magnet synchronous machine (PMSG) which is used to convert the mechanical torque into three phase electrical power. The output is varied due to variations in wind speed from 0 to 12 m/s. The three phase output voltage is converted into DC using a rectifier. The DC output from the wind energy system is shown in figure 12.

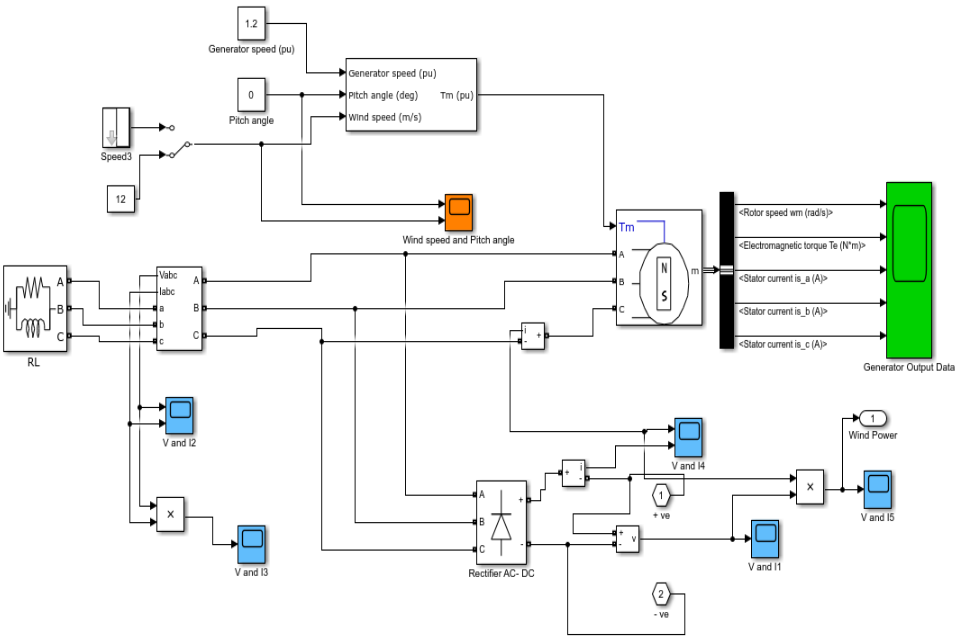

Figure 12 The MATLAB/SIMULINK model of wind energy system

The modeled wind energy system has following parameters which are being used are mentioned in the table below

Table 2 Wind Turbine Parameters

Parameters	Values
Rotor diameter	126 m
Rotating Speed	4 - 11.9 rpm
Nominal Wind Speed	11.4 m/s
Generator rated power	5 MW
Number of poles	100
Stator winding resistance	0.001 ohms
Unsaturated inductance	0.15 p.u
Generator inertia	0.84 s
Magnetic Strength	1 p.u.
Wind turbine inertia	5.54 s
Line voltage	3.3KV

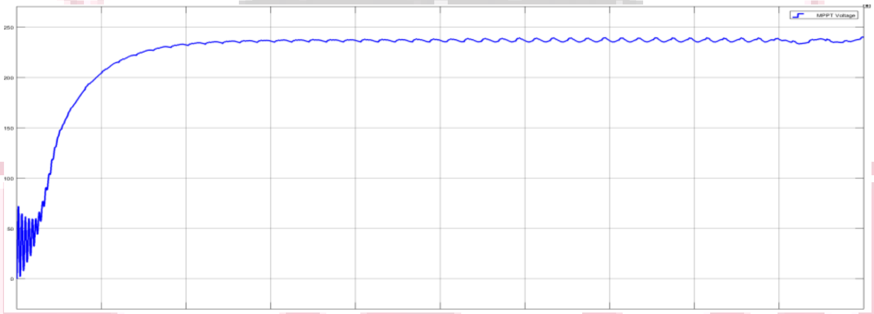

Figure 13 DC output from the wind energy system after rectification

The wind energy system gives approximately 200 volts DC output after it is being rectified. This output is then given to the inverter which converts it to three phase AC output and is then given to long distance DC transmission grid.

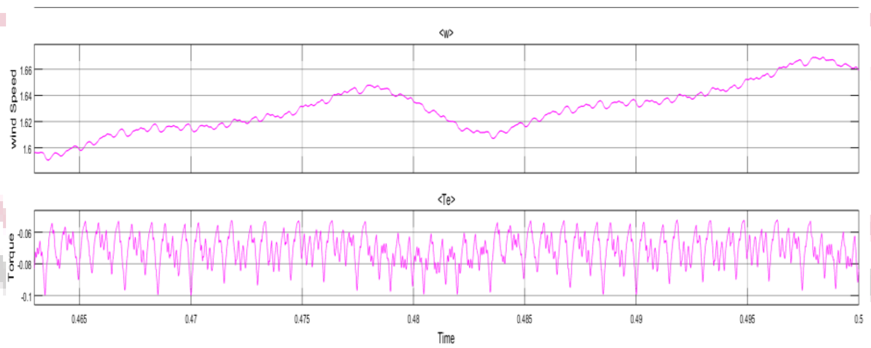

Figure 14 Wind Speed and Corresponding Torque output from the turbine

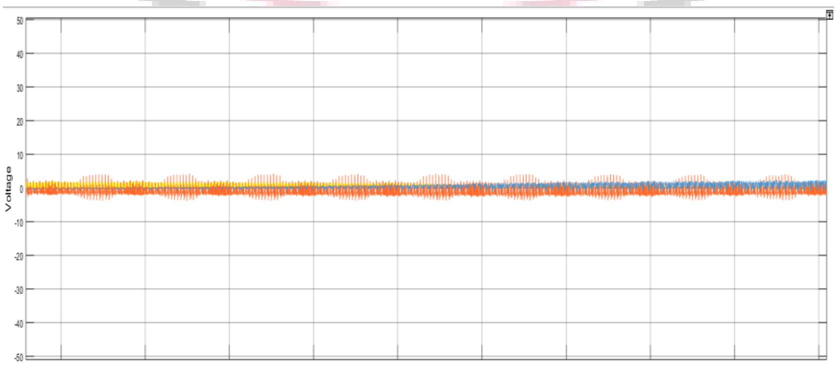

Figure 15 Voltage output from DCWT (p.u)

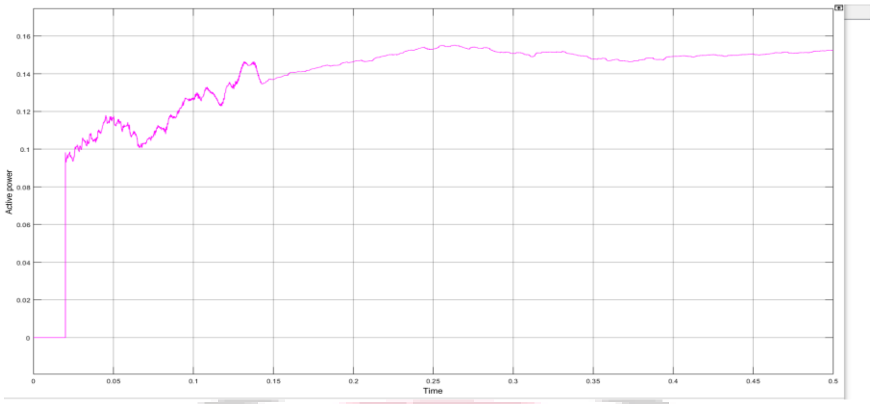

Figure 16 Active power output from DCWT (p.u)

The graph shows the Active power output from DC wind turbine in per unit. The power output is approximately 0.5 per unit.

C. Case 1: Offshore wind energy system integrated with the grid without any power controller.

The inverter converts the DC output from the wind energy system using a control system. This gives us three phase AC output and this output is then given to long distance DC transmission line. DC transmission is the most economical solution compared to high-voltage AC. The challenge, however, is that to transmit via HVDC, two converter stations are needed. First, the AC power must be converted to DC to begin the transmission process, and then when it gets to the desired tie-in destination, the DC power must be converted back to AC to be utilized on the grid. Hence the model uses two power converter stations which is used to convert AC to DC and then from DC to AC in the place where load has to be driven.

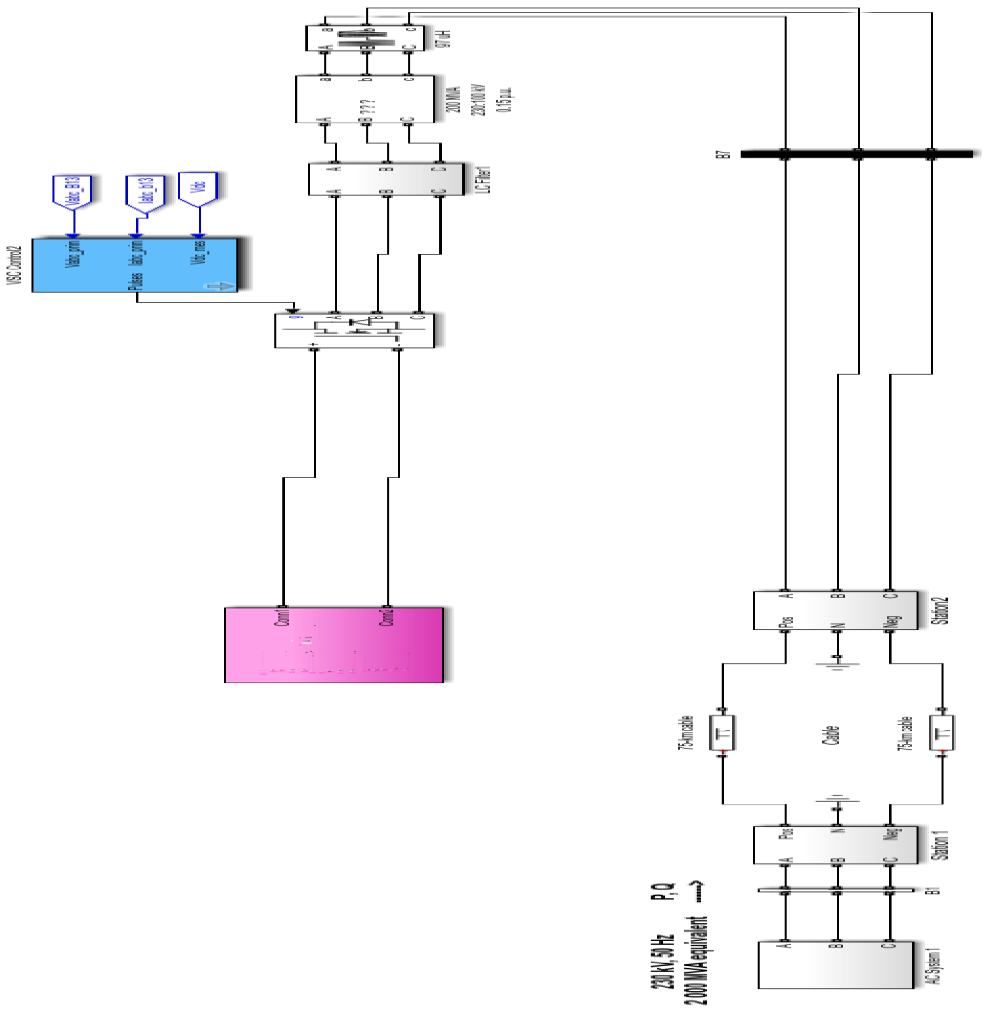

Figure 17 Grid-Integrated Offshore Wind Energy System without Power Control

In this system the AC side waveform is not affected by any kind of power enhancement device and controller. The AC power is generated in the generating station. First, this needs to be converted to DC. Rectifier is used to perform the conversion. The overhead lines will carry the DC power. This DC needs to be changed into AC at the user's end. An inverter is installed at the receiving end for that reason. The figures below show the voltage, current, power output from this energy system.

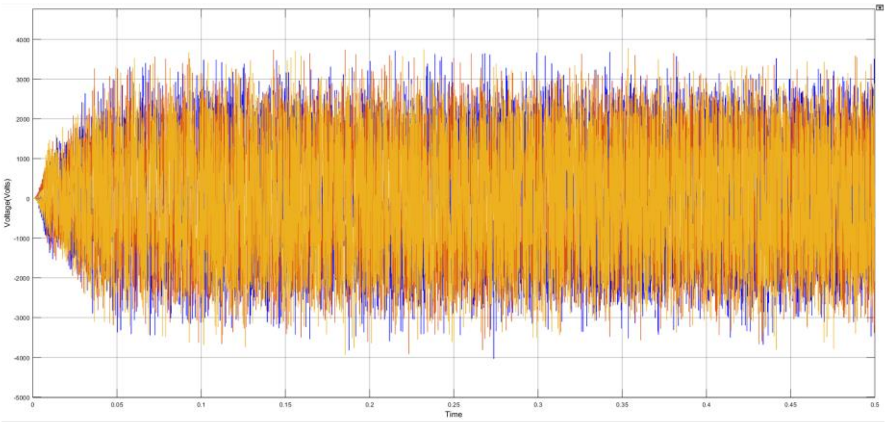

Figure 18 System Voltage Output in the Absence of a Power Controller

In this Wind energy system in which no power controller devices connected the voltage output is approximately 2.5 KV. This voltage output is from the system in which numerous DC wind turbine integrated and their voltage output is measured.

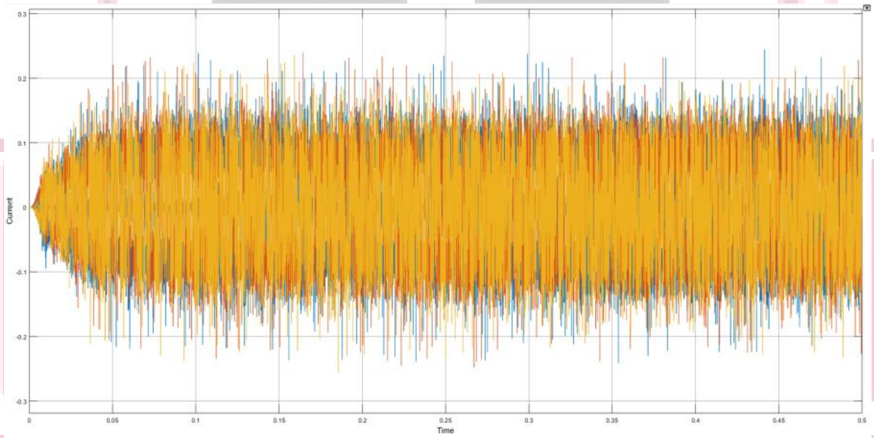

Figure 19 System Current Output in the Absence of a Power Controller

Fig. 19 is showing current output from the DC wind turbine at the point where the power is converted from DC to AC through inverter. The current is generated at 50 hertz which can be used for driving various kinds of loads at this point.

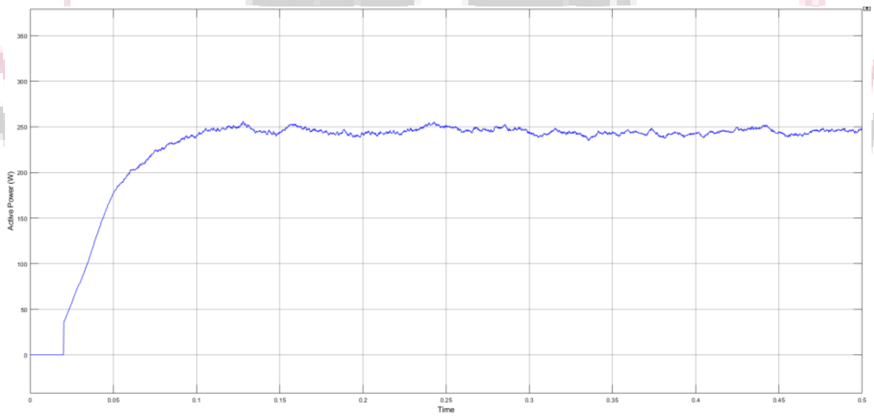

Figure 20 Active Power Output in a System Operated Without a Power Controller

The active power is the actual power which is dissipated in the circuit. In this Wind energy system in which we are not using any kind of power controller the figure 20 shows the active power output from the wind turbine which will then be transmitted to long distance DC transmission. The output is found to be approximately 250W.

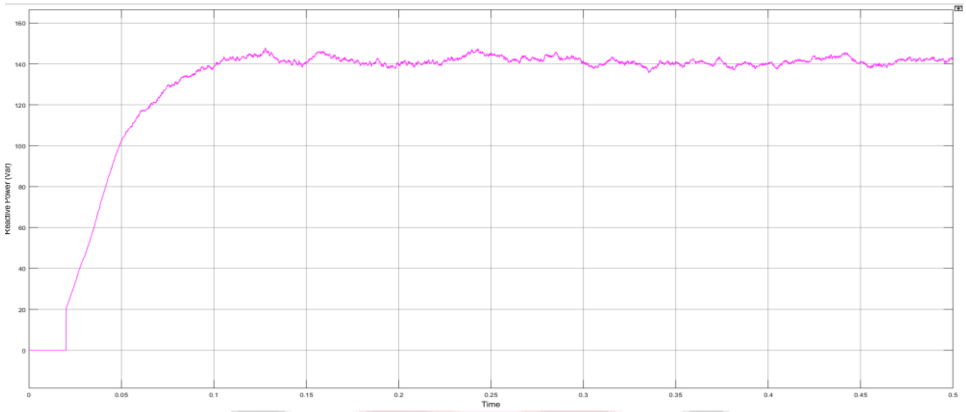

Figure 21 Reactive Power Output in a System Operating Without a Power Controller

The reactive power moves between the source and load of the circuit. Stability and reliability of electrical power system depends on reactive power management. The reactive power out [ut from the DCWT system was found to be approximately 140Var.

D. Case 2: Offshore wind energy system integrated with the grid having power enhancement fuzzy based controller.

The DCWT system in this case is connected to the DC transmission system for offshore energy system. In this case the system is connected by a power controller which is controlled by a fuzzy logic codes. The enhancement in output active as well as reactive power is further discussed to mark the reliability of the controller in DCWT wind energy systems particularly.

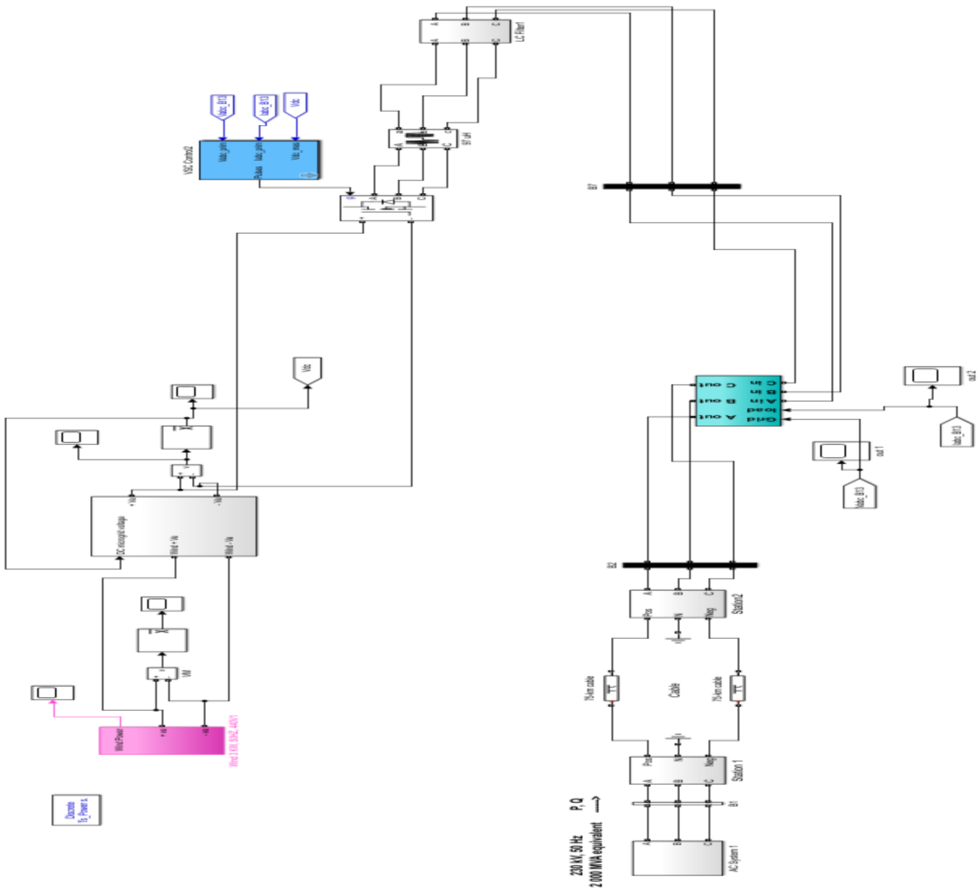

Figure 22 Grid-Integrated Offshore Wind Energy System with Fuzzy-Based Power Enhancement Controller

The fuzzy logic control utilized in DCWT system is expected to enhance the operation of the system. A fuzzy control system is a control system based on fuzzy logic—a mathematical system that analyzes analog input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic.

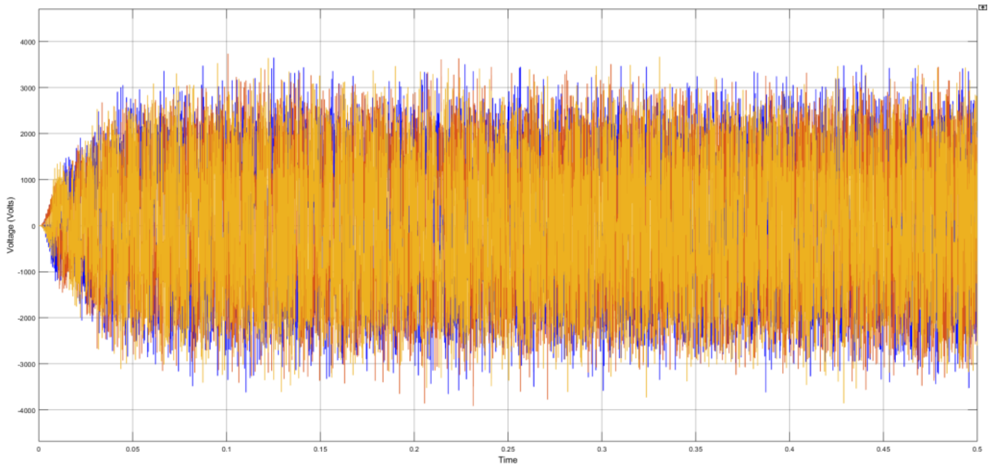

Figure 23 Voltage Enhancement in Systems Utilizing a Fuzzy-Based Power Controller

In this Wind energy system in which power controller based on fuzzy logic rules is connected the voltage output is approximately 2.5 KV. This voltage output is from the system in which numerous DC wind turbine integrated and their voltage output is measured.

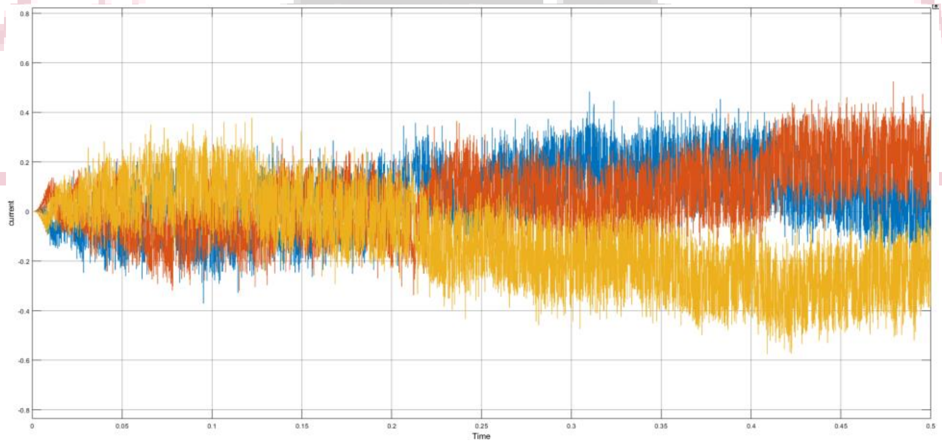

Figure 24 Current Output of the system having power enhancement fuzzy based controller

Figure 24 is showing current output from the DC wind turbine at the point where the power is converted from DC to AC through inverter and then the power enhancement device having fuzzy based rules is connected. The current is generated at 50 hertz which can be used for driving various kinds of loads at this point.

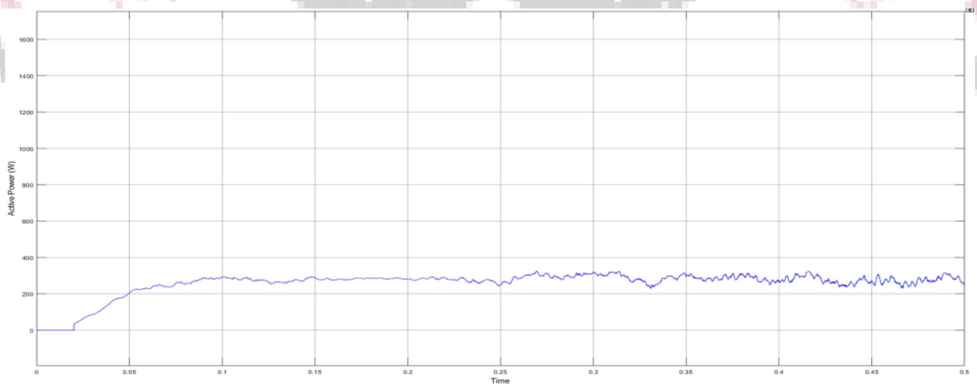

Figure 25 Enhancing Active Power Output with a Fuzzy-Based Controller in Power Systems

The figure 25 is showing the active power output from the system having fuzzy based controller for power enhancement. The output shows that the power has been enhanced as compared to the previous model to approximately 300Watts.

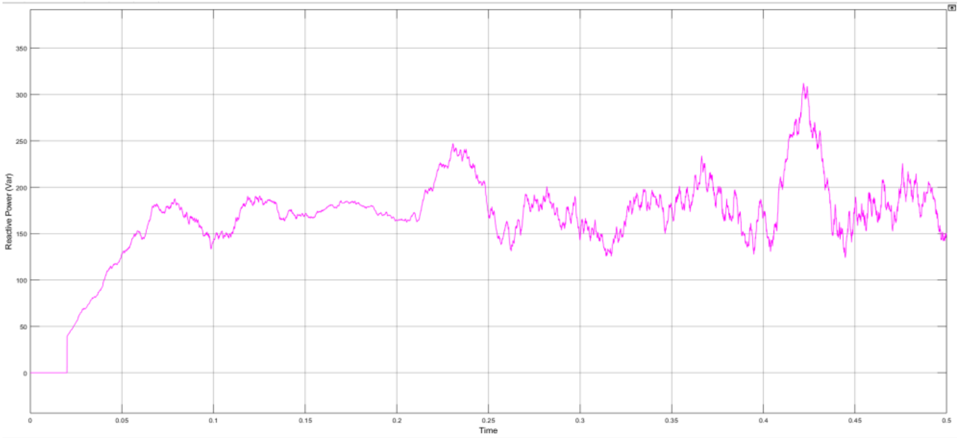

Figure 26 Enhancing Reactive Power Output with a Fuzzy-Based Controller in Power Systems

The reactive power moves between the source and load of the circuit. Stability and reliability of electrical power system depends on reactive power management. The reactive power output from the DCWT system having power enhancement device with fuzzy based power controller was found to be approximately 150Var.

D. Validation

Comparative analysis of the system having no power controller and wind energy system having UPFC based power flow controller is being discussed in this chapter. The active power outputs as well as reactive power outputs are being enhanced using fuzzy based control.

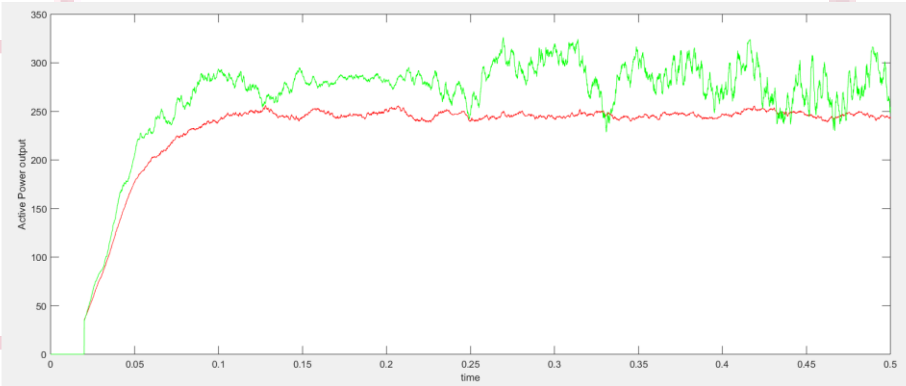

Figure 27 Comparative Assessment of Active Power Flow Control

Figure 27 is the depicting the active power output from the two systems and their comparison is being carried out. The red graph shows the active power generated from the system having no power controller whereas the green graph is showing the active power output from the system which is also having a power controller controlled by Fuzzy Logic rules. The figure is clearly showing that the active power has been enhanced by using the controller designed having intelligent control

The active power output of the system with no power flow control is approximately 250 W and wind energy system with fuzzy based control is approximately 300 W.

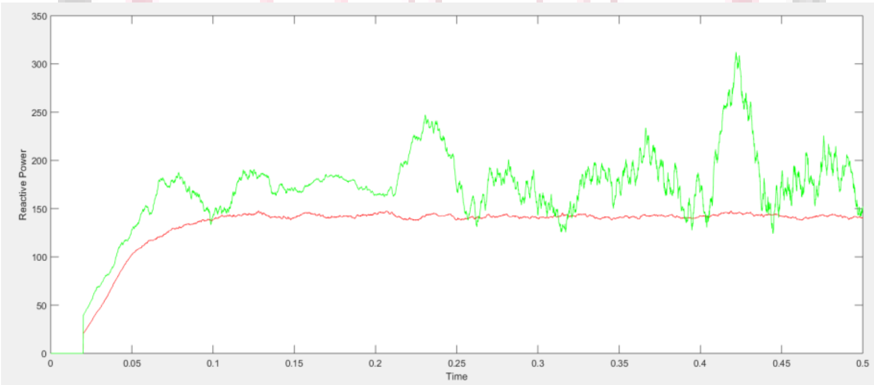

Figure 28 Comparative Assessment of Reactive Power Flow Control

The figure 28 shows the comparative analysis of the reactive power output from the two systems having no controller and the other word having a controller for power enhancement controlled by Fuzzy Logic rules. The power output has been found to be enhance from 140 Var to approximately 150 Var which can be used for compensation when the loads are connected

V. CONCLUSION

The study presents a comprehensive analysis of offshore wind energy system stability, emphasizing the role of advanced control techniques. Through meticulous modeling and simulation, it is demonstrated that integrating Fuzzy Logic-based Unified Power Flow Controllers (UPFC) significantly enhances both active and reactive power outputs in offshore wind systems. The proposed methodology, implemented in MATLAB/Simulink, showcases its effectiveness in managing varying wind speeds and disturbances. This research not only contributes to the understanding of offshore wind energy systems but also provides a robust foundation for future advancements in renewable energy integration, ensuring sustainable and stable power systems.

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