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Efficient Power Transmission from Offshore Wind Farms using 18-Pulse Diode Rectifiers

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Abstract: This study investigates the application of 18-pulse diode rectifiers for efficient power transmission from offshore wind farms to the grid. The increasing demand for renewable energy sources has led to the rapid growth of offshore wind farms, which pose significant challenges in terms of power transmission and grid integration. The 18-pulse diode rectifier offers a promising solution to these challenges, enabling the efficient and reliable transmission of power from offshore wind farms to the grid.

Key Words: Diode rectifier unit (DRU), High voltage direct current (HVDC), Converter Offshore wind farm (OWF), Offshore wind power (OWP), High voltage alternate current (HVAC).

I. INTRODUCTION

Denmark's successful establishment of the first offshore wind power (OWP) farm at Vindeby in 1991, several nations, including the UK, Holland, Ireland, and Sweden, started building their own OWP. The United States constructed the largest OWP in Texas, which generates 12.6% of the state's energy supply [6]. An offshore wind farm (OWP) is a wind farm that is situated miles or even hundreds of miles (within 200 sea miles) from the coast. It can be fixed or floating. Since these wind farms are government property, obtaining them is easier. A conventional wind farm (constructed in hill) is not as durable and stable as an OWP farm.

As a result, OWP has the capacity to produce gigawatts of power and rise as tall as 250 metres. Due to these advantages, OWP is important factor source of green energy. Based on their transmission route, the offshore wind farm design is separated into six groups. Each of the following groups is:

I. Offshore wind farm with model analysis, wind speed simulation, and data monitoring.

II. Cost: life cycle cost (LCC), monitoring of conditions, cost-benefit analysis, investment, modelling, and economic-effectiveness.

III. Floating wind turbines: floating base, fixed base.

IV. Fault detection and maintenance through the Condition Monitoring System (CMS).

V. The impact and comparison of ecological consequences in the marine environment.

VI. Transmission system: voltage direct current (HVDC), grid interactions between AC and DC, and droop management.

In this paper we are studying about the transmission system which is present in group VI. Offshore farms generate more power per installed capacity because offshore wind speeds are higher than on land. As offshore wind farms have less of an impact on the ecosystem and on people than onshore ones, they are also less contentious [1]. These days, a well-established technology called high voltage direct current transmission connections emerges to meet the needs of bulk power transmission.

The subject of why we preference HVDC over HVAC is an interesting one, as three-phase alternating current is used in the majority of power transports. In what way does HVDC transmission function within the present power transmission infrastructure? The important issue is: given that most three-phase power transmission employs AC, why would we choose the HVDC transmission technology over HVAC?

How is HVDC transmission going to succeed in the current transmission network? Our response is that AC has always been the preferred method of transmitting energy, whether it is for a house or business.

However, AC has several limitations, including its limited transmission capacity, long transmission distances, SKIN effect, and inability to link with systems that transmit electricity at different frequencies.

For DC and AC conductors, the skin effect and the corona effect are typically less noticeable [4]. HVDC transmission provides high reliability and controllability and is particularly useful for connecting disparate frequency AC grids.

We can choose to employ an HVDC power transmission system as DC can transport an extensive amount of electricity with minimal loss. Another issue with AC is that most renewable energy sources, such as hydropower, solar power, and other facilities, are found in areas with high populations, where DC electricity transmission makes more sense. In technical terms, HVDC is required or preferred [5].

Furthermore, compared to high voltage AC, HVDC has less of an environmental impact. HVDC is utilised for around 700 KM for overhead lines, 40 KM for underground lines and 100 KM for undersea lines. Using HVDC systems, two distinct grids with different frequencies may also be connected. Additionally, grid reliability and stability can be increased by connecting grids located on different continents or countries [3].

The 18 – pulse diode rectifier offers many advantages, such as flexible configuration expandability without the need for transformers, increased redundancy and reliability, low switching losses, high efficiency, and low output harmonic distortion that allows the removal of large AC side filters and a reduction in DC link capacitance.

The 12-pulse diode rectifier has several operational issues, including high harmonic current injection into the AC mains and low power factor. In 1992, IEEE Standard 519 was revised with explicit restrictions on distortions of voltage and current, in order negative.

The literature has reported on a variety of techniques based on the concept of increasing the number of rectification pulses in ac-dc converters [7-8].

One such method is the 18-pulse rectification technique based on the standard wye-delta transformer. Still, the transformer's kVA rating is 1.03 PO, where PO is the active power that the converter losses.[9] Autotransformer based multipulse ac-dc converters with a lower rating have been established in the literature as a way to lower the transformer rating [7]. Autotransformer based 18-pulse ac-dc converters have been observed to reduce the THD of ac mains current in applications where the 18-pulse ac-dc converter is commonly chose [9].

In new topology of 18-pulse diode rectifier says the THD of Ac main current is around 8% at full load. The proposed ac-dc converter results in elimination of 5^{th}, 7^{th}, 11^{th}, and 13^{th} harmonics.

II. LITERATURE REVIEW

This section deal is with Bipolar topology. In bipolar, transmission, a pair of conductors is used, each at a high potential with respect to ground, in opposite polarity. Transmission lines are more expensive than monopoles with return conductors since these wires need to be insulated for the full voltage. Bipolar transmission, however, has a lot of benefits, which may request it an attractive choice.

Unfortunately, since other topologies make use of all the power electronics available for power transmission, the extra converter is not utilized for power transfer. In order to minimize the need for extra components at the DRU station, such as a STATCOM, voltage and frequency control in the ac offshore grid may also be achieved by decentralized control utilizing the wind turbines. But in order to implement such methods, the traditional wind turbine (WT) control systems must be modified properly.

The decentralized voltage and frequency control's topology is found in [20-23]. Bipolar Topology of a Diode-Rectifier-based HVDC System for Offshore Wind Farms. Increases dc/dc power conversion at rated Dc voltage we need use the 18-pulse DRU topology.

The footprint required for this topology is similar to that of a fully rated DRU-HVdc system. There are several disadvantages to this topology despite its apparent advantages. Due to the variable and load-dependent dc voltage on the DRU, OWF cannot be energized via the HVdc connection. In order to manage the power flow, an additional dc link voltage controller is suggested to be used in connection with the DRU-HVdc to provide voltage and frequency control in the OWF ac side.

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However, this approach has certain stability issues because of the large gain that occurs between the powers transmitted through the DRU-HVdc link and the dc voltage, which causes a small modification in the offshore voltage to result in a major boost in the transmitted power. Additionally, the cost of the HVdc link rises because each converter needs some dc capacitors in order to maintain a constant dc voltage.

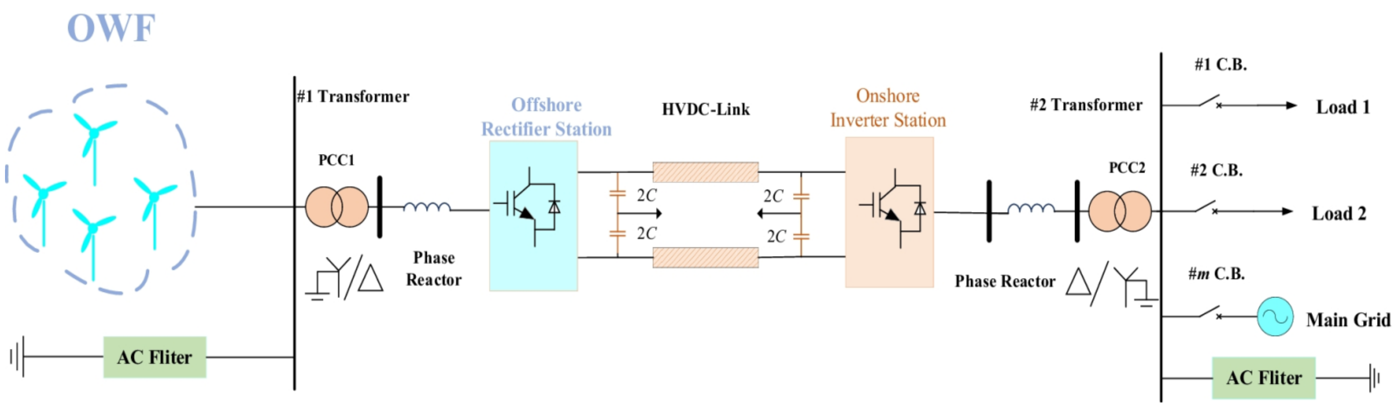

Figure-1: Bipolar HVDC connection for OFW.

III. WORKING

Wind turbines employ wind to generate power rather than electricity, like a fan produces. A turbine's propeller-like blades are turned by wind around a rotor, which drives a generator, producing power. Aerodynamic force is used by the rotor blades of a wind turbine, which similar to the rotor blades of a helicopter or an aeroplane, to transform wind energy into electrical power. As the wind flows across the blade, the air pressure on one side of it decreases. Both lift and drag are produced by the blade's two sides having different air pressures. The rotor rotates because the force of lift exceeds the force of drag. If the turbine is a direct drive type, the rotor is connected to the generator directly; otherwise, it is connected through a gearbox, which is a shaft and set of gears that accelerates spinning and makes the generator smaller in size. Through AC cables transmit this AC power from each wind turbine to a central offshore substation. Inside the offshore substation, the AC power undergoes conversion to DC (Direct Current) using a technology called a converter station. This is typically a High Voltage Direct Current (HVDC) converter station.

In which we are using the 18-pulse Diode rectifier for power converted into dc. The goal of achieving a smoother DC output with reduced harmonics. In a 3-phase AC system, a basic 6-pulse rectifier configuration uses six diodes arranged to rectify each phase of the AC input. Group of 6 Diode are connected in parallel with each.

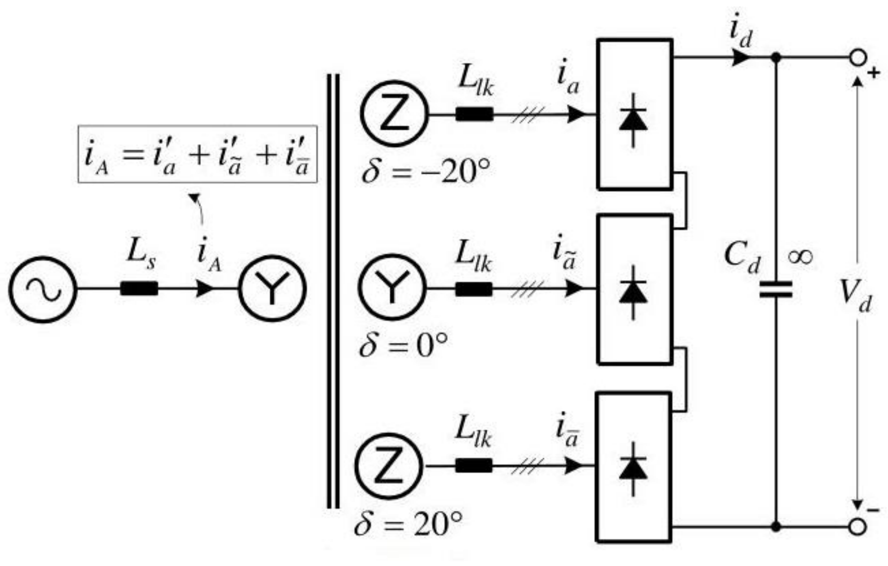

Figure-2:- The 18-pulse diode rectifier[13].

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The 18-pulse DRU builds upon the 6-pulse concept but utilizes additional transformers and diode connections to achieve a smoother DC output.

Each Group of diode rectifier need separate transformers. A specific phase shift is introduced between the secondary voltages of the transformers is shown in figure-2. The 18-pulse DRU uses a ± 20 phase shift to minimise magnetic size, and symmetrical pulses with less output dc voltage ripple are produced when the line voltages' magnitudes are equal. This phase shift can be achieved using a zig-zag transformer or other techniques.

The phase shift between the transformer outputs plays a crucial role. During the positive half cycle of one transformer's secondary voltage, the other transformer's secondary voltage might be in its negative half cycle (due to the phase shift). This partial cancellation of the negative half cycles, two 6-pulse rectifier circuits, helps to reduce certain harmonic components present in the rectified DC output, leading to a smoother waveform with less distortion.

IV. METHODOLOGY

The offshore wind farm power transmission involves several stages, from generation to ac grid.

a. Offshore wind power generation:-
b. Substation.
c. Transmission
d. AC grid.

Wind turbines operate on the principle of converting kinetic energy (energy of motion) from wind into electrical energy.

4.1 Offshore wind power generation.

a. Wind Power:

This formula calculates the theoretical maximum power available in wind:

Pwind = 0.5 * rho * A * V^3

Where:

- Pwind is the wind power (Watts)
- rho (rho) is the air density (kg/m^3) - This value varies depending on altitude and temperature, but a standard value of 1.225 kg/m^3 is often used for sea level calculations.
- A is the swept area of the turbine blades (m^2) - This is calculated by taking the radius of the rotor blades squared and multiplied by pi (π)
- V is the wind speed (m/s)

Important Note: This is the theoretical maximum power. In reality, wind turbines can only capture a portion of this power, limited by a factor called the Power Coefficient (Cp). The Cp is typically between 0.3 and 0.5 for modern wind turbines.

b. Blades:

The large, propeller-like blades capture the wind's energy. As wind flows over the blades, it creates lift, similar to an airplane wing, causing the blades to rotate.
This formula relates wind speed to the force exerted on the turbine blades:

F_thrust = 0.5 * rho * A * Cp * V^2

Where:

- F_thrust is the thrust force on the blades (Newtons)
- All other variables are the same as in the wind power formula.

c. Rotor:

The blades are connected to a central shaft that forms the rotor. The rotation of the blades is transmitted to the rotor. The rotational speed of the rotor is a critical factor in efficiency. It's often related to wind speed through the Tip Speed Ratio (TSR):

TSR = Ω * R / V

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Where:

- TSR is the Tip Speed Ratio (unitless)
- Ω (Omega) is the rotor angular velocity (rad/s) - This can be converted to RPM (revolutions per minute) by multiplying by 60/(2*pi)
- R is the rotor blade radius (meters)
- V is the wind speed (m/s)

Different TSR values are optimal for different wind speeds to maximize power capture. Turbine control systems adjust the rotor speed based on wind conditions.

d. Drivetrain:

The drivetrain may include gears or other mechanisms that convert the rotational speed of the rotor to a speed suitable for the generator. This is necessary because wind turbines operate at a slower speed than generators typically require for efficient electricity production.

e. Generator:

The generator is a device that generates electrical energy from the drivetrain's rotating motion. The electromagnetic induction concept serves as the foundation for this conversion.

f. Power Output:

The actual power generated by the turbine depends on the efficiency of the turbine's drivetrain and generator.

4.2 Substation:-

The 18-pulse diode rectifier present in the substation, which to convert the Alternate current into Direct Current. The advantage of Diode rectifier over other type of HVDC System, including a simpler structure, lower switching and conduction losses, easier the transport and installation.

Comprehensive formula for an 18-pulse diode rectifier (DRU) due to the system's complexity and harmonic content. However, we can examine pertinent ideas and split the conversion procedure into steps:

a. AC Input and Rectification:

- Each of the three phases in the AC input can be represented by a sinusoidal waveform

($V_{ph}(t) = V_m \sin(\omega t + \varphi)$, where Vm is the peak voltage, ω is the angular frequency, t is time, and φ is the phase angle).

- Diodes in a single 6-pulse rectifier circuit allow current flow only during the positive half cycle of each phase, essentially clipping the negative portion of the waveform.

b. Double 6-Pulse Rectification in 18-Pulse DRU:

The 18-pulse DRU utilizes two sets of transformers and two separate 6-pulse rectifier circuits. The key here is the introduction of a phase shift between the secondary voltages of the transformers.

c. Phase Shift and Harmonic Reduction:

- The transformers might employ a zig-zag transformer or other techniques to create a specific phase shift (Δθ) between their secondary voltages.
- This phase shift partially cancels out certain harmonic components present in the rectified DC output from each 6-pulse rectifier.

Zig-Zag Transformer and Standard Transformer Relationship:

A zig-zag transformer can be analyzed by conceptually breaking it down into two interconnected, standard transformers. This simplifies the calculations for voltage and current relationships.

Standard Transformer Formulas:

For a standard two-winding transformer (without considering leakage reactance for simplicity):

➢ **Voltage Ratio (Primary to Secondary):**

$V_p / V_s = N_p / N_s$ (Equation 1)

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Where:

- Vp is the primary voltage (Volts)
- Vs is the secondary voltage (Volts)
- Np is the number of turns in the primary winding
- N_s is the number of turns in the secondary winding

➢ **Current Ratio (Secondary to Primary):**

Ip / Is = Ns / Np (Equation 2)

Where:

- Ip is the primary current (Amps)
- Is is the secondary current (Amps)

➢ **Applying the Concept to Zig-Zag:**

A zig-zag transformer has its primary or secondary windings (or both) in a zig-zag configuration. This means each output terminal is connected to two winding sections from the star connection. While the basic voltage and current relationships (Equations 1 & 2) still hold true for each individual section of the winding, the overall voltage and current at the output terminals depend on how these sections are connected (series or parallel).

Analysis through Equivalent Circuits:
Detailed analysis of a zig-zag transformer often involves creating equivalent circuits that consider the winding connections and leakage reactance. These equivalent circuits can then be used with standard circuit analysis techniques to determine voltages, currents, and phase shifts.

d. Fourier Series Analysis:
While there's no single formula for the complete 18-pulse DRU output, Fourier Series Analysis is a mathematical tool to understand the harmonic content. It decomposes the AC input waveforms and the rectified DC output into their fundamental frequency (50 Hz or 60 Hz depending on the grid) and harmonic components (multiples of the fundamental frequency).

Analysing the Output:

- The DC component (average value) of the rectified output represents the usable DC voltage available for further processing (e.g., transmission in offshore wind farms).
- The presence of harmonics in the output can be undesirable, causing issues like increased power losses and potential stress on equipment. The 18-pulse DRU aims to minimize these harmonics compared to a traditional 6-pulse rectifier.

This above process of rectification (AC to DC) for HVDC power transmission line will get revered for conversions of power (DC to AC) for HVAC power transmission to the Grid.

4.3 Transmission line:-
The power of offshore wind farm needs the HVDC line for transmit power to the onshore substation. Because the long distance transmission HVDC is the best way to power flow. In HVDC transmission it has low power losses, Good voltage regulation, No line loading limits, lesser coronal loss and radio interference, it has the ability to operate the high voltage.

In these study paper we are using the bipolar technic of Hdvc transmission. It contain two conductors one with the +ve polarity and other one with –ve polarity. Also the neutral configuration is also the best technic. In bipolar technic have several sub-feature for power transmission, we can transfer the power by bipolar configuration, neutral with +ve polarity, neutral with –ve Polarity.

4.4 AC grid:-
After the Transmission of Power to Onshore substation, The substation convert the power to AC. The AC power will be given to AC grid for distribution.

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V. RESULT

In this section we are discussion about the comparative result. We developmented the Matlab Simulink model for Offshore wind farm without using 18-pules diode rectifier connected to HVDC. There is input, output, and THD waveform is present below.

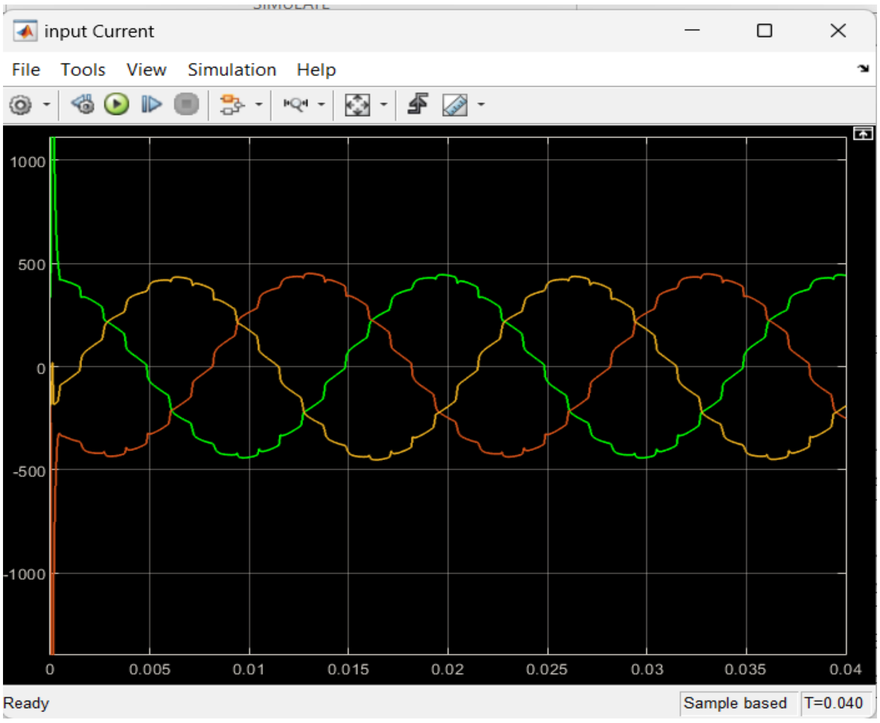

Figure-3:- AC Input Current

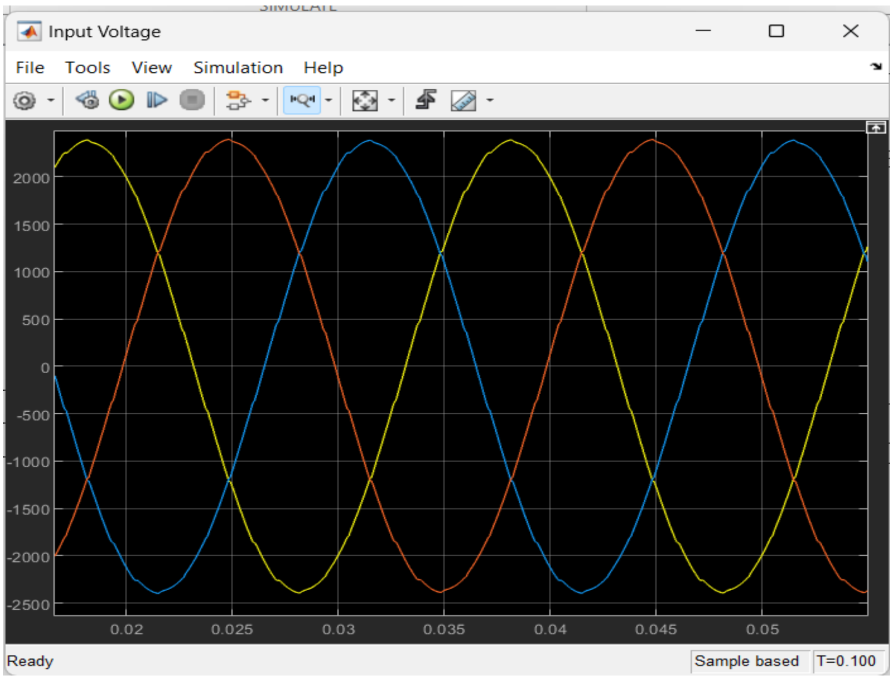

Figure-4:- AC Input Voltage

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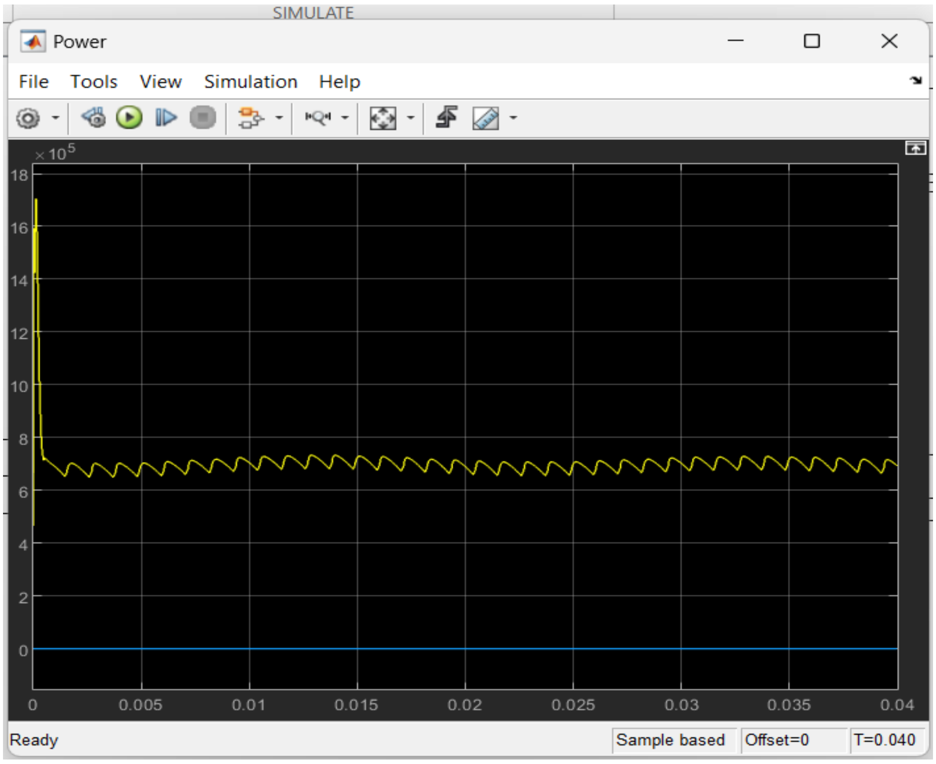

Figure-5:- AC Input Power

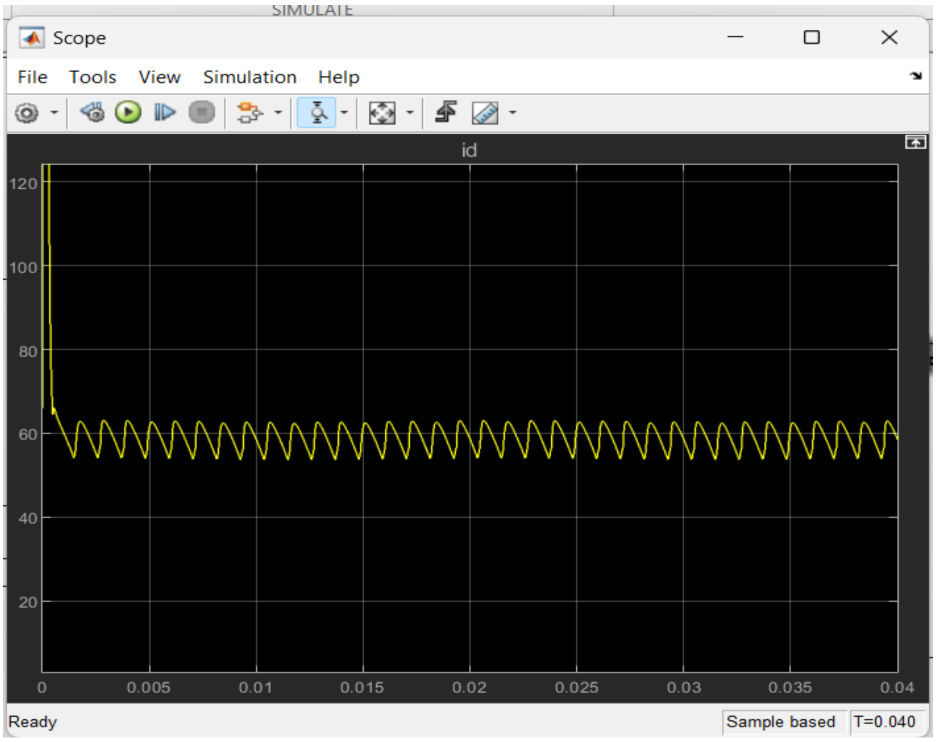

Figure-6:- DC Output Current

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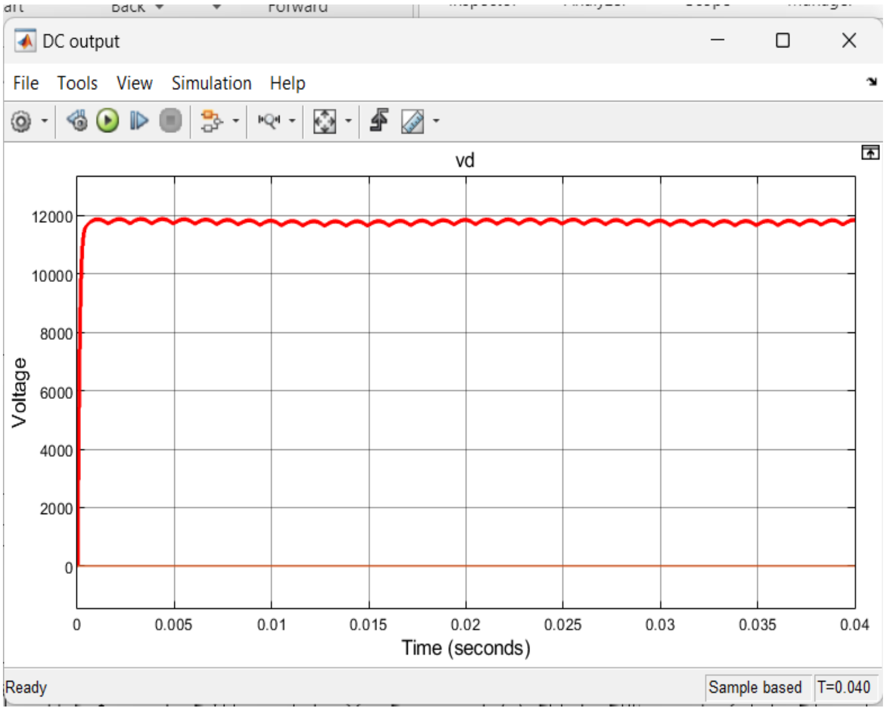

Figure-7:- DC Output Voltage

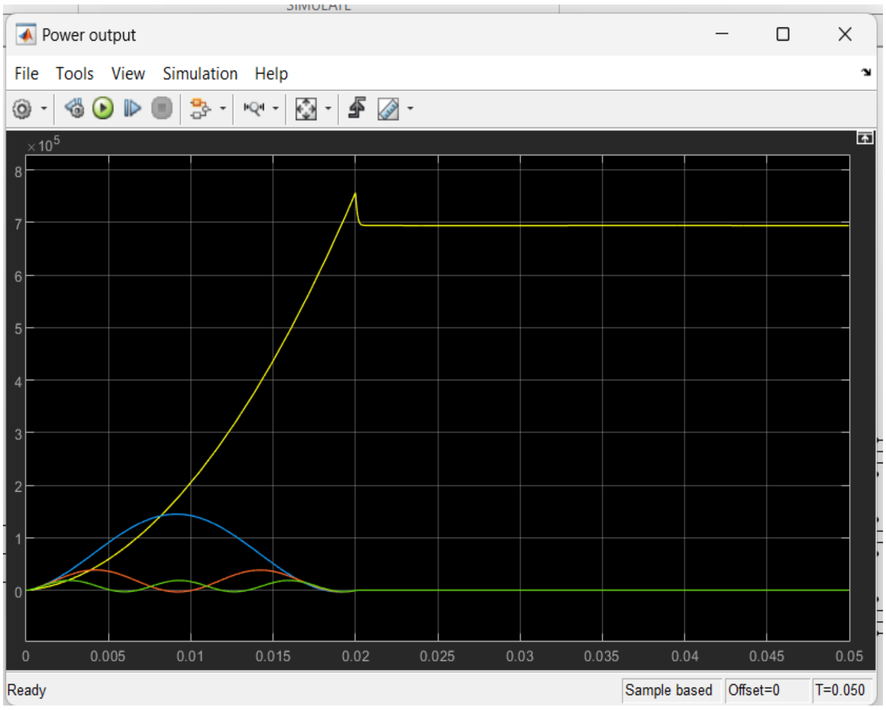

Figure-8: DC Output Power

VI. CONCLUSION

This Paper has demonstrated the feasibility and effectiveness of connecting an offshore wind farm to an 18-pulse diode rectifier for efficient and reliable power transmission. The use of an 18-pulse diode rectifier in offshore wind farms offers several advantages, including reduced filter costs, increased system reliability, and improved power quality.

Additionally, the reduced harmonic distortion enables the wind farm to operate at a higher power factor, resulting in increased energy production and revenue.

The growth of offshore wind farms and the transmission of renewable energy sources throughout the electrical grid are significantly impacted by this research report. As the world transitions to a low-carbon economy, the efficient and reliable transmission of renewable energy is critical. The findings of this research contribute to the development of more efficient and sustainable power transmission systems, supporting the growth of offshore wind energy and the transition to a cleaner, more sustainable energy future.

The Model 18-pulse diode rectifier connected with Offshore Wind farm. The model design in Matlab Simulink.

REFERENCES

[1]. Madsen & Krogsgaard, Offshore Wind Power 2010 Archived 30 June 2011 at the Wayback Machine BTM consult, 22 November 2010. Retrieved: 22 November 2010.
[2]. Vloemans, Pepijn (27 January 2022), “Energia per tutti”, Internazionale (in Italian). Retrieved 1 February 2023.
[3]. Miguel Ángel Cardiel-Álvarez, Ashkan Nami, Santiago Arnaltes ∗, Jose Luis Rodriguez-Amenedo, “Hybrid bipolar VSC-DRU HVdc connection for offshore wind farms”, In Elsevier Journal September 2023.
[4]. P. Zeng, Q. Zhou and Q. Dai, “Study on the development and reliability of HVDC transmission systems in China”IEEE 2016.
[5]. Guarnieri, M. (2013). "The Alternating Evolution of DC Power Transmission". IEEE Industrial Electronics Magazine. 7 (3): 60–63. doi:10.1109/MIE.2013.2272238.
[6]. B. Snyder and M. J. Kaiser, “Ecological and economic cost-benefit analysis of offshore wind energy,” Renewable Energy, vol. 34(6), pp. 1567-1578, 2009b.
[7]. D. A. Paice, “Power Electronic Converter Harmonics: Multipulse Methodsfor Clean Power”, New York, IEEE Press 1996.
[8]. F.J. Chivite-Zabalza, A.J.Forsyth and D.R.Trainer, "Analysis and practical evaluation of an 18-pulse rectifer for aerospace application,” in Proc. 2004, IEEE PEMD, Conf., pp.338-343.
[9]. D.A. Paice, "Multipulse converter system", U.S. Patent No. 4876634, 24 October, 1989.
[10]. Chih-Hung Hsieh “Offshore Wind Energy Research Trajectory and Trends” Honolulu, HI, USA” IEEE 2018”.
[11]. Goertz M, Wenig S, Beckler S, Hirsching C, Suriyah M, Leibfried T. “Analysis of cable overvoltages in symmetrical monopolar and rigid bipolar HVDC configuration”. IEEE Trans Power Deliv 2019;35(4):2097–107.
[12]. Miguel Ángel Cardiel-Álvarez, Ashkan Nami, Santiago Arnaltes ∗, Jose Luis Rodriguez-Amenedo, “Hybrid bipolar VSC-DRU HVdc connection for offshore wind farms”, In Elsevier Journal September 2023.
[13]. Bin Wu, “High power converter and Ac drives”, A John Wiley & Sons, Inc., Publication 2006.
[14]. BS Reporter (11 May 2012). "Suzlon creates country's largest wind park". Business Standard India. Retrieved 28 May 2015.
[15]. Hoffmann M, Rathke C, Menze A, Hemdan NG, Kurrat M. Parallel operation of HVDC DRU and VSC converters for offshore wind farm connection: Technical and economic feasibility. In: 15th IET international conference on AC and DC power transmission. IET; 2019, p. 6.
[16]. Nami A, Rodriguez-Amenedo JL, Arnaltes S, Cardiel-Alvarez MA, Alves R. Control of the parallel operation of DR-HVDC and VSC-HVDC for offshore wind power transmission. IEEE Trans Power Deliv 2021.
[17]. Blasco-Gimenez R, Ano-Villalba S, Rodríguez-D’Derlée J, Morant F, Bernal- Perez S. Distributed voltage and frequency control of offshore wind farms connected with a diode-based HVdc link. IEEE Trans Power Electron 2010;25(12):3095–105.
[18]. Yu L, Li R, Xu L. Distributed pll-based control of offshore wind turbines connected with diode-rectifier-based HVdc systems. IEEE Trans Power Deliv 2018;33(3):1328–36.
[19]. Bidadfar A, Saborío-Romano O, Cutululis NA, Sørensen PE. Control of offshore wind turbines connected to diode-rectifier-based HVdc systems. IEEE Trans Sustain Energy 2020;12(1):514–23.
[20]. Cardiel-Álvarez MÁ, Arnaltes S, Rodriguez-Amenedo JL, Nami A. Decentralized control of offshore wind farms connected to diode-based HVDC links. IEEE Trans Energy Convers 2018;33(3):1233–41.
[21]. P. Zeng, Q. Zhou and Q. Dai, “Study on the development and reliability of HVDC transmission systems in China” IEEE 2016