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

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Abstract: This study paper presents an offshore wind farm connected to an 18-pulse diode rectifier for efficient power transmission and harmonic mitigation. The proposed configuration utilizes a combination of wind turbines, transformers, and an 18-pulse diode rectifier to minimize harmonic distortion and ensure compliance with grid codes. This study paper presents a bipolar high voltage direct current (HVdc) link for offshore wind farms (OWFs) connection.

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

A wind farm or wind park, also called a wind power station or wind power plant,[1] is a group of wind turbines in the same location used to produce electricity. Wind farms vary in size from a small number of turbines to several hundred wind turbines covering an extensive area. Wind farms can be either onshore or offshore.

The first known wind turbine used to produce electricity is built in Scotland. The wind turbine is created by Prof James Blyth of Anderson’s College, Glasgow (now known as Strathclyde University). Many of the largest operational onshore wind farms are located in China, India, and the United States.

For example, the largest wind farm in India capacity of 1,500 MW wind farm named “Muppandal Wind Farm” which is located in Kanyakumari district, Tamil Nadu, India[1].

Since the fact that onshore planning frequently restricts the turbines' "tip heights," which does not apply to offshore turbines, onshore wind farms have a lower "capacity factor" than their offshore equivalents. [8]. An average onshore wind turbine produces around 2.5 to 3 megawatts (MW), in comparison to the offshore average of 3.6 MW.

Offshore wind farms are located in bodies of water and generate electricity from wind blowing across the sea. They require specialised equipment and vessels for installation and maintenance, making them more expensive to construct and maintain.

However, offshore wind turbines are typically larger and taller than those at onshore wind farms. This modification can result in a 34% improve in wind turbine efficiency. In addition to being stronger and less chaotic than on land, the wind at sea makes it possible to create more power with more consistency.

Offshore wind turbines are more efficient, offshore installations need fewer turbines to produce the same amount of electricity as onshore wind farms because of greater wind speeds and direction stability. Oceans provide more area for construction, making them the ideal site for wind farms due to their openness and magnitude. Additional clean, sustainable electricity can be created as additional wind farms are constructed.

For transmission of power generated by offshore wind farm, we want to convert the alternative current into direct current. Hence, we want to use a transmission system for quality power supply. Whereas alternating current (AC) transmission systems are more widely used, high-voltage direct current (HVDC) transmission systems employ direct current (DC) for electric power transmission [2].

Most HVDC links use voltages between 100 kV and 800 kV. However, a 1,100 kV link in China was completed in 2019 over a distance of 3,300 km (2,100 mi) with a power capacity of 12 GW.[3] With this dimension, intercontinental connections become possible which could help to deal with the fluctuations of wind power and photovoltaics.[4]

Since HVDC lines require fewer conductors and have lower power loss than identical AC lines, they are frequently utilised for long-distance power transmission. Power transfer between asynchronized AC transmission networks is also made possible by HVDC. An HVDC connection helps stabilise a network against disruptions caused by abrupt changes in power as it allows the power flow to be managed regardless of the phase angle between the source and the load.

There are several types Configurations for Power Transmission, like Monopolar, Bipolar, Back to back, etc., we are using the Bipolar configuration quality configuration.

In bipolar transmission, two conductors with opposing polarities and high potentials relative to ground are employed. The cost of the transmission line is higher than that of a monopole with a return conductor since these conductors need to be insulated for the entire voltage. Bipolar transmission can, however, be a desirable alternative due to a number of its benefits.

Bipolar systems may carry as much as 4 GW at voltages of ±660 kV with a single converter per pole, as on the Ningdong–Shandong project in China. With a power rating of 2,000 MW per twelve-pulse converter, the converters for that project were (as of 2010) the most powerful HVDC converters ever built.[5] For the offshore wind power transmission we are using the 18-pules diode rectifier. In the world of converting AC (alternating current) to DC (direct current), the 18-pulse diode rectifier stands out for its ability to deliver smoother, cleaner power.

An 18-pulse rectifier is a type of AC-to-DC converter that utilizes a special configuration to achieve a more refined DC output. Diodes are like one-way valves for electricity, allowing current to flow in one direction. By using 18 strategically placed diodes, the rectifier converts AC into a pulsing DC waveform with more pulses per cycle compared to simpler rectifiers. The increased number of pulses translates to a smoother DC output, with less fluctuation and ripple. This is beneficial for many applications that require a clean and stable DC power supply. A major benefit of 18-pulse rectifiers is their ability to reduce harmonics. Harmonics are distortions in the AC waveform that can cause problems for electrical equipment. By achieving a more sinusoidal DC output, the 18-pulse rectifier minimizes these distortions on the AC input side.

For applications where the demand for harmonic current reduction is more stringent, an 18-pulse ac-dc converter is enerall referred. With help of 18-pulse diode rectifier the elimination of harmonic occur [10]. 18-pulse DRU proposed the result in elimination of 5^{th}, 7^{th}, 11^{th}, and 13^{th} harmonic. DRU is also reduce the THD of the current and voltage less then 5% [7].

II. LITERATURE REVIEW

The topology of an 18-pulse diode rectifier involves a combination of transformers and diode bridge rectifiers to achieve a smoother DC output compared to simpler designs. Two or three transformers with specific winding configurations are used to create the required phase shifts for the 18-pulse operation. Common configurations include: Delta-delta: This is a popular choice as it avoids the need for a neutral connection. The windings are arranged in a triangular pattern on both the primary and secondary sides. Delta-wye: This configuration can be used if a neutral connection is available or desired. The primary windings are connected in a delta pattern, while the secondary windings are connected in a star (wye) pattern with a neutral point.

Phase Shifting: The key to achieving 18 pulses is creating multiple rectified outputs with specific phase shifts. The transformer winding connections introduce these phase shifts. For example, in a delta-delta configuration, each secondary winding will have a 30-degree phase shift compared to its neighbors. Multiple diode bridge rectifiers are used, with each bridge receiving one of the phase-shifted outputs from the transformers.

A standard diode bridge rectifier consists of four diodes connected in a specific way to allow current flow only in one direction (DC output). The three-phase AC supply is fed into the primary windings of the transformers. The transformer windings create the necessary phase shifts between the secondary outputs. Each phase-shifted secondary output feeds a separate diode bridge rectifier. The diode bridge rectifies the AC waveform from each secondary, resulting in a pulsating DC output. Since there are multiple phase-shifted outputs feeding separate bridges, the final DC output has a higher number of pulses (18 in this case) compared to a basic 6-pulse rectifier. By understanding the topology of the 18-pulse diode rectifier, you can appreciate its role in achieving a cleaner and more stable DC output for various power electronics applications.

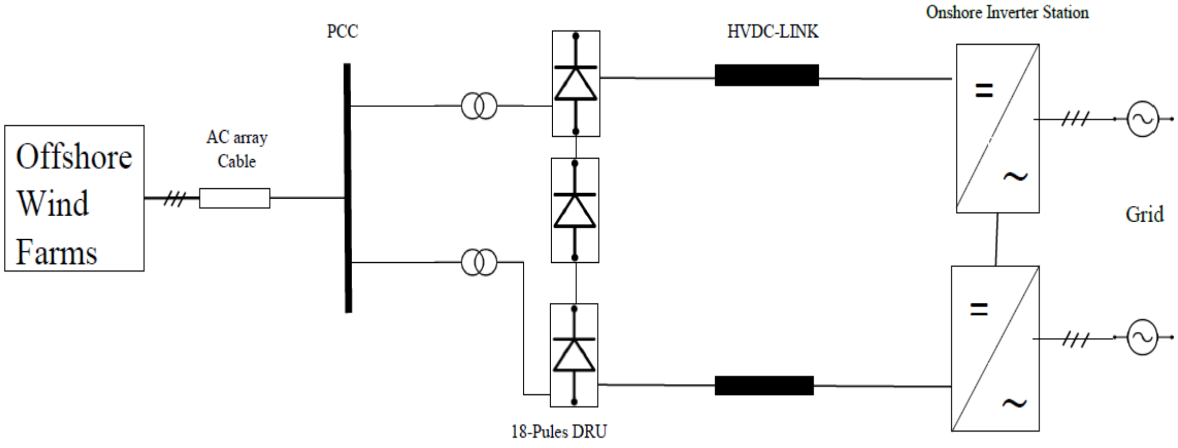

Figure-1:- Circuit diagram of Bipolar HVDC connection for Offshore Wind farm.

III. METHODOLOGY

The methodology of an 18-pulse diode rectifier revolves around achieving a smoother DC output by combining transformers, phase shifting, and diode bridge rectification. Utilizing Transformers for Phase Shifting, Two or three transformers are employed, depending on the chosen configuration (delta-delta or delta-wye).The transformer windings are arranged strategically to introduce specific phase shifts between the secondary outputs. In a delta-delta configuration, each secondary winding has a 30-degree phase shift compared to its neighbors. Creating Multiple Rectified Outputs The transformer secondary windings provide several AC outputs with the introduced phase shifts. The number of outputs depends on the configuration: Delta-delta: Six phase-shifted outputs (since each winding has a 30-degree difference). Delta-wye: Three phase-shifted outputs (one for each phase of the wye connection).

Diode Bridge Rectification Multiple diode bridge rectifiers are employed, equal to the number of phase-shifted outputs from the transformers. Each bridge rectifier consists of four diodes configured to allow current flow only in one direction (conversion to DC). Each phase-shifted AC output from the transformers feeds a separate diode bridge rectifier. Combining Rectified Outputs (18 Pulses) The individual diode bridge rectifiers convert their respective phase-shifted AC inputs into pulsating DC outputs. Since these outputs come from phase-shifted AC sources, they are not in sync with each other. By combining the outputs from all the bridge rectifiers, a final DC output with a higher pulse count (18 in this case) is achieved. Compared to a basic 6-pulse rectifier, the 18-pulse design offers a significant increase in the number of pulses within the DC output. This translates to a smoother DC waveform with less ripple voltage, leading to cleaner and more stable power.

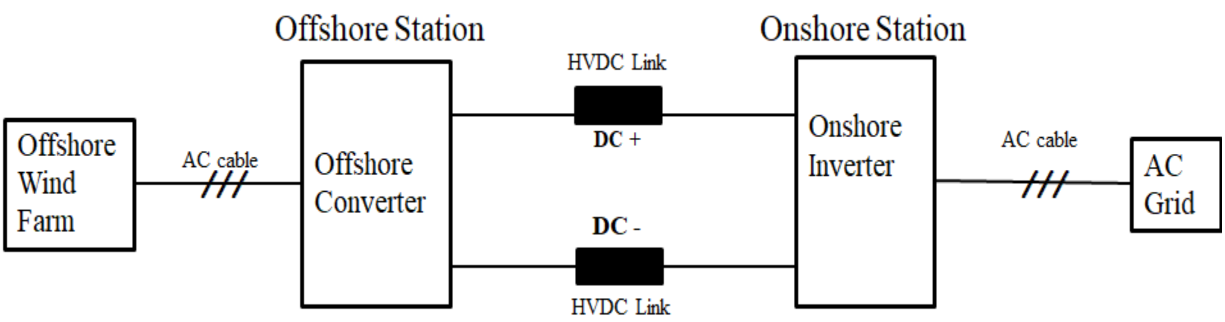

Figure-2:- Block diagram of HVDC connection for Offshore wind farm.

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The methodology achieves reduced harmonic distortion on the AC input side due to the cancellation effect of the multiple rectified phases. The trade-off for this improved output is the increased complexity of the system compared to simpler rectifiers. Depending on the specific configuration, controlling the 18-pulse rectifier might involve managing the firing angles of converter switches (if present). By understanding this methodology, you can appreciate the 18-pulse diode rectifier's approach to achieving a superior quality DC output for various applications requiring clean and stable power.

The equations of outputs and THD for an 18-pulse diode rectifier is

Output Voltage:
$Vout = 18Vpeak \sin(\omega t + \theta)$

Output Current:
$Iout = 18Ipeak \sin(\omega t + \theta)$

Average Output Voltage:
$Vavg = 18Vpeak / \pi$

Average Output Current:
$Iavg = 18Ipeak / \pi$

Total Harmonic Distortion (THD):
$THD = \sqrt{(\Sigma(hn^2))} / (V1^2 + \Sigma(hn^2))$

where:
- Vpeak is the peak voltage of the input waveform
- Ipeak is the peak current of the input waveform
- ω is the angular frequency of the input waveform
- θ is the phase angle
- hn is the nth harmonic voltage or current
- V1 is the fundamental voltage or current

The 18-pulse diode rectifier has 18 pulses per cycle, which reduces the total harmonic distortion (THD) and improves the output waveform quality. The formula assumes a balanced and symmetric input waveform. Also, [10] the output voltage and current of the 18-pulse diode rectifier can be expressed as:

Output Voltage:
$Vout = 18Vpeak \sin(\omega t + \theta) = 18Vpeak [\sin(\omega t) \cos(\theta) + \cos(\omega t) \sin(\theta)]$

Output Current:
$Iout = 18Ipeak \sin(\omega t + \theta) = 18Ipeak [\sin(\omega t) \cos(\theta) + \cos(\omega t) \sin(\theta)]$
These formulas show that the output voltage and current of the 18-pulse diode rectifier are sinusoidal and have a high degree of purity, with minimal harmonic distortion.

IV. CONCLUSION

This Study 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.

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