High Voltage DC Transmission Systems for Offshore Wind Farms with Different Topologies

Rajesh Babu Damala, Bishu Prasad Misra, Rajesh Kumar Patnaik

Abstract: Theoretical review of various topologies of high voltage DC links in application to off shore wind farms has been studied and analysed. In addition to that, various types of high voltage DC links such as back to back, two terminal, multi-terminal systems has been covered under this study. The Line-Commutated Converters, Voltage Source Converter, Modular Multi-Level Converter as well as some of advanced hybrid high voltage DC topologies in application to off shore wind farms has been reviewed. This study covers complication arising from large-scale wind power generation. The review paper also points out the scope of future research in high voltage DC converters.

Key words: High Voltage DC links, Hybrid Converter, Line-Commutated Converters, Modular Multi-Level Converter, Voltage Source Converter, Offshore wind farms.

I. INTRODUCTION

The transformation of electrical energy from off shore wind farms to the main land using high voltage direct current (HVDC) technology mainly depends on the type of converter being used in it. The conversion through HVDC system has been done by using line commutated converter, voltage source converter, modular multi-level converter and hybrid converter. Among them, the Voltage source converter (VSC), High Voltage Direct current (HVDC) plays a key role for transmission in present scenario. It becomes new trend for long distance wind power transmission. The Cost, efficiency, reliability of VSC-HVDC system is low. The objective of this research is to review the LCC, VSC, MMC and hybrid converter-HVDC transmission technologies and advancements of the HVDC transmission system over the HVAC transmission system with techno-economic consideration and the need and role of HVDC in the present scenario. Focus on the main components and different types of HVDC transmission topologies for the HVDC system has been made for finding a cheaper hardware combination. The advantages of HVDC system over HVAC system are as follows. For longer distances, greater than break-even distance HVDC system has less cost and more efficiency. Investment cost is low. Losses are less in DC compared to HVAC system, hence efficiency increases. For longer distance transmission, HVAC offers more short circuit current (Isc) at the receiving end. The objective of this paper is to find out suitable converter system for high voltage DC or AC long transmission system with low cost. In addition to that analysing different high voltage DC links and its topologies, which gives maximum efficiency with good reliability depending on the distance.

Fig1.HVDC and HVAC cost comparison

II. REVIEW OF LITERATURE

1.1 Introduction:
The components for AC and DC systems have been studied by many researchers. 20 papers have been collected and the finding of all these papers are tabulated in form of achievement and unresolved issues. They are classified as transmission system, techno-economic consideration, and types of system, reliability of the system, topology, transmission lines and converters.

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Role of HVDC Transmission system

The reasons for selecting HVDC transmission system over long distances instead of HVAC because of its advantages. They are:
- Asynchronous interconnections
- Low investment cost
- Less losses
- Limited short-circuit currents
- Controllability
- Environment
- Interference with nearby communication lines

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1.2 Techno-Economic considerations

Comparison of AC and DC transmission:

1.3 Line Compensation

Shunt and series compensation are required in AC lines require in long distance transmission. Line charging and stability problems can be also solved by compensation technique. By using Static Var Systems (SVS) also we can increase the power transfer and control the voltage.

Problems of AC Interconnection

The reason for problems in coordinated control system are

a) Presence of huge power oscillations that causes frequent tripping
b) Fault level increment
c) Transformation of disturbances from one system to another system.

1.4 Reliability

Comparatively with HVAC, the reliability of DC transmission systems is good. It is necessary to be noticed that the thyristor valves performance and further developments in devices, protection and control is improved which increases the reliability level. The development of direct light triggered thyristors (LTT) is expected to improve the reliability of the system because of elimination of high voltage pulse transformers and auxiliary supplies for turning on the devices.

3.4 DC Links:

1) Power Transmission Economics

The capital cost and operational cost together would be the total cost of a transmission line. The capital cost of Right of Way (RoW), conductors, insulators transmission towers. The maintains cost and losses cost together would be the operational cost.

For less than break even distance the AC tends to be more economical than DC and for longer distances DC is preferable. Based on the per unit line cost, the break-even distances can vary from 500 to 800 km in overhead lines.

2) Technical Performance

The advantages in HVDC transmission system areas follows:

Power transmission system is fully controlled.
Fast control over limitation of fault currents in DC lines which makes avoiding DC breakers in two terminal DC links.
The power carrying capability of an AC and DC lines varies with respect to distance is shown in above figure.

III. VSC-HVDC TRANSMISSION SYSTEM COMPONENTS:

i. Converters
ii. DC cables and breakers
iii. AC filters
iv. Transformers
v. DC Links
vi. Phase reactors
vii. DC capacitors and filters

3.1 Converters:

In this transmission system, converters can do both the operations i.e., rectification and inversion. The frequency modification ratio by PWM technique helps to make a balance between harmonic losses and switching losses.

3.2 Transformers:

Three 1-phase transformers are being used to transform AC voltage to the required level. These are simple in design and conventional, because of harmonic content of current is low in the VSC high voltage DC transmission system.

3.3 Phase Reactors (Single-phase air-cooled reactors):

By regulating of currents in phase reactors, active and reactive power flow can be controlled.

3.4.1. Mono-polar Link: It consists of only one conductor with negative polarity and it uses ground as return path. Sometimes it uses metallic run also.

Fig.2 Power transfer capability vs Distance

Fig.3. Mono-polar link circuit
3.4.2. Bipolar Link:
It is having two conductors, one is positive and another one is negative. Each terminal consists of two sets of converters of same ratings in series with DC side.

![Bipolar Link Circuit](image)

**Fig.4 Bipolar Link circuit**

3.4.3. Homopolar Link: It is having two or more conductors which are usually having negative polarity. Like monopolar link, it also uses ground as its return path.

![Homopolar Link Circuit](image)

**Fig.5 Homopolar link circuit**

IV. HVDC SYSTEM CLASSIFICATION

4.1 Back to Back HVDC System:
The back-to-back HVDC system transfers energy between the several AC buses at the same location. In this type of HVDC stations, the rectifiers and converters have been set up in the same stations. An asynchronous interconnection exist between two controlled AC networks, which are adjacent independently that do not transfer the frequency disturbances. The bipolar operation is suitable for back-to-back system.

4.2 Two Terminal HVDC System:
The converter station and HVDC transmission line together forms two terminal HVDC system. No HVDC intermediate tapping are available as it does not having parallel HVDC line. There is no requirement of HVDC circuit breaker in this scheme. The converter controller controls the current at fault and no fault condition.

4.3 Multi-terminal DC System
It consists three or more converter stations and DC terminal lines. Some of the converter stations operated as rectifier while others operated as an inverter. The total power drawn from the rectifier station is equal to the power supplied by the inverter station. The MTDC Systems classified as follows

**Advantages of MTDC systems:**

a) More economical and flexible.

b) Damping of frequency oscillations in AC interconnected system is very quickly.

c) Reinforcing of heavy loaded AC networks is possible.

**Applications of MTDC systems:**

a) Bulk power transmission is easy

b) Through radial type connection several AC system can be connected.

**Different topologies for multi-terminal HVDC system:**

4.3.1 Point to point topology:
The separation of substations is possible be connecting every wind farm in this type of topology. Advantage is easy to construct, maintenance and main disadvantage is that it is only used for two nodes; if any fault occurs in the line then entire wind farm will be lost. Its construction is shown below
4.3.2 General ring topology: All the wind farms are connected to the substations in a circular manner as shown in figure below. The advantage of this system is it has more flexibility. The main disadvantage of this type of topology is if a fault occurs in the line anywhere the system will be failed.

4.3.3 Star topology: In this type of topology, all the wind farms are connected to a common point as shown in the figure below. If any fault occurs in the centre node then the entire system will be shut down. Even though this system has many advantages, it is not used mostly because of this disadvantage.
4.3.4 Star with a central switching ring topology:

This is the combination of both general ring topology and star topology. Hence, it is called as hybrid system. It overcomes the disadvantage of the star topology. Regarding flexibility, this topology also having the same problem as star topology. Its construction is shown below.

4.3.5 Ring topology in Wind farms:

It has many advantages compared to all other topologies. Its construction is shown in figure below.
4.3.6 Substation ring topology:
The construction and performance of this system are almost similar to the wind farm ring topology. But it forms a ring like structure on the substation side. Its construction is shown in the figure below.
4.3.7 Comparison among varies topologies

| Topology                     | Subclass | Offshore platform | Communication | Flexibility | Redundancy | Overall                                      |
|-----------------------------|----------|-------------------|---------------|-------------|------------|----------------------------------------------|
| Point to point topology     | -        | N                 | N             | N           | N          | Low flexibility and easy to connect          |
| General Ring Topology       | -        | N                 | Y             | Very good   | Very good  | Good flexibility but few circuits should be rated for full system power |

| Star Topology               | SS side  | WF side           | Total         |            |            |                                              |
|-----------------------------|----------|-------------------|---------------|------------|------------|----------------------------------------------|
|                            | Y        | Y                 | N             | Good       | Y          | Wind farm rating is equal to circuit’s rating, but weak point exist at the central node |

| Wind Farm Ring Topology     | -        | N                 | Y             | Quite Good | Quite Good |                                              |
|-----------------------------|----------|-------------------|---------------|------------|------------|----------------------------------------------|
|                            |          |                   |               |            |            | GRT and ST Has the advantages of both, but at central switching ring needs full power in the |

| Central Switching Ring Topology with star | Ring | Line | Total |            |            |                                              |
|------------------------------------------|------|------|-------|------------|------------|----------------------------------------------|
|                                          | No   | No   | no    | Good       | Y          | Full power rating is not required            |

|                            | NA    | NA    | NA    | NA         | NA         |                                              |

V. TRANSMISSION

5.1. LCC for HVDC Transmission in Offshore Wind Energy: HVDC based on line-commutated converters connected in a 6 pulses with a set of thyristor valves shown in below figure.

![Six-Pulse Line Commutated Converter](image)

LCC based high voltage DC technology, which is more suitable to the bulk transmission, and its reliability and availability have been demonstrated since years on main land installation. Due to following reasons the use of LCC for grid integration of marine energy parks not adopted
• LCC-HVDC requires more space as it requires passive filters
• External commutating AC voltage for the commutation
• At both sides of the system LCC takes more reactive power
• Harmonics are more

Moreover, the reactive power compensation can be done by STATCOM at the
time of steady state, dynamic, and transient conditions. The back-to-back PWM converter provides reactive power demand.

5.2. VSC-HVDC for high voltage DC Transmission in Offshore Wind Energy:
Self-commutated devices are being used in VSC-HVDC transmission system. VSC uses latest converters with series IGBT with antiparallel diodes. The advantages as follows:
- NO External commutating voltage source is required
- The VSC-based high voltage DC system gives Lower harmonic distortion
- Over active and reactive power the ability to have independent control if good
- Passive grids can be supplied by VSC-HVDC. For the integration of OWF this feature is more important
- Active and reactive power can be controlled so that power quality issues are reduced.
- Reduced land requirement and controllability is high.

5.3 Modular Multi-Level Converter:
Professor Marquardt introduced modular multilevel converter (MMC which gives better efficiency for high voltage and high power application. The only converter from multilevel family, which represents model design only for two DC terminals, that suits for HVDC transmission. Smooth and ideal AC output voltage can be given by this topology that requires no filtering at all. Though the modular is failed it gives continue operation. It can be operated at lower switching frequencies.
5.4 Hybrid Topologies: With help of self-commutated converter, a hybrid HVDC system is designed which is an alternative solution. The benefits from the both forced and line commutated exits in this type. So the efficiency is improved and capital cost also decreased.

The commutation voltage and land requirement is more in this type. The installing cost and power losses can be reduced by diode-based rectifier and LCC. Here it is new control technique for transient state and steady state, which is PWM-CSC that consisting current converter with self-commutation.

Fig. 15 MMC- HVDC circuit

Fig. 16 Hybrid HVDC system

Fig. 17 a diode rectifier and LCC
The LCC connected the main grid at onshore side, in other hand the PWM-CSC is connected to an off shore Windfarm side. Due to this technique power, loss is reduced, good voltage control and AC OR DC faults have good response.

VI. CONCLUSIONS

The suitable method to transmit offshore wind power economically and technically if VSC based HVDC transmission technology. This paper reviewed the importance of VSC based high voltage DC transmission technology. The components involved in VSC High voltage technology are presented in this paper. The Energy conversion between DC and AC systems can be performed by VSC HVDC Technology. This paper briefly explained Various converter topologies. It observed that MMC is the best promising converter for VSC High voltage DC system. The Multi-terminal VSC HVDC systems can perform additional controllability in transmission system when compared to two-terminal system. Various converter controllers briefed in this paper. The VSC high voltage DC system can provide benefits to wind turbine manufactures, wind farm developers as the technical features and enhanced. The main importance is given to the control methods of the VSC high voltage DC connected offshore wind power plant. This paper also reviewed a survey on large-scale wind power generation more than 100MW with location

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