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Design and Implementation of Multi-Terminal VSC -HVDC Transmission Systems for Offshore Wind Power Plant

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***ABSTRACT*--This paper discusses a multi-terminal VSC HVDC system proposed for integration of deep sea wind farms and offshore thermal and nuclear platforms in to the grid onshore. An equivalent circuit of the VSC in synchronous d-q reference frame has been established and decoupled control of active and reactive power was developed. A three terminal VSC-HVDC was modeled and simulated in MATLAB/SIMULINK software. Voltage margin method has been used for reliable operation of the HVDC system without the need of communication. Simulation results show that the proposed multi-terminal VSC-HVDC was able to maintain constant DC voltage operation during load switching, step changes in power demand and was able to secure power to passive loads during loss of a DC voltage regulating VSC-HVDC terminal without the use of communication between terminals.**

Index Terms --VSC-HVDC Multi-Terminal HVDC (MHVDC), Transmission system for offshore wind power, voltage control, and wind power generation.

1. INTRODUCTION

Growth of electric power transmission facilities is restricted despite the fact that bulk power transfers and use of transmission systems by third parties are increasing. Transmission bottlenecks, non uniform utilization of facilities and unwanted parallel path or loop flows are not uncommon. Transmission system expansion is needed, but not easily accomplished. Factors that contribute to this situation include a variety of environmental, land-use and regulatory requirements. As a result, the utility industry is facing the challenge of the efficient utilization of the existing AC transmission lines. Offshore wind farms present a number of benefits compared to traditional onshore wind farms. Namely, the availability of higher wind speed, the ease of transport of very large structures (allowing larger wind turbines), and the limited available inland locations to install new wind farms in some countries (mainly in Europe) render them a promising alternative [1].

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Thus, the number of offshore wind farms has grown in the recent years. Eight hundred sixty-six megawatt of can be connected to the main ac grid using transmission

systems based on ac or dc technology [3]. The choice between these technologies depends on the cost of the installation which depends, in turn, on the transmission distance and power. The need to compensate for the impedance of the lines in ac transmission [4] makes its price grow with the distance at a higher rate than dc transmission, whereas dc transmission implies a high fixed cost due to the need of large power converters. Thus, there is a break-even distance from which the dc options become lower priced than ac [5], [6]. An interconnection between the offshore wind farms, the oil and gas platforms and onshore grid can result in reduced operational costs, increased reliability and reduce CO2emissions. The connection of different wind farms and different onshore ac grids can be performed with a common dc grid based in a multiterminal HVDC (MHVDC) grid arrangement, where the terminals are wind farms or grid connections. A multi-terminal HVDC (MTDC) network will then be the core of such an interconnection system. MTDC can also open new power market opportunities and result in better utilization of transmission lines [7].

Classical HVDC based upon line commutated converters has a main challenge in that it needs reversal of voltage polarity during reversal of power flow. This means that classical HVDC is unable to operate at fixed DC voltage level for both rectifier mode and inverter mode of operation. Since maintaining a constant dc voltage during all conditions is one expected and important feature of the MTDC, the thyristor based classical HVDC may not be a good candidate in developing MTDC. New converter topologies and lower priced fast-switching semiconductors have recently made it possible to build voltage source converter (VSC)-based HVDC transmission systems. The benefits of using VSC and fast switching are the ability to independently control the active and reactive power while reducing the size of the output filters needed to have a low harmonic distortion [8]–[11].

Voltage source converters (VSC) on the other hand do not need reversal of polarity for changing the direction of power flow and also are capable of independent control of active and reactive power. This makes VSC and ideal component in making MTDC.

This paper presents a proposed three terminal VSC-HVDC model linking an onshore grid, offshore wind farm and offshore oil and gas platform and discusses the control strategy for the terminals.

2. PROPOSED SYSTEM

The fig (1) system under analysis is an M-HVDC transmission system with four terminals: two offshore wind farms and two onshore main ac grid connections. The two offshore wind farm VSC (WFC) power converters inject the power generated in each wind farm into the HVDC grid, whereas the gridside VSC (GSC) power converters inject the power from the HVDC grid into the main ac grid. The HVDC grid consists of three submarine cables: Two of them connect each wind farm to an onshore VSC, while a third tie cable connects the two wind farms together in order to provide redundancy and share the power injected by each onshore converter.

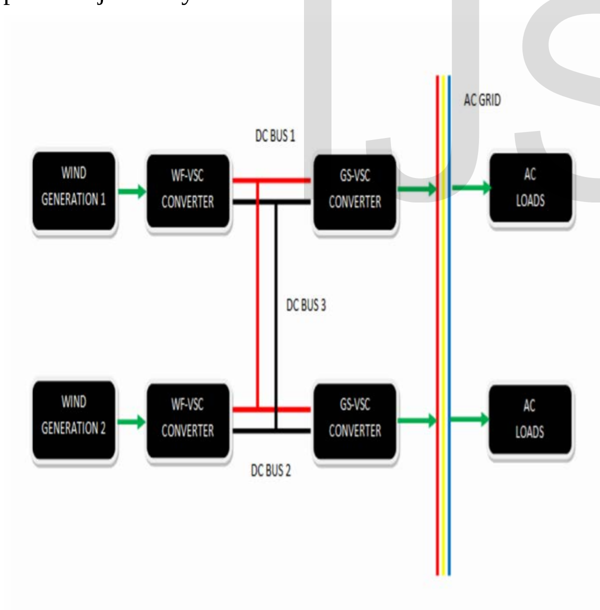

Fig 1 PROPOSED SYSTEM

3. Wind generator

Today the wind power industry is one of the thriving industries in the electrical energy production sector. In fig (2) 2007 the global turnover of the wind power industry was estimated to be 160MNOK.The leaders of the market are Vestas (Denmark), Gamesa (Spain), GE Wind (USA), Enercon (Germany), Suzlon (India) and Siemens (Germany).

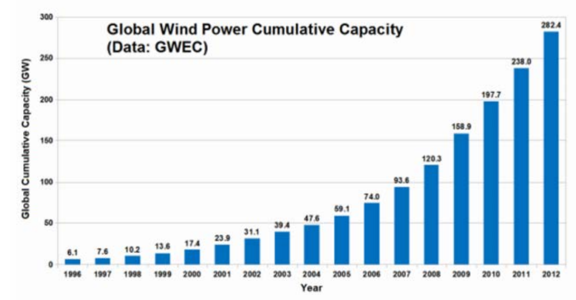

Fig 2 wind generation

Wind turbine

Wind turbine consists in a nacelle fixed on a tower where a vertical rotor blade rotates and transforms wind energy in electrical energy. The nacelle houses electrical and mechanical parts of the wind turbine. The number of blades can vary from one to twenty or more but typically there are three blades on a wind turbine. With this number of blades the performances of the wind turbine are the best for the production of electricity. The diameter of the rotor reaches 124m and the tower sizes are from 30m to up to 100m. Today, wind turbines power is rated between 2 and 5MW but as it can be seen on Figure rated power evolutes quickly and turbines with a bigger rated power are under development.

Wind is created by the difference of temperatures between air masses in the atmosphere. The mechanical power from the wind (*PW)* is given by:

$$P=\frac{1}{2}A V^3$$

With *ρ* the air density, *A* the area swept by the rotor blades and *V* the velocity of the air. However a wind turbine is not able to extract all the power from the wind. Indeed, a part of the wind will be completely stopped by the rotor area. According to Betz, the maximal wind power that can be converted in mechanical power by a wind turbine is

$$P=\frac{1}{2}A V^3 C_{pmax}$$

Where *Cp*is the power coefficient of the rotor or the rotor efficiency. Thus a theoretical maximum of 59% of the wind power can be used if the system has no losses. Today, for a modern three-blade wind turbine, *Cp*ranges between 0.4 and 0.5.

Performance curve and regulation

Figure (3), (4) shows the typical wind turbine power curve. The wind turbine starts producing at the cut-in speed i.e. around 4-5m/s. below this speed, it is not efficient to start the production.

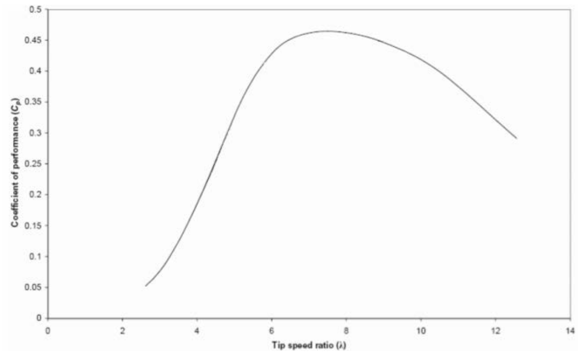

Fig 3.Performance curve and regulation

Between the cut-in speed and wind speeds around 13m/s, the wind turbine is producing at its maximum efficiency. When the wind turbine reaches its rated power, the production becomes constant independently of the wind speed until a certain limit. This limit is the cut out speed. When the wind speed is too important, the wind turbine risks to be damaged. Thus, the production is stopped in order to protect the blades and the wind turbine in general. The cut out speed corresponds to winds with speed around 25m/s. Three options are used in the wind turbine design in order to control the power output.

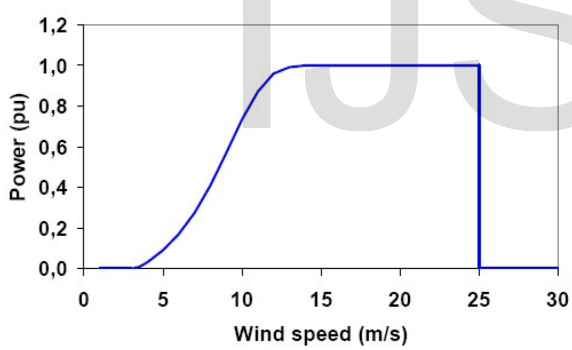

Fig 4. Performance curve and regulation

The first option is called stall regulation. The principle is, with wind speeds superior to a certain limit, to achieve a constant rotor speed independently of the wind speed.

Blades are design to created turbulences when the wind reaches the speed limit. Thus the aerodynamic forces on the blades are reduced and the output power too.

Furthermore, stall effect permits to protect blades from mechanical overstress but also to protect generators from overloading and overheating. The advantage of this technique is that blades are fixed so it avoids moving part in the rotor and complex control systems. However, the aero dynamical design of the blades is very complex and some vibrations due to the stall effect can cause problems in the whole wind turbine. The second option is called pitch regulation. In this concept, the blades can turn on their longitudinal axis. As for a plane wing, the rotation modifies the aero dynamical profile of the blades and then the forces applied on them can be controlled. A control system adjusts the angle of each blade independently from the other and then the output power can be maintained constant. Pitch-control gives to the wind turbine a better yield for low wind speed than stallcontrol, as blades can be kept at the optimum angle every time.

The last option is a combination of the two other control options and it is call active stall regulation. For low wind speeds, the blades are pitched like in a pitch regulation hence a better efficiency is achieved. When the turbine reaches its rated power, the angle of attack of the blade is increased in order to create a stall effect on the blades but in the opposite direction from the pitch regulation. An advantage of this regulation is that the output power can be controlled more accurately compare to a stall regulation.

Furthermore, the control system is simpler than pitch regulation.

4. Voltage source converter (VSC)

A schematic view fig (5) of voltage source converter is shown in below. The series inductance on the ac side, also called ac reactor, smoothens the sinusoidal current on the ac network and is also useful for providing the reference point for ac voltage, current and active and reactive power measurements. The shunt connected capacitors on the DC network side are used for DC voltage source and harmonic attenuation.

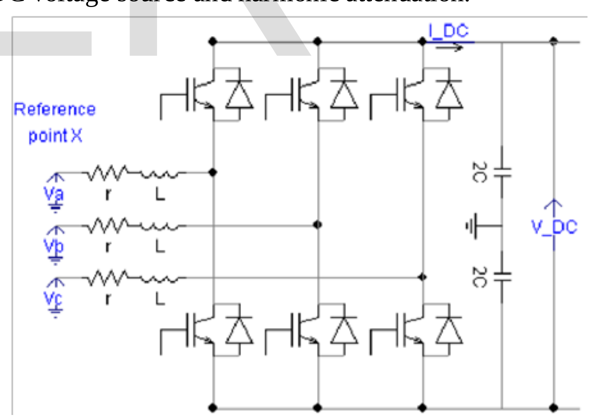

Fig 5Voltage source converter (VSC)

Usually, a VSC station works in either of the four control modes listed below.

a. Constant active power control
b. Constant DC voltage control
c. Constant DC current control
d. Constant AC voltage control In this paper active power control, DC voltage control and AC voltage control will be used at different terminals to establish an MTDC network.

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5. HVDC Transmission:

HVDC Schemes using Voltage-Sourced Converter (VSC) are becoming increasingly prevalent, especially at power ratings up to 1000MW. This paper fig (6) aims to consider the physical site impact of the choice between LCC-HVDC and VSC-HVDC, with all other factors assumed to be equal.

A schematic diagram of some common system topologies is shown in below.

Symmetric Monopole: A single converter with mid-point ground between positive and negative voltage polarities.

Asymmetric Monopole: A single converter with grounded neutral. This could be with either ground or metallic return.

Bipole: A converter comprised of two monopoles. This could be with either ground or metallic neutral.

Series Bridge Scheme: A converter comprised of monopoles in series. This could be with either ground or metallic return.

Multi-Terminal: Multiple converters (more than two) connected to a DC network.

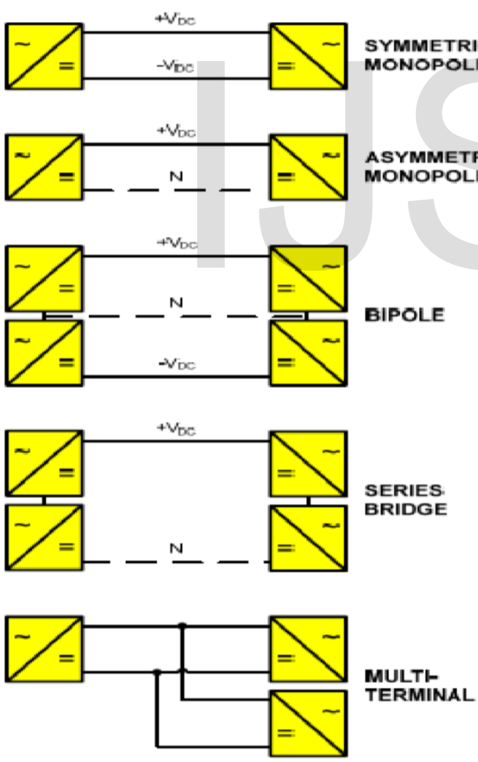

Fig 6 HVDC Transmission

6. Simulation results

The proposed control scheme designed with the proposed methodology has been simulated using MATLAB/Simulink software. Fig(7),(8),(9).

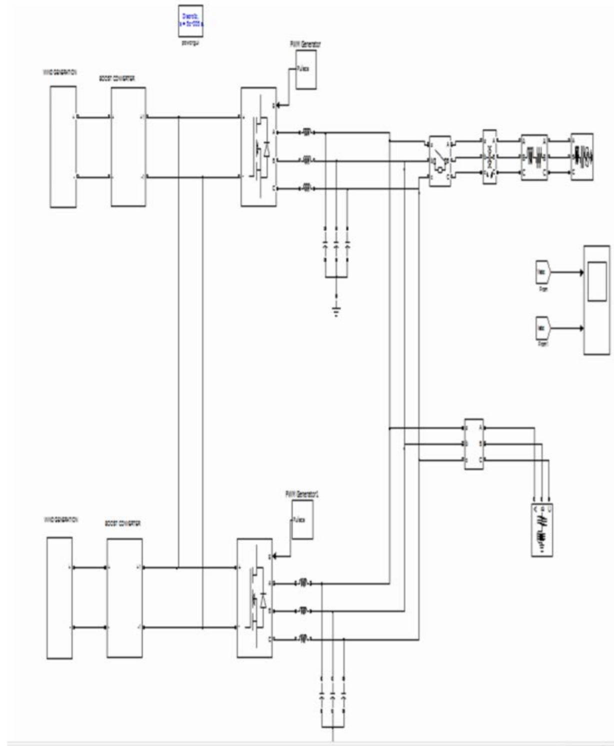

Fig 7 Simulation diagram

Wind model

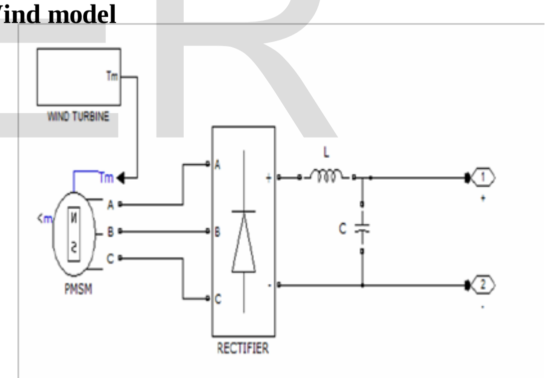

Fig 8. Wind model

7. Output results

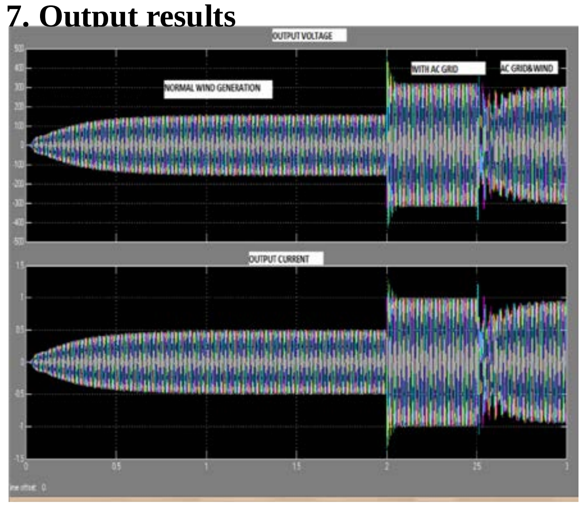

Fig 9 output

7. Conclusion

This paper has addressed the operation and control of multiterminal VSC-HVDC transmission systems for offshore wind farms. A robust converter concept with low losses, scalable upwards to any practically useful transmission voltage level, has been presented. Simulation results have confirmed that the proposed control results in a stable steady state and dynamic state operation and is also capable of restoring operation during loss of DC voltage regulating terminal without the need of communication between terminals.

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