An Enhanced Offshore Wind Farms with Low Frequency AC Transmission Connection

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Abstract: The possible solutions for transmitting power from wind farms are HVAC, Line commutated HVDC and Voltage source based HVDC (VSC-HVDC). The limitations of both the HVAC and HVDC technologies when applied for far offshore wind farm connection Low Frequency AC (LFAC) transmission system is a new and alternating solution. In LFAC systems, an intermediate-frequency level is used, which is created using a cycloconverter that lowers the grid frequency to a smaller value, typically to one-third its value. For interconnecting the offshore wind farms with Low Frequency AC (LFAC) transmission system for improving the transmission capability and distance compared to the conventional AC solution at the nominal frequency, e.g.50Hz or 60Hz. The dc collecting system with series connected wind turbines are used at the offshore to reduce the cabling requirement. The wind power plant collection system is dc based, and connects to the LFAC transmission line with a 48-pulse converter. The output waveforms are observed in MATLAB.

Keywords: Power transmission, wind energy, thyristor converters, low frequency AC (LFAC)

I. INTRODUCTION

The increasing interest and gradual necessity of using Renewable resources, such as wind, solar and hydro energy, have brought about strong demands for economic and technical innovation and development. Especially offshore wind farms are expected to represent a significant component of the future electric generation selection due to larger space availability and better wind energy potential in offshore locations. In particular, both the interconnection and transmission of renewable resources into synchronous grid systems have become promising topics to power engineers. For robust and reliable transmission and interconnection of renewable energy into central grid system Switching systems have been used, Since switching systems can easily permit excellent controllability of electrical signals such as changing voltage and frequency levels, and power factors. At present, high-voltage ac (HVAC) and high-voltage dc (HVDC) are well-known technologies for transmission HVAC transmission is advantageous because it is somewhat simple to design the protection system and to change voltage levels using transformers. However, the substantial charging current due to the high capacitance of submarine ac power cables reduces the active power transmission capacity and limits the transmission distance. Therefore HVAC is adopted for relatively short underwater transmission distances. HVAC is applied for distances less than 60km for offshore wind power transmission. Two classes of HVDC systems exist, depending on the types of power-electronic devices used line commutated converter HVDC (LCC-HVDC) using thyristors and voltage-source converter HVDC (VSC-HVDC) using self commutated Devices, for example, insulated-gate bipolar Transistors (IGBTs)[The major advantage of HVDC technology is that it imposes effectively no limit on transmission distance due to the absence of reactive current in the transmission line. LCC-HVDC systems can transmit power up to 1GW with high reliability LCCs consume reactive power from the ac grid and introduce low-order harmonics, which results in the requirement for auxiliary equipment, such as, ac filters, static synchronous compensators and capacitor banks. In contrast, VSC-HVDC Systems are able to independently regulate active and reactive power exchanged with the onshore grid and the offshore ac collection grid the reduced efficiency and cost of the converters are the drawbacks of VSC-HVDC systems.

Power levels and reliability are lower than those of LCC-HVDC. HVDC is applied for distances greater than100 km for offshore wind power transmission. In addition HVAC and HVDC, highvoltage low frequency (LFAC) transmission has been recently proposed InLFAC systems, an intermediate frequency level 16.66 or20Hz is used, which is created by using a cycloconverter, that lowers the grid frequency to a smaller value, normally to one-third its value. In general, the main advantage of the LFAC technology is the increase of power capacity and Transmission distance for a given submarine cable compared to 50-Hz or 60- Hz HVAC This leads to substantial cost savings due to the reduction in cabling requirements (i.e. fewer lines in parallel for a required power level) and the use of normal ac breakers for protection. In this paper, a novel LFAC transmission topology is analyzed. The proposed system differs from previous work. Here the wind turbines are assumed to be Interconnected with a medium-voltage (MV) dc grid, in contrast with current practice, where the use of MVac collection grids is standard DC collection is becoming a feasible alternative with the development of cost-effective and reliable dc circuit breakers, and studies have shown that it might be advantageous with respect to ac collection in terms of efficiency and reduced production cost.

The required dc voltage level can be built by Using the series connection of wind turbines For example, multi MW permanent-magnet Synchronous generator (PMSG) with fully Rated power converters (Type-4 turbines) are Commonly used in offshore wind plants eliminating grid-side inverters, a medium-voltage collection system can be formed by interconnecting the rectified output of the generators. The main reason for using a dc collection system with LFAC transmission is that the wind turbines would not need to be redesigned to output low-frequency ac power, This would lead to larger, heavier, and costlier magnetic components such as step-up transformers and generators. The proposed LFAC system could be built with commercially available power system components, such as the receiving-end transformers and submarine cables designed for regular power frequency.

Low Frequency Alternating Current (LFAC) transmission systems represent more cost effective technology than the HVDC system for intermediate distances (50-150km). The basic concept of the LFAC transmission is to use a frequency (16.666/20Hz) lower than nominal frequency (50/60Hz) by introducing a phase-controlled thyristor cycloconverter. This usage makes economics of low frequency transmission systems more effective. For example, rating voltage of electrical switches in converters can be reduced, and high voltage transmission is available, since existing standard transformers can be also used in low frequency transmission [2].

II. SYSTEM OVERVIEW

Operation of LFAC system:
LFAC transmission system can be understood to proceed as follows. First, the cycloconverter at the receiving end is activated, and the submarine power cables are energized by a 20-Hz voltage. In the meantime, the dc collection bus at the sending end is charged using power from the wind turbines. After the 20-Hz voltage and the dc bus voltage are established, the 48-pulse inverter at the sending end can synchronize with the 20-Hz voltage, and starts the transmission of power. In reality, more sophisticated schemes for system startup would have to be devised, based nevertheless on this operating principle. The following assumptions are considered for the steady state analysis of LFAC transmission systems.

- Only fundamental components of voltages and currents are considered. The receiving end is modeled as a 20-Hz voltage source of nominal magnitude.
- The power losses of the reactor, thyristors, filters, and transformers are ignored.
- The resistances and leakage inductances of transformers are neglected.
- The ac filters are represented by an equivalent capacitance corresponding to the fundamental frequency.
- The design is based on rated operating conditions (i.e., maximum power output).

Design of wind turbine: Permanent-magnet synchronous generators (PMSGs) are considered in this paper for their attractive power density and efficiency, which makes them good for offshore application. PMSGs are particularly suited for dc connection due to their need for fully rated power converters for variable speed operation [6]. Offshore wind plants are expected to represent a significant component of future electric generation due to greater space availability and better wind potential [6]-[8]. Electric power can be produced from wind energy by using wind turbine generator. The output of PMSG is converted to dc power through a thyristor converter. The output power of the wind turbine Pt, which is equal to converted dc power if the losses in the generator and converter are neglected.

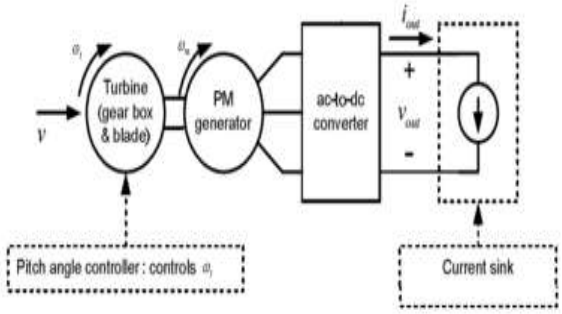

Fig.1 PMSG wind configuration

The control structure for the sending-end inverter is shown in Figure. The controller regulates the dc bus voltage by adjusting the voltage at the inverter terminals. The cosine wave crossing method is applied to determine the firing angle. Where linearity of transfer characteristics is achieved is known as cosine wave crossing method. 48 pulse inverter control configuration is shown in fig.2. The inputs of the PLL model are the three phase voltages measured on the 20-HZ side and the output is the tracked phase angle. The PLL model is implemented in synchronous dq reference frame, where a Park transformation is used. The sine wave supply voltage is phase advanced by pi/2 to generate a cosine wave; it is phase inverted every second half cycle to construct the cosine wave shown in Fig.3.[12]

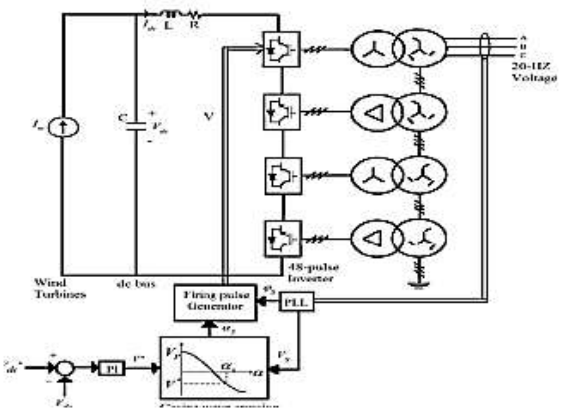

Fig.2 Inverter control

Cycloconverter control: The structure of receiving end controller is illustrated in Fig.3. The objective of controller is to provide a constant 20Hz voltage and to modulate frequency, magnitude and phase angle of output voltage. The frequency level is limited to 20Hz because higher frequency can cause distortion. The basic principle of controller is to continuously vary the firing angles of converters. Cosine wave crossing method with circulating current free mode operation is considered for switching sequence. According to the controller algorithm, partial circulating current mode can prevent discontinuous operation during bank exchange function from positive to negative bank with minimal circulating loss. Cosine wave crossing method is used to reduce total harmonic distortion (THD) of output voltages [12]

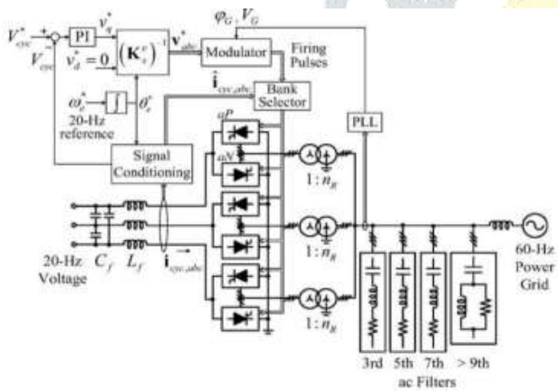

Fig.4 Cycloconverter control

III. SIMULATION RESULTS

The 20-Hz LFAC system is designed to transmit 180 MW over 160 km. At the sending end, the dc bus voltage level is chosen as 30 kV. The rating of wind power plant is 180MW which is transmitted over a distance of 160Km. The transmission voltage is chosen as 132kV. The power grid voltage is 132kV line to line. Simulation results are shown for the 20Hz LFAC transmission system. To demonstrate the validity of the proposed LFAC system, simulations have been carried out by using Matlab/Simulink software. The steady state line to line voltage and current waveforms at the sending end, the receiving end, the 20Hz side of the cycloconverter and 60Hz power grid side simulation results are as shown below.

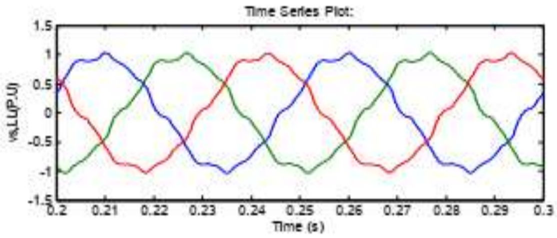

Fig.5 simulated voltage at sending end side

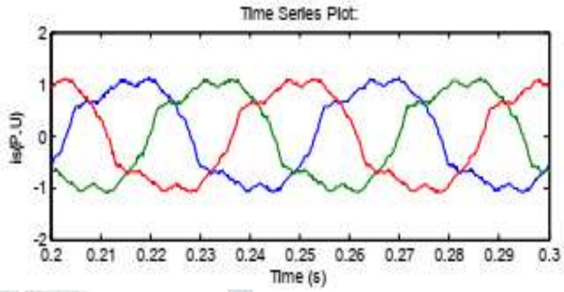

Fig.6 simulated current at sending end side

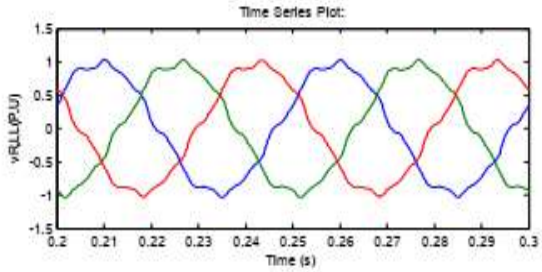

Fig.7 simulated voltage at receiving end side

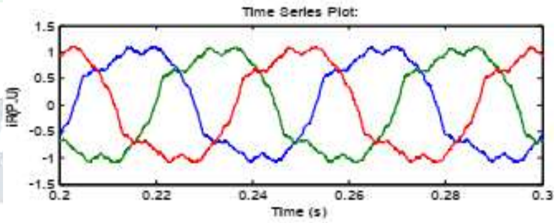

Fig.8 simulated current at receiving end side

IV. CONCLUSION

A low-frequency ac transmission system for offshore wind vigor has been proposed. A procedure to design the process's components and control procedures has been mentioned. The usage of a low frequency can strengthen the transmission capability of submarine energy cables because of decrease cable charging current. The proposed LFAC procedure seems to be a viable answer for the mixing of offshore wind power vegetation over long distances, and it might be a suitable replacement over HVDC programs in specific instances.

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