Low-Frequency AC Transmission for Offshore Wind Power

[1]Palagiri Mehantaj, [2]D.Chinna Dastagiri

M.Tech Student, Dept. of EEE, Sri Sai engineering college, Andhra Pradesh, India [1]
Assistant professor ,Dept. of EEE, sri sai engineering college, Andhra Pradesh, India [2]
Email: 226mehantaj@gmail.com,chinnadastagiri.d@gmail.com

Abstract: Now a days the amount of electricity produced from wind has grown rapidly. Offshore wind farm is currently seen as a promising solution to satisfy the growing demand for renewable energy source. The main reasons for the rapid development of offshore wind farms includes much better wind resources and smaller environmental impact. However, the current state of the offshore wind farms presents economic challenges significantly greater than onshore. The integration of offshore wind farms with the main power grid is a major issue. The possible solutions for transmitting power from wind farms are HVAC, Line commutated HVDC and voltage source based HVDC (VSCHVDC). In this paper Low Frequency AC (LFAC) transmission system is used for interconnecting the offshore wind farms for improving the transmission capability and also the dc collecting system with series connected wind turbines are used at the offshore to reduce the cabling requirement. Design of system components and their control strategies are discussed. Simulations are performed using MATLAB/SIMULINK to illustrate the system's performance.

Keywords— High voltage AC (HVAC), high voltage DC (HVDC), permanent magnet synchronous generator (PMSG), thyristor converters, underwater power cables, wind farms.

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 [1- 3]. 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: 1) line-commutated converter HVDC (LCC-HVDC) using thyristors and 2) voltage-source converter HVDC (VSC-HVDC) using selfcommutated devices, for example, insulated-gate bipolar transistors (IGBTs)[4]. 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 [1]. 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, VSCHVDC systems are able to independently regulate active and reactive power exchanged with the onshore grid and the offshore ac collection grid [7]. The reduced efficiency and cost of the converters are the drawbacks of VSCHVDC systems. Power levels and reliability are lower than those of LCC-HVDC. HVDC is applied for distances greater than 100 km for offshore wind power transmission. In addition HVAC and HVDC, high-voltage low frequency ac (LFAC) transmission has been recently proposed[8-9]. In LFAC systems, an intermediate frequency level 16.66 or 20Hz 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 MV ac collection grids is standard[9]. 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 costs[11]. The required dc voltage level can be built by using the series connection of wind turbines[12]. For example, multi MW permanent-magnet synchronous generator (PMSG) with fully rated power converters (Type-4 turbines) are commonly used in offshore wind plants[10]. By eliminating grid-side inverters, a medium-voltage dc 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, which 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 ac cables designed for regular power frequency. The phase-shift transformer used at the sending end could be a 60-Hz transformer de rated by a factor of three, with the same rated current but only one-third of the original rated voltage. Another advantage of the proposed LFAC scheme is its feasibility for multi terminal transmission, since the design of multi terminal HVDC is complicated, but the analysis of such an application is not undertaken herein. In summary, LFAC transmission could be an attractive technical solution for medium-distance transmission i.e., 50 to 160km

II. POWER SYSTEM DETAILS

The system under study consists of a wind farm of 50 wind turbines with each turbine's MVA-rating of 3.6MV A. The wind farm MVA-rating is thus 180MV A. Turbines are equipped with induction generators and a backto-back full range voltage source converters (VSC) for variable speed operation. Some advantages of variable speed wind turbines with back-to-back full-range voltage source converters (VSC) are: (a) Power optimization, e.g. gaining more power output at various wind speeds and (b) Reducing mechanical loads due to slower rotation and then less cost on maintenance. With this turbine structure of induction generator and back-to-back full-range converters, it is also possible to have independent variable speed for each wind turbines in the wind farm depending upon the available wind at that particular wind turbine. For a very large wind farm, the distribution of wind is not uniform for all the wind turbines. A layout of the wind turbine components is presented in figure 1 and discussed in detail in

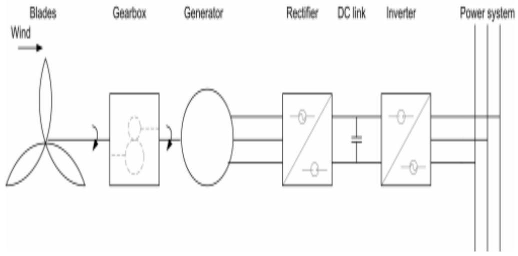

Fig. 1. Wind turbine components layout.

conventional wind farm layout is considered, where all turbines are connected to an AC collector network at 33kV. At the offshore platform, the collector network voltage is stepped up to 100kV with a park transformer. The collection network cables are modeled using a lumped equivalent Π model. The transmission of power from the wind farm to the on-land AC grid/pcc is done via a HVDC link, so that a rectifier VSC is present at offshore platform and an inverter VSC present on-land connects the wind farm to the on-land transmission system. The multilevel voltage source converters at each end are controlled in a way so all the power from the wind farm is transmitted to the grid under normal operating conditions. The details of the control strategy will follow in the coming sections. A 100km DC bipolar transmission is considered with two poles at ±100kV. The schematic diagram of the system is presented in figure 2.

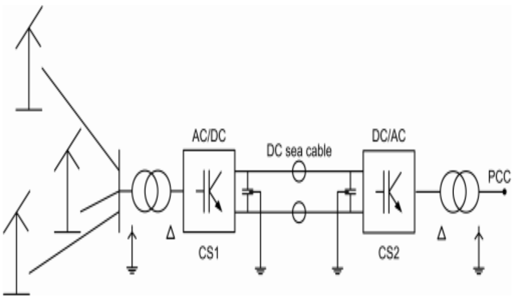

Fig. 2. Schematic connection of wind farm to the on-land grid.

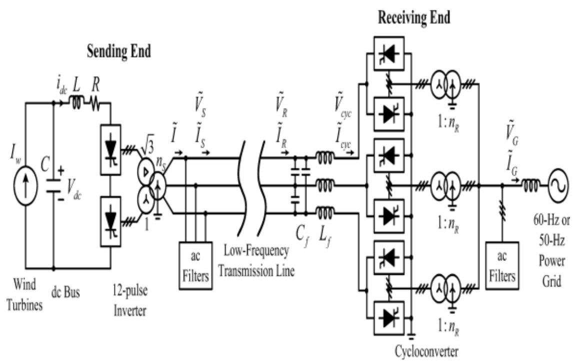

Fig 3:Configuration of the proposed LFAC transmission system.

SYSTEM CONFIGURATION

The proposed LFAC transmission system is shown in Fig. 3, assuming a 60-Hz main grid. At the sending end, a medium-voltage dc collection bus is formed by rectifying the ac output power of series-connected wind turbines . A dc current source represents the total power delivered from the wind turbines. A dc/ac 12-pulse thyristor-based inverter is used to convert dc power to low-frequency (20-Hz) ac power. It is connected to a three-winding transformer that raises the voltage to a higher level for transmission. AC filters are used to suppress the 11th, 13th, and higher-order current harmonics, and to supply reactive power to the converter. A smoothing reactor is connected at the dc terminals of the inverter. At the receiving end, a three-phase bridge (6-pulse) cycloconverter is used to generate 20-Hz voltage. A filter is connected at the low-frequency side. At the grid side, ac filters are used to suppress odd current harmonics,

and to supply reactive power to the cycloconverter. Simply put, the operation of the 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 12-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.

A. Sending-End Control

The control structure for the sending-end inverter is shown in Fig. 2. 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

$$\alpha_S = \arccos\left(\frac{V^*}{V_P}\right) \qquad (1)$$

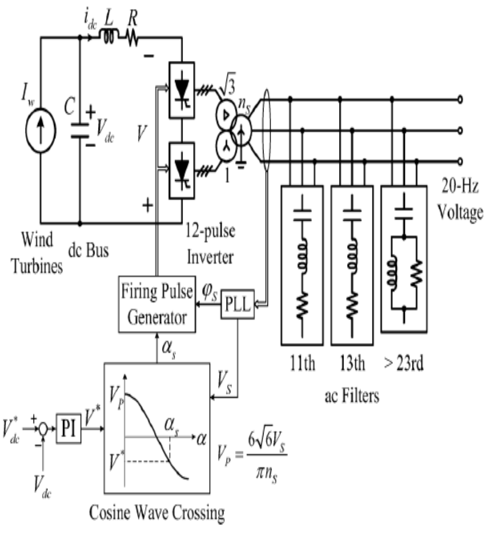

Fig. 4. Sending-end inverter control.

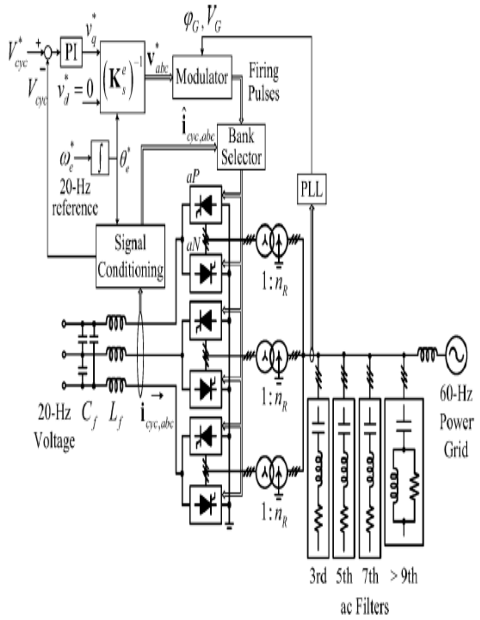

Fig. 5. Receiving-end cycloconverter control. (The reference frame transformation matrix is defined in , and transforms variables from the stationary to the synchronous reference frame.)

B. Receiving-End Control

The structure of the cycloconverter controller at the receiving end is illustrated in Fig. 3. The control objective is to provide a constant 20-Hz voltage1 of a given rms value (line-to-neutral).

The fundamental component of the cycloconverter voltage is obtained with the signal conditioning logic depicted in Fig. 4.The firing angles are determined with the cosine wave

crossing method, as shown in Fig. 5, which uses phase- as an example. The firing angles of the phase- positive and negative converters (denoted as "aP" and "aN" in Fig. 3) are and , respectively. For the positive converter, the average voltage at the 20-Hz terminals is given by

$$V_{aP} = \frac{3\sqrt{6}V_G}{\pi n_R}\cos(\alpha_{aP}) \qquad (3)$$

III. SIMULATION RESULTS

To demonstrate the validity of the proposed LFAC system, simulations have been carried out using Matlab/Simulink and the Piecewise Linear Electrical Circuit Simulation (PLECS) toolbox. The wind power plant is rated at 180 MW, and the transmission distanceis160km.

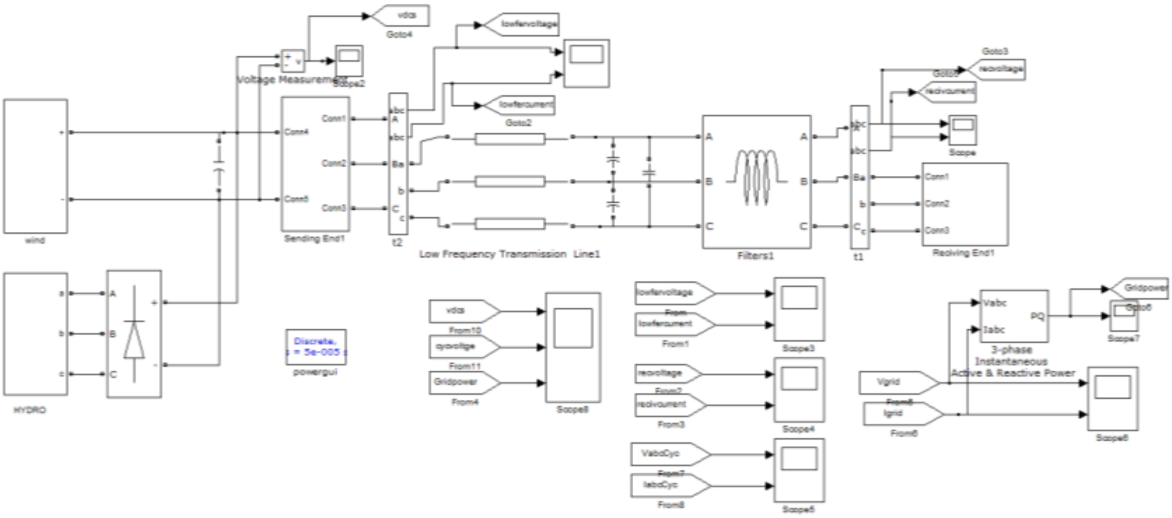

Fig 6:MATLAB/Simulink model of LFAC transmission system

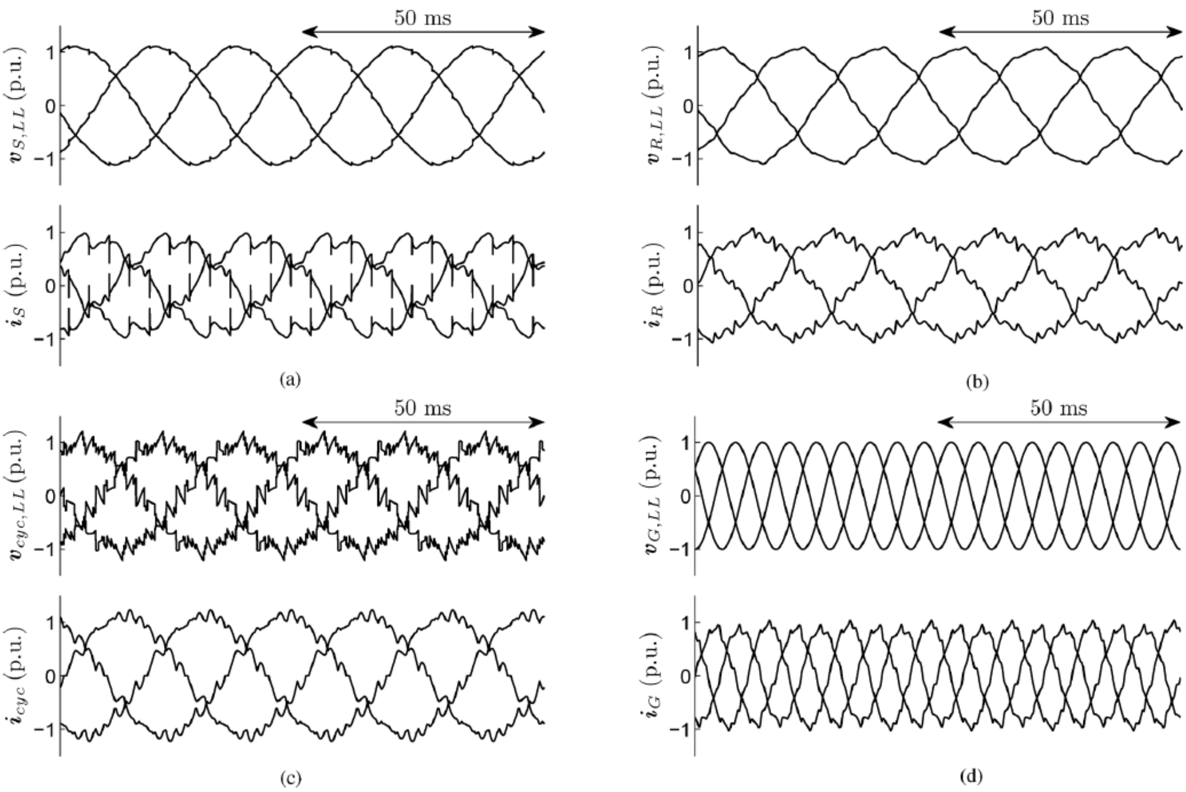

Fig. 13. Simulated voltage and current waveforms. (Please refer to Fig. 1 for voltage and current monitoring positions.) (a) Sending end. (b) Receiving end. (c) Cycloconverter 20-Hz side. (d) 60-Hz power grid side.

VI. CONCLUSION

A low-frequency ac transmission system for offshore wind power has been proposed. A method to design the system's components and control strategies has been discussed. The use of a low frequency can improve the transmission capability of submarine power cables due to lower cable charging current. The proposed LFAC system appears to be a feasible solution for the integration of offshore wind power plants over long distances, and it might be a suitable alternative over HVDC systems in certain cases. Furthermore, it might be easier to establish an interconnected low-frequency ac network to transmit bulk power from multiple plants. The major advantage of such a control scheme of the wind farm side VSC is that the turbines with different generator-converter topologies (e.g. induction generators with full range converters and double fed induction generators with partial converters) can be connected to the same VSC platform. The simulation results above show the system response and the power balance during and outside the grid fault conditions.

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