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Grid Synchronization with Wind Power System for Induction Motor Drive

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***Abstract* – This paper presents a low-frequency ac (LFAC) transmission system for offshore wind power. The LFAC system is interfaced with the main power grid with a cyclo converter. The wind power plant collection system is dc based, and connects to the LFAC transmission line with a 12-pulse thyristor converter. A method to design the system's components and controls is set forth. Simulation results are provided to illustrate the system's performance.**

***Keywords:* wind power, lfac system, power grid, cycloconverter, matlab/simulink.**

I. INTRODUCTION

Off shore wind power plants are expected to represent a significant component of the future electric generation portfolio due to greater space availability and better wind energy potential in offshore locations [1], [2]. The integration of offshore wind power plant switch the main power grid is a subject of ongoing research [3]–[5]. Presently, high-voltage ac (HVAC) and high-voltage dc (HVDC) are well-established technologies for transmission [6]. HVAC transmission is advantageous because it is relatively straightforward to design the protection system and to change voltage levels using transformers. However, the high capacitance of submarine ac power cables leads to considerable charging current, which, in turn, reduces the active power transmission capacity and limits the transmission distance. HVAC is adopted for relatively short (up to 50–75 km) underwater transmission distances [7]. 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 self-commutated devices, for example, insulated-gate bipolar transistors (IGBTs) [8].

LCC-HVDC systems are capable of handling power up to 1 GW with high reliability [7]. LCCs consume reactive power from the ac grid and introduce low-order harmonics, which inevitably results in the requirement for auxiliary equipment, such as capacitor banks, ac filters, and static synchronous compensators [4]. On the other hand, 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 can be identified as drawbacks of VSC-HVDC systems [6]. Power levels (typically on the order of 300–400MW) and reliability are lower than those of LCC-HVDC [7], [9]. HVDC is applied for distances greater than 100 km for offshore wind power transmission. Besides HVAC and HVDC, high-voltage low-frequency ac (LFAC) transmission has been recently proposed [10]–[13]. 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. 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., less lines in parallel for a desired 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 [11]–[13] in that 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 [14]. DC collection is becoming a feasible alternative with the development of cost-effective and reliable dc circuit breakers [15], and studies have shown that it might be advantageous with respect to ac collection in terms of efficiency and improved production costs [16]. The required dc voltage level can be built by using high-power dc–dc converters [17], [18] and/or by the series connection of wind turbines [19]–[22]. For example, multi-MW permanent-magnet synchronous generators with fully rated power converters (Type-4 turbines) are commonly used in offshore wind plants. By eliminating grid-side inverters, a medium-voltage dc collection system can be formed by interconnecting the rectified output of the generators [23].

At the sending end of the proposed LFAC system, a dc/ac 12-pulse thyristor-based inverter is used to generate low-frequency (20- or 16 2/3-Hz) ac power, as shown in Fig. 1. At the onshore substation (the receiving end), a thyristor-based cycloconverter is used as an interface between the low-frequency side and the 60- or 50-Hz onshore power grid. Thyristor-based converters can transmit more power with increased reliability and lower cost compared to VSC-HVDC systems. However, large filters are necessary at both ends to suppress low-order harmonics and to supply reactive power. Furthermore, the system can be vulnerable to main power grid disturbances.

II. Configuration and Control the Proposed System

The proposed LFAC transmission system is shown in Fig. 1, 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 [16]. 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 (23rd) 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.

$$\propto_s = arc\cos\left(\frac{V^*}{V_P}\right)$$

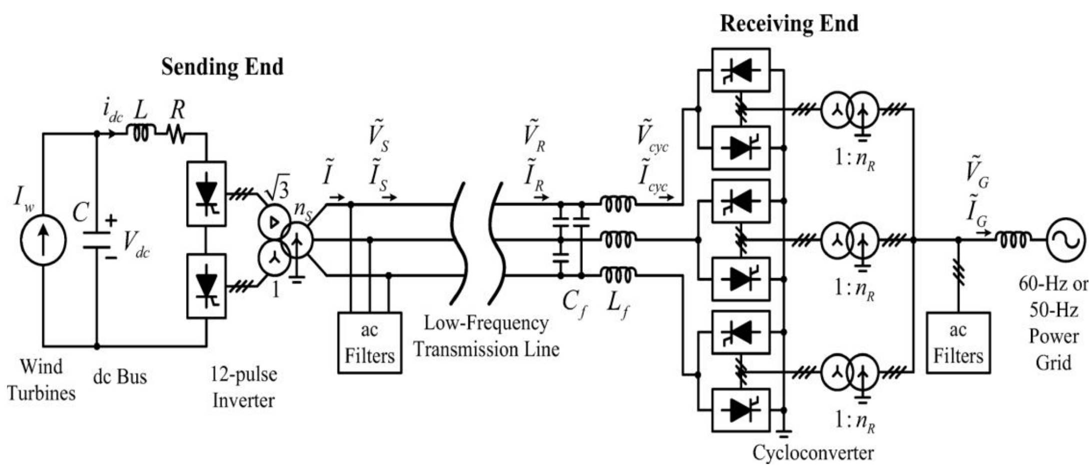

Figure 1: Configuration of the proposed LFAC transmission system

A phase-locked loop (PLL) provides the angular position of the ac-side voltage, which is necessary for generating the firing pulses of the thyristors. It also outputs the rms value of the fundamental component of the voltage, which is used in the firing-angle calculation.

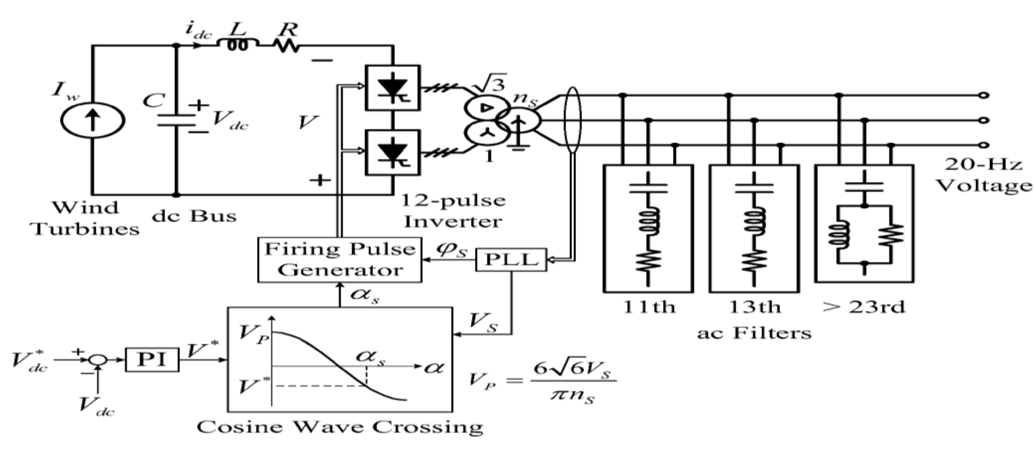

Figure 2: Sending-end inverter control.

The structure of the cycloconverter controller at the receiving end is illustrated. 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. The firing angles are determined with the cosine wave crossing method, as shown in Figure, which uses phase- as an example. The firing angles of the phase-positive and negative converters (denoted as “aP” and “aN”) are and , respectively. For the positive converter, the average voltage at the 20-Hz terminals is given by [28].

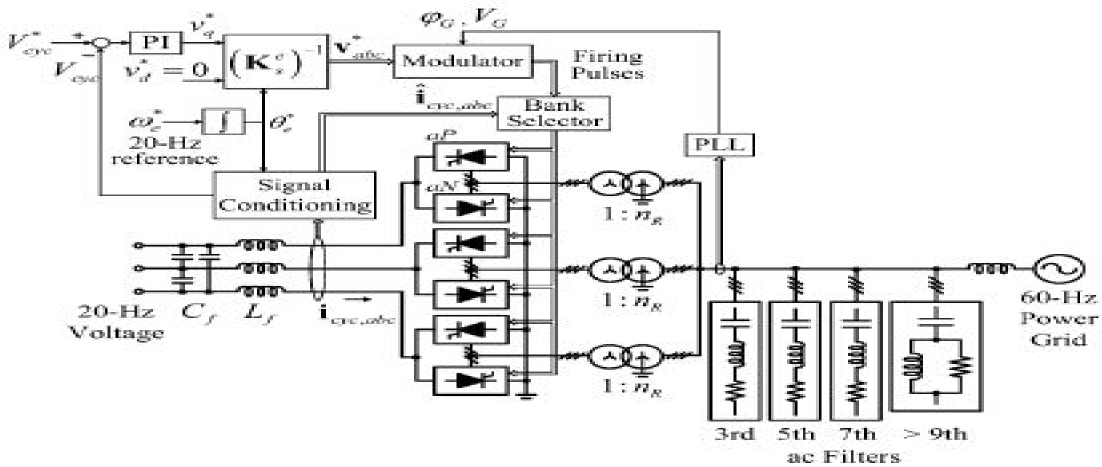

Figure 3: Receiving-end cycloconverter control

III. CYCLO CONVERTER

In industrial applications, two forms of electrical energy are used: direct current (dc) and alternating current (ac). Usually constant voltage constant frequency single-phase or three-phase ac is readily available. However, for different applications, different forms, magnitudes and/or frequencies are required. There are four different conversions between dc and ac power sources.

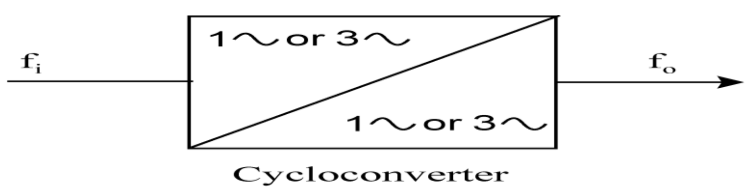

Figure 4: Block diagram of a cycloconverter

The average and root-mean-square output voltages of an ideal single phase full wave rectifier can be calculated as:

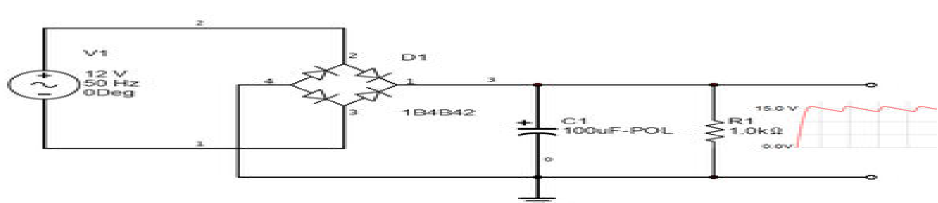

Figure 5: RC-Filter Rectifier

$$V_{dc} = V_{av} = \frac{2V_p}{\pi}$$

$$V_{rms} = \frac{V_p}{\sqrt{2}}$$

Where:

V_{dc},V_{av} - the average or DC output voltage,

V_p - the peak value of half wave,

V_{rms} - the root-mean-square value of output voltage.

π = ~ 3.14159

IV. SIMULINK MODEL

The proposed concept simulink models are shown below

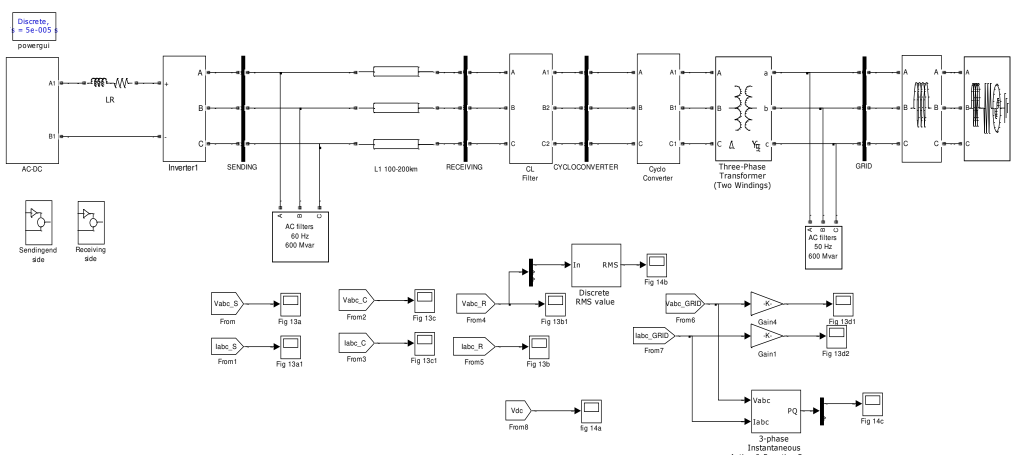

Figure 6: circuit diagram

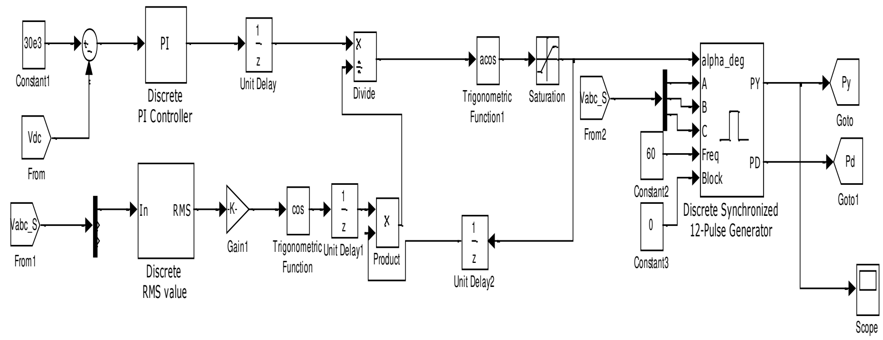

Figure 7: Sending end side controller:

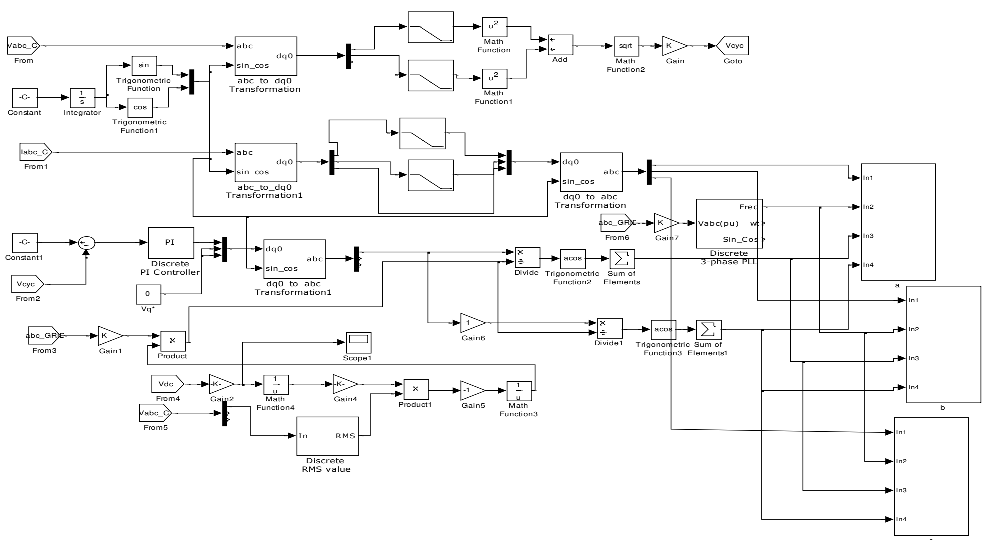

Figure 8: Receiving end side controller

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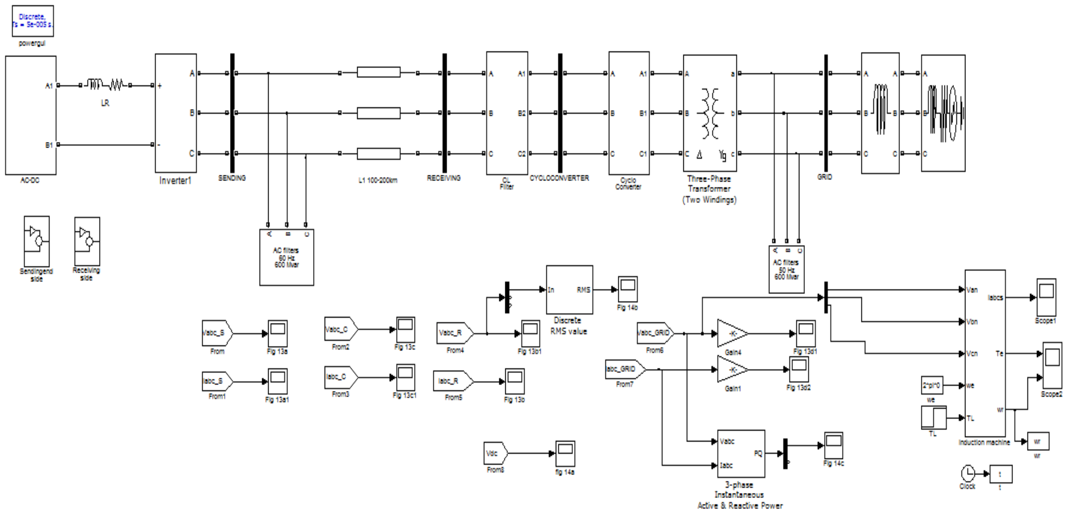

Figure 9: Proposed model with induction motor drive

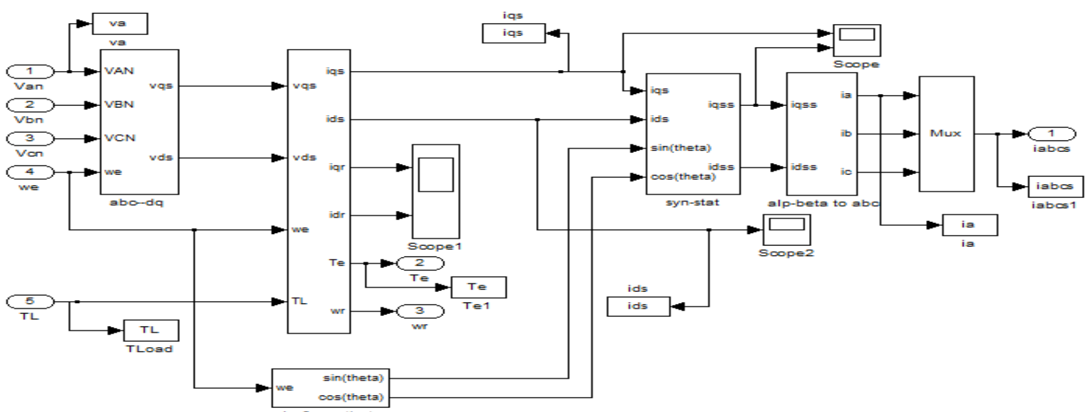

Figure 10: Induction motor modeling

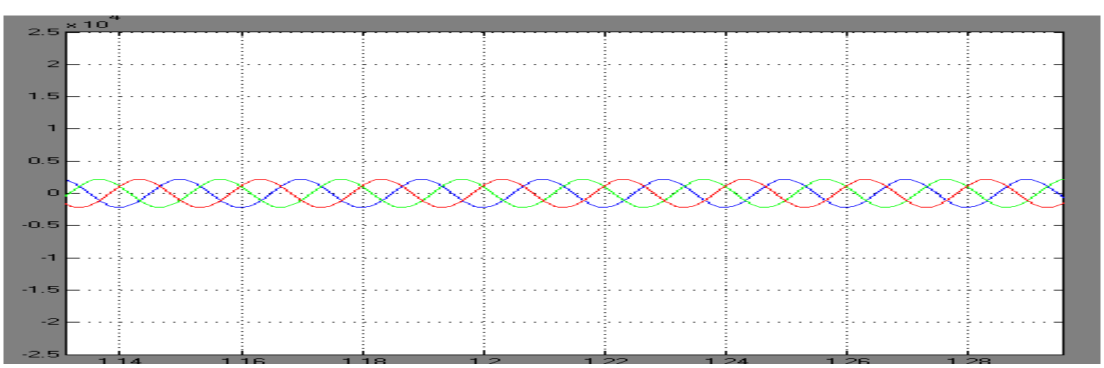

Figure 11: Motor output current

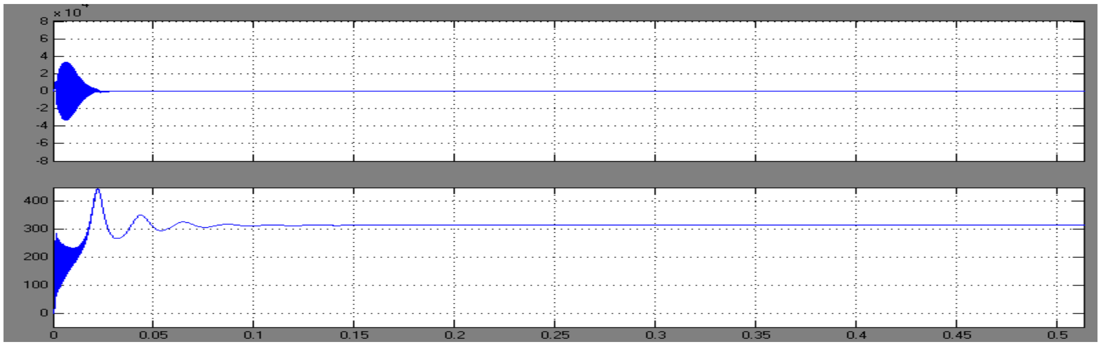

Figure 12: Speed and torque char.

V. RESULTS

The results of the proposed model are shown below:

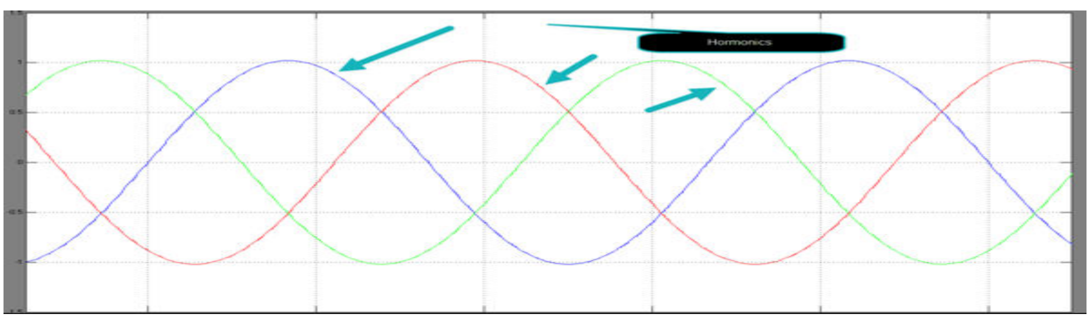

Figure 13: source voltage waveform

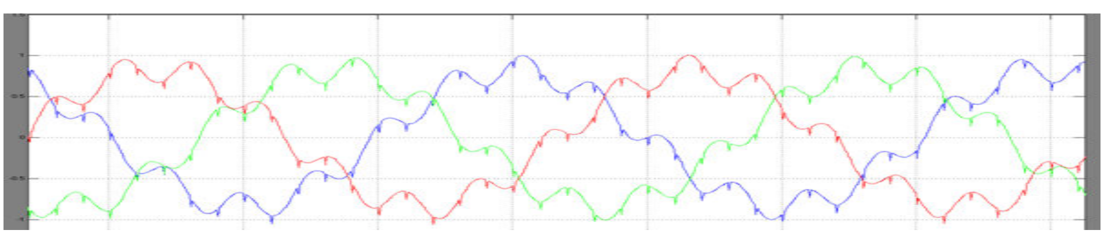

Figure 14: source current waveform

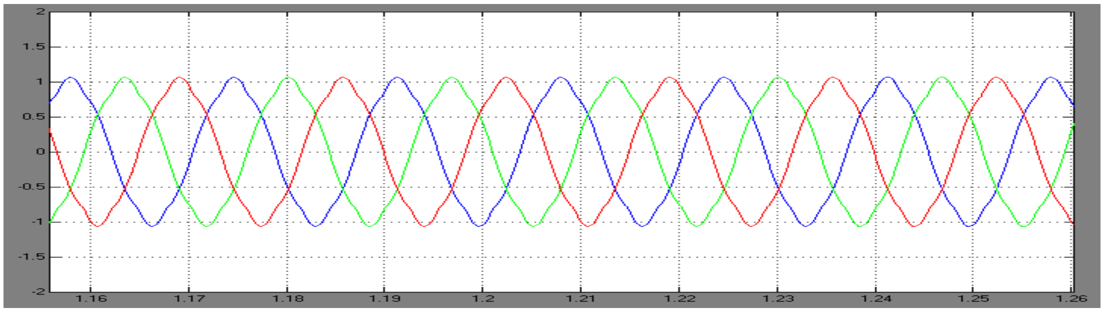

Figure 15: receiving end voltage

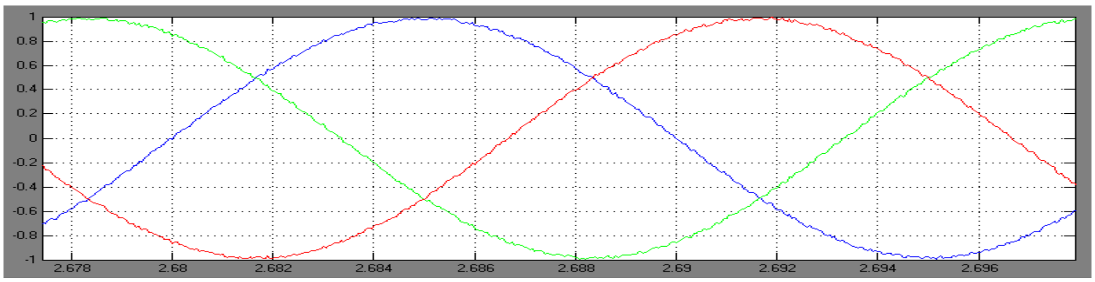

Figure 16: receiving end current

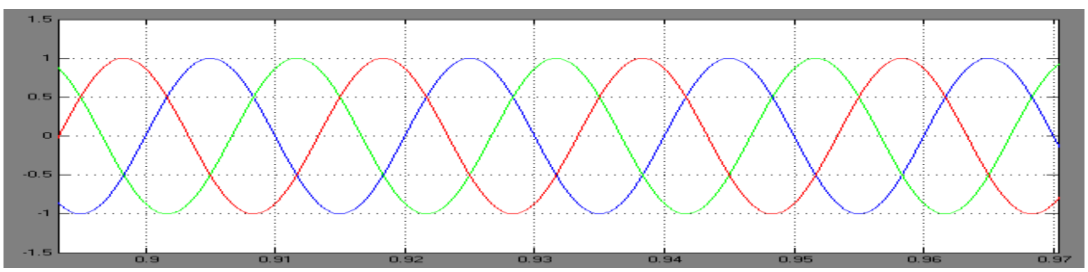

Figure 17: grid voltage waveform

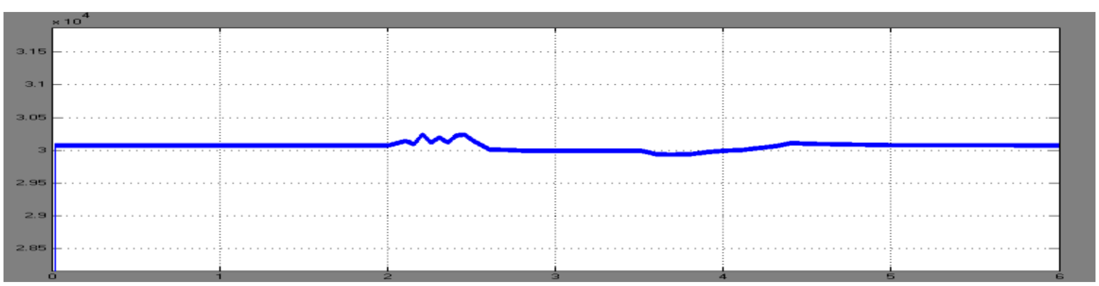

Figure 18 DC voltage waveform

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. An induction motor load is connected to check the performance like speed and torque.

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