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Design and implementation of Low-Frequency AC Transmission System for Offshore Wind Farms

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Abstract:

In recent years the amountofelectricityproduced from wind has grown rapidly. Offshorewindfarm is currently seen as a promising solution to satisfythe growing demand for renewable energy source. The mainreasonsfor the rapid development of offshore wind farmsincludesmuchbetter wind resources and smallerenvironmentalimpact. However, the current state of the offshorewindfarmspresents economic challenges significantlygreaterthanonshore. The integration of offshore wind farms withthemainpower grid is a major issue. The possiblesolutionsfor transmitting power from wind farms areHVAC,Line commutated HVDC and voltage source basedHVDC(VSC-HVDC). In this paper Low FrequencyAC(LFAC)transmission system is used for interconnectingtheoffshore wind farms for improving the transmission capabilityandalsothe dc collecting system with series connectedwindturbinesare used at the offshore to reduce thecablingrequirement.Design of system components and their controlstrategiesare discussed. Simulations are performed using MATLAB/ SIMULINK to illustrate the system'sperformance.

Keywords:

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

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 powerfactors.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 powertransmission.

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)[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.

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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 [7]. 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 than 100 km for offshore wind powertransmission.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-HzHVAC[8].

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 forprotection. 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 productioncosts[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 andgenerators. 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 to160km. The structure of this paper is as follows. The principle and configuration of the system is briefly explained in section II. The control strategies of converters arediscussed in sectionIII. The selection of the major system components and filter design are discussed in Section IV. Simulation results are presented in section V and finally section VI concludes this paper.

II.PRINCIPLE AND CONFIGURATION OF LFACSYSTEM

A.Principle of LFACsystem:

For AC transmission system, the active power(p) transmitting over the transmission lines, which should be cables for connecting offshore wind farms ,which can be expressed by

$$P = \frac{V_S V_R}{X_L} \qquad (1)$$

Where VS and are VR the sending end voltage and receiving end voltages, respectively. XL is the line reactance. δ is the transmitting angle. Eq. (1) is valid when the cable is short that neglects the effect of the line angle, increasing transmitting power is either by increasing the voltage level or lowering the impedance of the cable. Furthermore, with the fixed sending end voltages, the only way to improve the transmission capability by reducing the impedance of the cable. The reactance is proportional to power frequencyf,

$$X = 2\pi f L \qquad (2)$$

Where L is the total inductance over the line, decreasing the electricity frequency can proportionally increase the transmission capability. The LFAC system uses low- frequency to reduce the reactance of the transmission system thus, its transmission capacity can be increased several fold. For instance, when frequency is 50/3 Hz, the theoretically transmission capability can be raised three times.

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The LFAC system can also improve the voltage stability given the same amount of reactive power transmission as given in eq.(3).

$$\%\Delta V = \frac{QX}{V^2} * 100 \qquad (3)$$

Where ΔV is the voltage drop over the cable, V is the nominal voltage, Q is the reactive power flow of the cable. Because the impedance is reduced in the LFAC system due to the power lower grid frequency, the voltage drop over the cable is proportionally reducedaccordingly.

B.Configuration of LFACsystem:

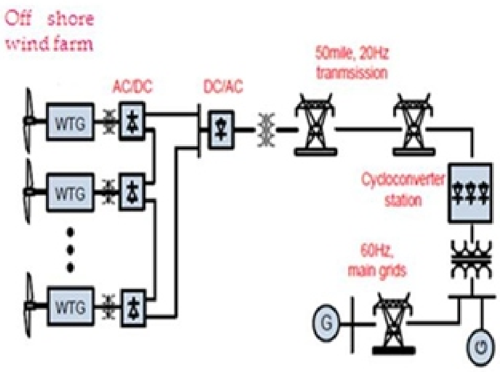

Fig.1.ConfigurationoftheproposedLFACtransmission-system.

The proposed LFAC transmission system is shown in Fig.1, assuming a 60-Hz main grid at the receiving end. 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/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 connected at the inverter side to suppress the 11th, 13th, and higher-order (23rd) current harmonics, and to supply reactive power to the converter. At the receiving end, a three-phase (6-pulse) bridge cycloconverter is used to generate 20-Hz voltage. A filter the amplitude of the harmonics generated by the cycloconverter. At the grid side, ac filters are used to suppress odd current harmonics, and to supply reactive power to thecycloconverter. 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 endis charged using power from the wind turbines. After the 20Hz 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 ofpower.

III.CONTROL OF LFACSYSTEM:

A.Invertercontrol:

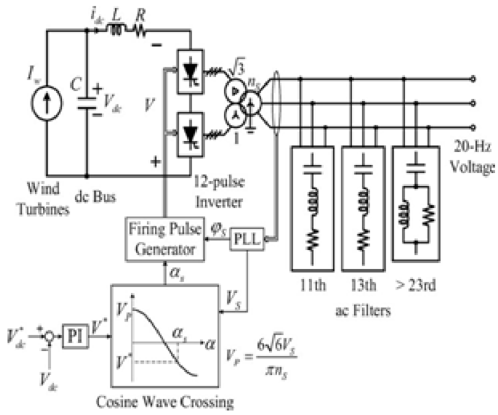

Fig .2. Sending-end invertercontrol.

The control structure for the sending-end inverter is shown in Fig. 2. The controller regulates the dc bus voltage Vdc by adjusting the voltage V at the inverter terminals. The cosine wave crossing method is applied to determine the firing angle. Firing pulses are generated by the crossing points of both wanted and threshold voltages of reference voltages. This method demonstrates superior properties, such as minimum total harmonic distortion of output voltages, and simplicity of implementation. The firing angle for the 12 pulse inverter is givenby

$$s = \left(\frac{V^*}{V_P}\right) \qquad (4)$$

Where Vp is the peak value of the cosine wave, V* is the reference voltage and αs is sending end inverter firing angle. Note that V<0 and 90<α<180 (using common notation), since the converter is in the inverter mode of operation. V And VS (line-to-neutral, rms) are related by

$$V = \frac{\sqrt{6}}{\pi n_S} V_S \cos(\alpha_S) \qquad (5)$$

A phase-locked loop (PLL) provides the angularposition of the ac-side voltage, which is necessary for generating the firing pulses of thethyristors.

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It also outputs the rms value of the fundamental component of the voltage, which is used in the firing-angle calculation.

B.Cycloconvertercontrol:

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 valueVcyc (line-to-neutral).The fundamental componentof the cycloconverter voltage is obtained with the signal conditioning logic depicted in Fig.4.

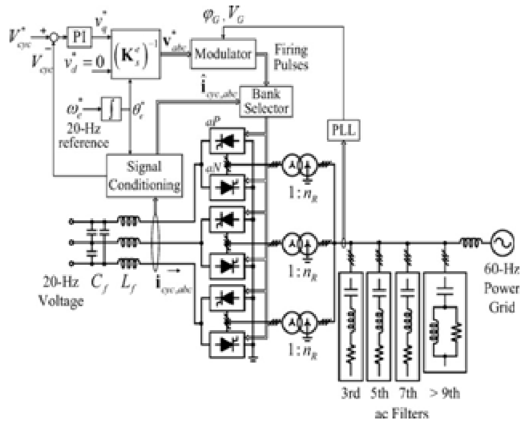

Fig. 3. Receiving-end cycloconvertercontrol.

The basic control principle of the three-phase, six-pulse cycloconverter is to continuously modulate the firing angles of the individual converters (positive and negative converters), according to its control algorithms. Here, the cosine wave-crossing method with the circulating current free mode or blocking mode of operation is selected for its switching sequences, since the proposed controlalgorithm has demonstrated the following properties. The partial circulating current mode can prevent discontinuous operations during bank-exchange operations from the positive to negative bank, or conversely, with minimal circulating loss. Distortion of output-currents can be eliminated in this mode. Firing pulses are generated by the crossing points of both wanted and threshold voltages of reference voltages. Cosine wave crossing method is used to reduce the total harmonic distortion (THD) of output- voltages.The control action for the three-phase, six-pulse cycloconverter can modulate the frequency, magnitude, and phase angle ofoutput-voltages. The operating-frequency level in this work is limited to 20-Hz, since frequencies higher than 20Hz can cause high THD (Total Harmonic Distortion).

The voltage level and phase angle are also controlled by the application of the cosine wave-crossing method, since electrical power (capacity) can be regulated by the voltage level and phase angle.The firing angles of the phase-a positive and negative αaN respectively. For the positive converter, theaverage voltage at the 20-Hz terminals is givenby[13] converters(denotedas—aP‖and—aN‖inFig .4)areαaPand

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

Where V_G is the rms value of the line-to-neutral voltage at the grid side, and is the turns ratio of the transformers.

The condition $\alpha_{aP}+\alpha_{aN}=\pi$ Ensures that average Voltages with the same polarity are generated from the positive and negative converter at the 20-Hzterminals.

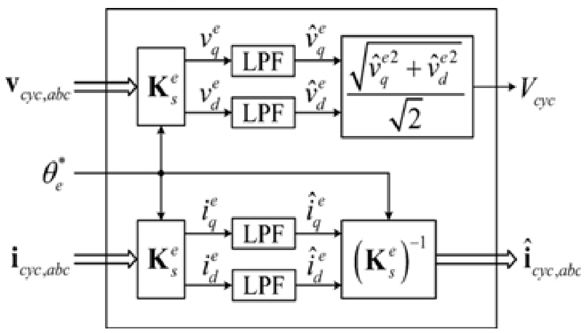

Fig. 4. Details of the signal conditioningblock.

The firing pulses SaP and SaN are not simultaneously applied to both converters, in order to obtain a non circulating current mode of operation. This functionality is embedded in the—BankSelector‖ block of Fig. 5, whichoperates based on the filtered current . Note (for later use) that the maximum line-to-neutral rms value of the 20-Hz cycloconverter voltageis

$$V_{cyc}^{Max}=\frac{3\sqrt{3}}{\pi n_R}$$

and that a voltage ratio is defined as

$$r=\frac{V_{cyc}}{V_{cyc}^{max}} \quad (8)$$

In practice, the theoretical maximum value r=1cannot be achieved, due to the leakage inductance of the transformers, which was ignored in theanalysis.

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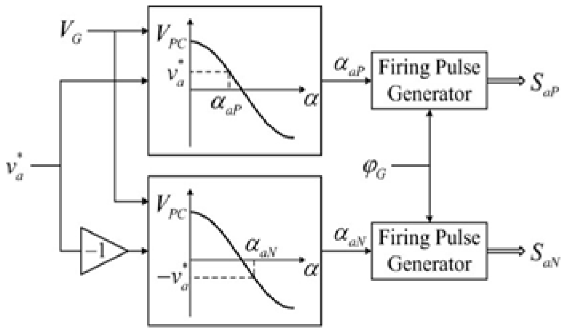

Fig. 5. Modulator forphase.

IV.DESIGN OF LFACSYSTEM:

A.Main powerComponents:

The main power components are selected based on a steady-state analysis of the LFAC transmission system shown in Fig. 1, under the followingassumptions:

•Only fundamental components of voltages and currents are considered. The receiving end is modeled as a 20-Hz voltage source of nominalmagnitude.

•The power losses of the reactor, thyristors, filters, and transformers areignored.

•The resistances and leakage inductances oftransformers areneglected

•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 poweroutput).

At the steady state, the average value of the dc Idc current is equal to Iw , so the power delivered from the wind turbinesis

$$P_w = V_{dc} I_W \quad (9)$$

For the 12-pulse converter, the rms value of the current at the transmission side is

$$I = \frac{2\sqrt{6}}{\pi n_S} I_W \quad (10)$$

Hence, eq. (9) can be written as

$$I = M P_W \quad (11)$$

with

$$M = \frac{2\sqrt{6}}{\pi n_S V_{dc}} \quad (12)$$

Let $V_S = V_S \angle 0$ And denote the phasors of the line-to neutral voltage and line current, respectively. Since $-I$ lags Vs by αs , it follows that $I = I\angle 180 - \alpha_S$. The active Power delivered by the 12-pulse inverter is given by

$$P_S = P_W = 3V_S I\cos(\alpha_S - 180^0) = -3V_S I\cos(\alpha_S) > 0 \quad (13)$$

Substitution of eq. (11) into eq. (13) yields

$$\cos(\alpha_S) = -\frac{1}{3MV_S} \quad (14)$$

and

$$\sin(\alpha_S) = \sqrt{1 - \frac{1}{9M^2V_S^2}} \quad (15)$$

The reactive power generated from the 12-pulseinverter is

$$Q_S = 3V_S I\sin(\alpha_S - 180^0) = -3V_S I\sin(\alpha_S) \quad (16)$$

From (13)–(16), it follows that

$$Q_S = P_S\tan(\alpha_S) = -P_S\sqrt{9M^2V_S^2 - 1} \quad (17)$$

The negative sign in (16) and (17) indicates that the 12-pulse inverter always absorbs reactive power. Eq. (17) shows that can be expressed as a function QS = f (PS,VS).

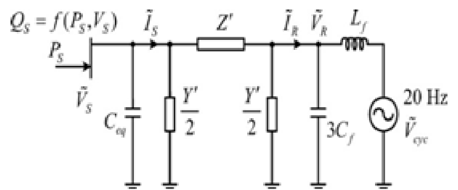

Fig.6. Equivalent circuit of the LFAC transmission system a fundamentalfrequency.

Based on the aforementioned analysis, thesteady-state single-phase equivalent circuit of the LFACtransmission system is shown in Fig.6. The equivalent capacitance of the sending-end ac filters at the fundamental frequency is Ceq. The transmission line is modeled by π equivalent(positive- sequence) circuit using lumpedparameters.

The well-known hyperbolic trigonometric expressions for Z′ and Y′ are used. Given a power rating of awind power plant Prated, the maximum reactive power that is absorbed by the 12-pulse inverter can be estimated according to eq. (14), whichyields

$$Q_{rated} = P_{rated} \sqrt{3M^2V_0^2 - 1} \quad (18)$$

where V0 is the nominal transmission voltage level (line-to-line rms). Here, it is assumed that the sending-end ac filters supply the rated reactive power to the inverter. Therefore

$$C \approx \frac{Q_{rated}}{{}_{e}V_0} \quad (19)$$

Where $\omega_e = 2\pi 20$ rad/s. In addition, the apparent power rating of the transformer at the sending end should satisfy

$$S_{tS} > \sqrt{P_{rated} + Q^2_{rated}} = \sqrt{3}P_{rated}\, MV_0 \quad (20)$$

At the 60-Hz grid side, the reactive power capacity of the ac filters and the apparent power rating of the transformers depend on the cyclo-converter's voltage ratio r, which is a design parameter, and the 20-Hz side power factor , which can be estimated as follows. For a given transmission cable, the voltage ratings (nominal and maximum voltage), the current rating, and the distributed cable parameters (resistance, inductance, and capacitance per unit length) are known. Here, it is assumed that a power cable is chosen to transmit the rated wind power plant power Prated without violating the cable's voltage and current ratings. (The relationship between active power through the cable and maximum transmission distance, given a certain cable.) For simplicity, it is further assumed that the rms value of line-to-line voltage at both sending and receiving ends is V0 and the current through Z′ and Lf is approximately equal to the current rating of the cable Irated .Since the ac filters are designed to supply all reactive power to the 12-pulse inverter at the sending end, the reactive power injected into the 20-Hz side of the cyclo-converter can be estimated byusing

$$Q_{cyc} \sim \mathrm{Im}\; YV_0 \quad \omega_e C_f V_0 \quad I_{rated} \; \mathrm{Im}\; Z \quad I_{rated}\,\omega_e L_f \quad (21)$$

Where the first two terms represent the reactive power generated from the cable and the capacitor of the LC filter, and the last two terms represent the reactive power consumed by the cable and the LC filter's inductor. The active power injected into the cyclo-converter from the 20- Hz side can be estimated byusing

$$P^{20}_{cyc} \approx P_{rated} - \mathrm{Re}\{Y'\}V_0^2 - 3I^2_{rated}\,\mathrm{Re}\{Z'\} \quad (22)$$

Where the last two terms represent the power loss of the cable. The 20-Hz side power factor can be estimated according to eq. (18) and eq.(19).

The 60-Hz side power factor at the transformers' grid side terminals can be obtained using the 20-Hz power factor and the voltage ratio based on the analysis and calculations of ([13, p. 358]). . Then, the apparent power rating of each of the three receiving-end transformers should-satisfy.

$$S \quad \frac{P^{20}_{cyc}}{\ldots} \quad (23)$$

Also, it is assumed that the grid-side ac filters are designed to supply the rated amount of reactive power to thecycloconverter..

B.FilterDesign:

At the sending end, the 12-pulse inverter produces harmonics of order m=12k±1, k =1, 2,.., and can be represented as a source of harmonic currents. These current harmonics are filtered by two single-tuned filters for the 11th and 13th harmonic, and one damped filter for higher-order harmonics (≥23rd). Generally, the filter design is dependent on the reactive power supplied at fundamental frequency (also known as the filter size) and the required quality factor (QF). The total reactive power requirement of these filters can be estimated based on eq. (18). Here, it is assumed that the total reactive power requirement is divided equally among the three filters. A high quality factor (QF = 100) is used for the single-tuned filters, and a low quality factor (QF = 1) is used for the high-pass damped filter. Finally, with the capacitance and quality factor known, the inductance and resistance of each filter can be determined. With such filter design, the 12-pulse-related current harmonics originating at the sending end are essentially absent from the transmission line. At the receiving end, there are two groups of filters, namely, the ac filters at the 60-Hz side and the LC filter at the 20-Hz side. At the 60-Hz side, if the cycloconvertergenerates exactly one-third of the grid frequency, that the linecurrent has only odd harmonic components (3rd, 5th, 7th,etc).Subharmonic and interharmonic components are not generated. Here, three single-tuned filters and one damped filter are used to prevent these harmonic currents from being injected into the 60-Hz power grid. These filters are designed with a procedure similar to that for the ac filters at the sendingend. At the 20-Hz side, the line-to-neutral voltage has harmonics of order 3, 5, 7, , without subharmonic and inter harmonic components. However, the harmonic components of order equal to integer multiples of three are absent in the line-to-line voltage.

Therefore, as seen from the 20-Hz side, the cycloconverter acts as a source of harmonic voltages of order n=6k±1, k=1,2,..., . The design of the LC filter has two objectives 1) To decrease the amplitudes of the voltage harmonics generated by the cycloconverter 2) To increase the equivalent harmonic impedance magnitudes seen from the receiving end, indicated by ZR (ωn) in Fig.7.The design procedure presented here takes into account the voltage harmonics of order 5, 7, 11, and 13. For cycloconverters, the amplitude of the voltage harmonics only depends on the voltage ratio r and the fundamental power factor at the 20-Hz side, under the assumption of sinusoidal output current, which is sufficient for design purposes. Generally, the voltage harmonics tend to become worse with decreasing r. Here, we set r = 0.9. Fig.7 illustrates the relationship between the per-unit amplitudesof the voltage harmonics under consideration and the power factor angle Φ. Apparently, for the 5th and 7th voltage harmonics, the amplitudes are symmetric with respect to Φ=0, and positive (i.e., reactive power consumption by the cycloconverter) can result in reduced amplitudes of the 11th and 13th voltage harmonics. At Φ ≈ 850, minimum amplitudes are obtained. However, this value is unacceptably low, so Φ =350 is selected (for operation at ratedpower).

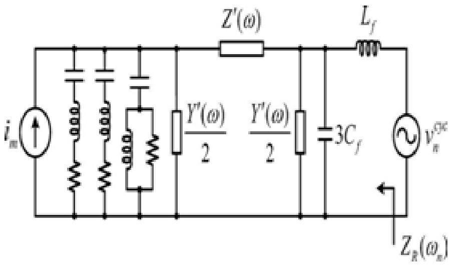

Fig.7. Equivalent circuit of the LFAC transmission system for harmonicanalysis.

After Φ has been determined, it follows from (21) and (22) that there is a linear relation between Lf and Cf , as in Cf = a Lf + b, since tan(Φ) = QcycPcyc since . However, any(Lf,Cf)pairdeterminedbasedonthisequationshould only be used as an initial guess. These initial parameters mightnotyieldtherequiredpowerfactorangleduetothe simplifying assumptions made in theanalysis.

The proper LC filter parameters can be obtained by solving the circuit shown in Fig.14. For example, given a value for Lf , the capacitance Cf that leads to the right power factor angle can be found by searching around its initial guess value.

Therefore, if varies within a certain range, a number of (Lf, Cf) pairs can be obtained. Among these candidates, a selection is made such that the magnitudes for n= 5, 7, 11, 13 are deemed to be adequately large.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 and a 214-MVA, 132/13.2-kV , 20-Hz phase-shift transformer is used. Due to the lower frequency, this transformer would be larger compared to a 60-Hz transformer. This is a drawback of the proposed LFAC system. The total size of the ac filters at the sending end is 115MVAr.

V.SIMULATION ANDRESULTS:

To demonstrate the validity of the proposed LFAC system, test system is modeled in MATLAB/ SIMULINK. Software. The Fig.1. is considered as the test system for the simulation. The Fig. 8, shows the overall SIMULINK model of LFAC transmission system for offshore wind farms. Control methods of Figs.2 and 3 were applied to control the sending end inverter and receiving end cycloconverter. The rating of wind power plant is 180 MW, and the transmission line distance is 160km.

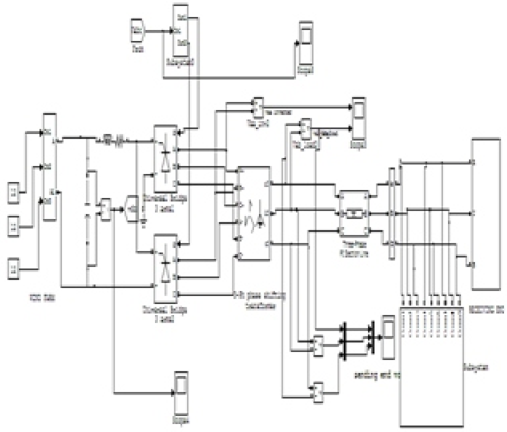

Fig.8. Overall SIMULINK model of LFAC transmission system for offshore windfarms.

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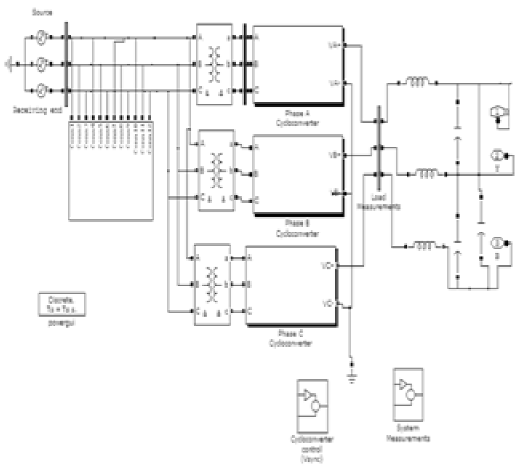


Fig.9. SIMULINK model of cyclo-convertersubsystem.

Fig.9, shows the SIMULINK model of cyclo converter subsystem and the fig.10 shows SIMULINK model of the series connected wind farm subsystem. Fig.11 fig.12 and fig.13 shows the steady-state line-to-line voltage and current waveforms at the sending-end, the cycloconverter side, and receiving end of the 60-Hz power grid side under rated powerconditions.

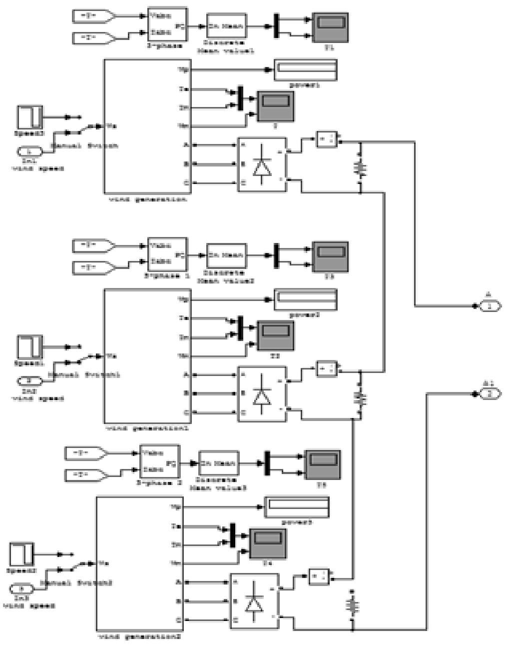
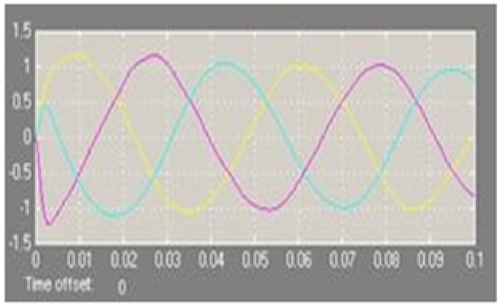
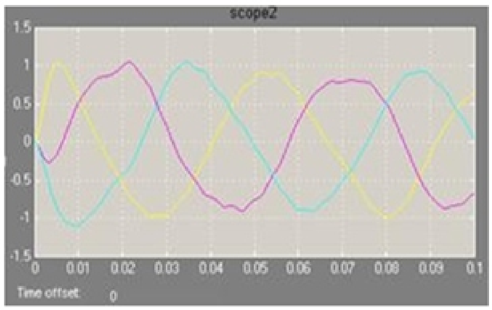


Fig.10. SIMULINK model for offshore windfarmsubsystem.

The following graphs presents the simulation results of wind-farm with an LFAC-transmission system connected to a power grid, as shown in Fig.11,.fig12 and fig.13. The wind farm consists of three wind turbine systems. The wind turbine systems are connected in series after the wind- generated power is rectified to DC, and the DC power is converted to 20-Hz AC power using an inverter. A transformer boosts the voltage to higher level. An LFAC line operated at 132-kV and transmits the power over a distance of 160-Km to the nearest power grid substation. At that point, a cycloconverter converts the LFAC power into 60-Hz AC power for theinterconnection. The fig.11, fig.12 and fig.13 are the simulated current and voltage waveforms at the sending end, cycloconverter side and the receiving-end siderespectively.

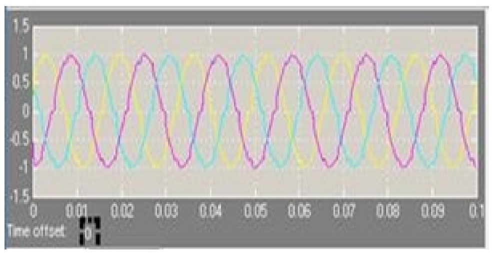


(a)



(b)

Fig.11. Simulated wave farms at the sending- end (a) Voltage waveform (b) Currentwaveform.



(a)

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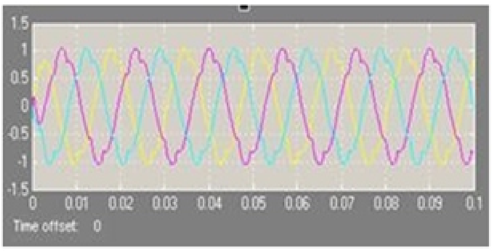
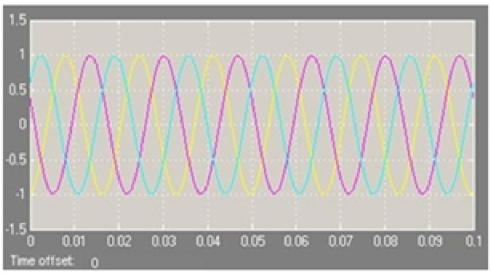
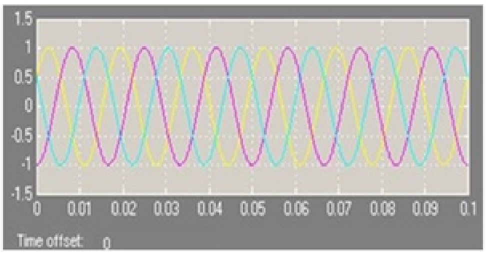


(b)

Fig.12.Simulatedwavefarmsatthecycloconverterside (a)voltage waveform(b) currentwaveform.



(a)



(b)

Fig.13.Simulatedwaveformsatreceivingend(a)Voltage-waveform (b) Currentwaveform.

The LFAC system appears to be a feasible solution for the integration of offshore wind farms for medium distances. APPENDIX

LFAC system parameters:

•Transmission line nominal voltage: 132kV
•Transmission line Maximum voltage: 145kV
•Transmission line Rated current: 825A
•Cable's cross section: 1000mm2
•Cable's resistance :17.6m/km,
•Cable's inductance 0.35mH/km
•Cable's capacitance : 0.25µF/km
•otal wind power :180MW
•Transmission line distance : 160km.
•DC bus capacitance: 1000µF.
•Sending-end transformer rating : 214MVA,132/13.2 kV,20Hz
•Receiving-end transformer rating :100 MVA, 132/88 kV.
•Sending-end AC filters :115 MVAr, 20Hz
•AC filters at the 60-Hz side : 200MVAr.
•LC filter rating : 63 mH and 8.7µF.

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