TRANSMISSION OF AC POWER FROM OFFSHORE TO ONSHORE BY USING LOW FREQUENCY AC TRANSMISSION

P. Jagannadh[1], J. Vijaychandra[2], Asish Kumar.P[3]

[1,2,3] *Assistant Professor, Department of EEE, SSCE, Andhra Pradesh, India*

Abstract- *Now a days, renewable energy sources became a most vital part to promote power generation. There are so many types of renewable energy sources but one of the most emerging power generation technology is offshore wind power. In this project, integration of offshore wind power plants with the main power grid by the help of low frequency AC transmission is described. 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.*

Key words: Power transmission, thyristor converter, underwater power cables, wind energy.

1. INTRODUCTION:

Offshore wind power or offshore wind energy is the use of wind farms constructed in bodies of water, usually in the ocean on the continental shelf, to harvest wind energy to generate electricity [1]. Higher wind speeds are available offshore compared to on land, so offshore wind power's contribution in terms of electricity supplied is higher, and NIMBY opposition to construction is usually much weaker. Unlike the typical usage of the term "offshore" in the marine industry, offshore wind power includes inshore water areas such as lakes, and sheltered coastal areas, utilizing traditional fixed-bottom wind turbine technologies, as well as deeper-water areas utilizing floating wind turbines.

Fixed foundation offshore wind farms employ turbines with fixed foundations underwater, installed in relatively shallow waters of up to 50–60 m. Almost all currently operating offshore wind farms are of fixed foundation type, with the exception of a few pilot projects. Types of underwater structures include monopole, tripod, and jacketed, with various foundations at the sea floor including monopole or multiple piles, gravity base, and caissons.[32] Offshore turbines require different types of bases for stability, according to the depth of water. The advantage of locating wind turbines offshore is that the wind is much stronger off the coasts, and unlike wind over the continent, offshore breezes can be strong in the afternoon, matching the time when people are using the most electricity.

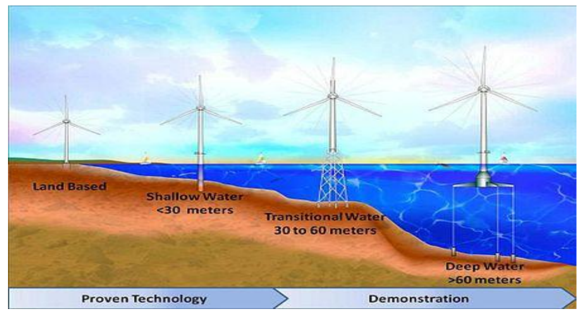

Fig 1.1 Offshore wind turbine evolution to deeper water

1.1 Classification of transmission:

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. 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).

LCC-HVDC systems are capable of handling power up to 1 GW with high reliability. 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. 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. Power levels (typically on the order of 300–400MW) and reliability are lower than those of LCC-HVDC. HVDC is applied for distances greater than 100 km for offshore wind power transmission[3].Besides HVAC and HVDC, high-voltage low-frequency ac LFAC transmission has been recently proposed. In LFAC systems, an intermediatefrequency level is used, which is created using a cyclo converter 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.

1.2 LFAC System:

In this Paper, a novel LFAC transmission topology is analyzed. The proposed system differs from previous work in that the wind turbines are assumed to be interconnected with a medium-voltage (MV) dc grid [4]-[5], in contrast with current practice, where the use of MV ac collection grids is standard. The required dc voltage level can be built by using high-power dc–dc converters and/or by the series connection of wind turbines. 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. 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 (e.g., step-up transformers and generators).

1.2.1 Advantages of LFAC:

1. It provides dynamic voltage and frequency support and efficient fault management.
2. It reduces cost and weight of wind power unit
3. It simplifies offshore maintenance task.
4. Prolong the undersea cable lifespan.

2. SYSTEM COMPONENTS:

2.1 Wind Turbine:

Slightly larger turbines can be used for making contributions to a domestic power supply while selling unused power back to the utility supplier via the electrical grid. Arrays of large turbines, known as wind farms, are becoming an increasingly important source of intermittent renewable energy and are used by many countries as part of a strategy to reduce their reliance on fossil fuels.

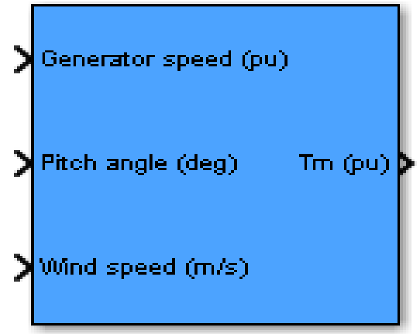

Fig 2.1 Simulink model of wind turbine

This block implements a variable pitch wind turbine model. The performance coefficient Cp of the turbine is the mechanical output power of the turbine divided by wind power and a function of wind speed, rotational speed, and pitch angle (beta). Select the wind-turbine power characteristics display to plot the turbine characteristics at the specified pitch angle. The first input is the generator speed in per unit of the generator base speed. For a synchronous or asynchronous generator, the base speed is the synchronous speed. For a permanent-magnet generator, the base speed is defined as the speed producing nominal voltage at no load. The second input is the blade pitch angle (beta) in degrees. The third input is the wind speed in m/s. The output is the torque applied to the generator shaft in per unit of the generator ratings.

2.2 Under water power cables:

A submarine power cable is a major transmission cable for carrying electric power below the surface of the water. These are called "submarine" because they usually carry electric power beneath salt water (arms of the ocean, seas, straits, etc.) but it is also possible to use submarine power cables beneath fresh water (large lake, sand rivers). Examples of the latter exist that connect the mainland with large islands in the St. Lawrence River.

There are actually many advantages to using these types of cables. The first advantage is that it is a source of renewable energy. With these cables using energy from wind turbines or ocean power, they are reducing human dependency on fossil fuels and helping us to move towards a much cleaner energy using society. The second advantage is that these cables don't interfere with human matters. Because the wind farms are located way offshore and the cables bring back the energy, they don't interfere with the people on land in ways that a giant power plant, factory, nuclear reactor, or solar/wind farm on land might. For this same reason they also allow for more of the land to be used for other purposes. The third advantage is that sea animals actually use the cables as a place to live near. Studies show that the cables have little to no interference with the marine animal life and that some types of algae and marine life actually grow near or on the cables providing a healthy reef and area to thrive. The fourth advantage is that the cables allow for power to be transferred to area, which could not get that power without them.

2.3 12 Pulse Inverter:

Three phase inverters are used for high power applications such as ac motor rives, induction heating, and un interruptive power supplies. A three phase inverter circuit changes DC input voltage to a three phase variable frequency, variable voltage output. The input DC voltage can be from a DC source or a rectified AC voltage. A three phase bridge inverter can be constructed by combining

three single –phase half bridges inverter. The figure 2.2 shows the basic circuit of three phase bridge inverter.

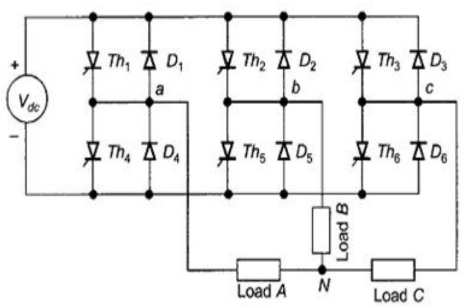

Fig 2.2 Three phase inverter

2.3.1 Working of 12 pulse inverter:

In this control scheme, each switch conducts for a period of 180 degrees or half-cycle electrical. Switches are triggered in sequence of their numbers with an interval of 60 degrees. At a time, three switches conduct. Thus, two switches of the same leg are prevented from conducting simultaneously. One complete cycle is divided into six modes, each of 60 degrees intervals. The operation of the circuit can be understood from the waveforms shown in figure, and the operation table. Switch pair in each leg, Th1, Th4, Th3, Th6, and Th5, Th2 are turned-on with a time interval of 180 degrees. It means that switch Th1 conducts for 180 degrees and switch Th4 for the next 180 degrees of a cycle Switches in the upper group, Th1, Th3, Th5 conduct at an interval of 120 degrees. It means that if Th1 is fired at 0 degrees, then Th3 must be triggered at 120 degrees and Th5 at 240 degrees. Same is true for lower group of switches [8].

Table 2.1 Operation Table of three phase inverter

S.NO	Interval	Device Conducting	Incoming Device	Outgoing Device
1	I	5,6,1	1	4
2	II	6,1,2	2	5
3	III	1,2,3	3	6
4	IV	2,3,4	4	1
5	V	3,4,5	5	2
6	VI	4,5,6	6	3

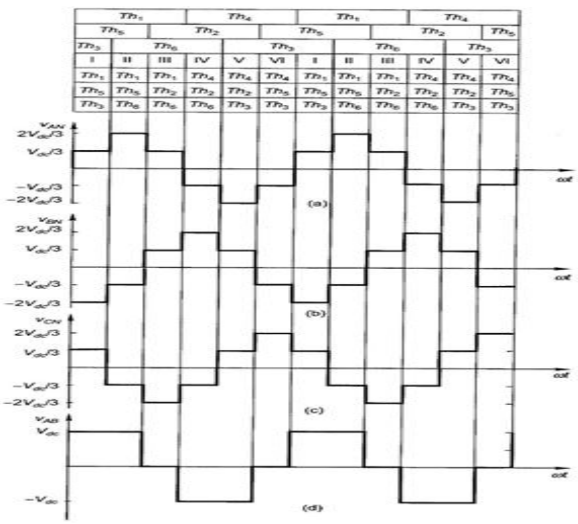

Fig 2.3 Sequence of conducting thyristors in 3-phase inverter and output voltage waveforms

2.4 Cyclo-converters:

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. These conversions are done by circuits called power converters. The converters are classified as: 1-rectifiers: from single-phase or three-phase ac to variable voltage dc 2-choppers: from dc to variable voltage dc 3-inverters: from dc to variable magnitude and variable frequency, single phase or three phase ac 4-cycloconverters: from single-phase or three-phase ac to variable magnitude and variable frequency, single-phase or three-phase ac.

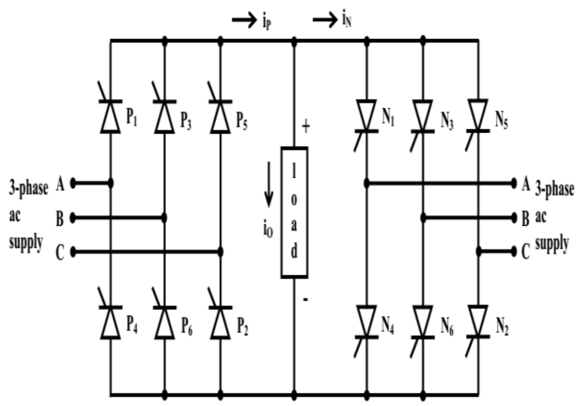

Fig 2.4 Three phase to single phase cycloconverter

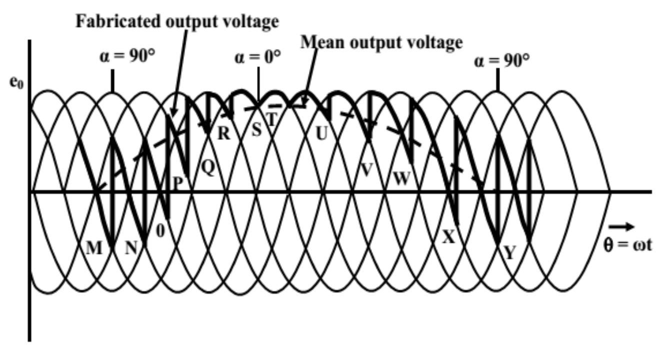

Fig.2.5 Output voltage waveforms for a three-phase to single phase cycloconverter.

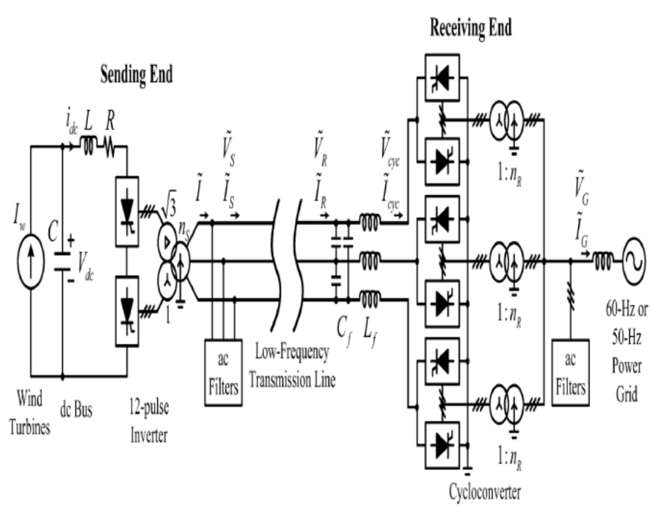

Fig.2.6 Configuration of the proposed LFAC transmission system.

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 derated 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. summary, LFAC transmission could be an attractive technical solution for medium-distance transmission (i.e., in between HVAC and HVDC.

3. CONTROL SYSTEM

3.1 Controller:

A controller is a device introduced in the system to modify the error signal and to produce a control signal. The manner in which the controller produces the control signal is called control action. It can be introduced in the feedback or forward path of the system, which controls the steady state and transient response as per the requirement

Depending on the control action provided, the controllers can be classified as follows

1. Proportional controller
2. Integral controller
3. Derivative controller
4. Proportional plus integral controller
5. Proportional plus derivative controller
6. Proportional plus integral pulse derivative controller

3.2 PI Controller:

As the name suggests it is a combination of proportional and an integral controller the output (also called the actuating signal) is equal to the summation of proportional and integral of the error signal.

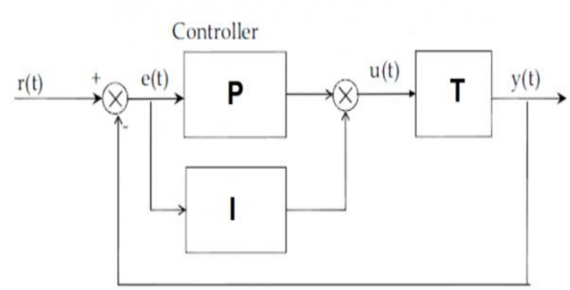

Fig 3.1 Block diagram of PI controller

3.2.1 Advantages of proportional and integral controller:

1. It's used to ensure long-term system precision.
2. It's almost always used together with P controller.
3. The controller sums up the errors until it reaches a reference value.
4. A pure integral control system is very slow and can sometimes determine system oscillations.

3.3 System Parameters:

Sending end:

Dc bus capacitor	C=1000μf
Smoothing indicator	L=0.1μH,R=1 mΩ
20 Hz phase shift transformer	
Rate power	214 MVA
Winding Resistance	0.001 P.U
Magnetizing resistance	1000 P.U
Leakage reactance	0.05 P.U
Magnetizing Reactance	200 P.U

AC Filters:

	R(Ω's)	L(mH)	C(μf)
11th	0.41	29.7	17.6
13th	0.35	21.3	17.6
>23rd	19.7	6.8	17.6

Transmission cable:

R(ohms)	17.6 Ω/km	L(Henry)	0.35 mH/km
C(farad)	0.25 μf/km	Rated current	82475 A

Receiving end:

LC FILTER		Lf=63Mh	Cf=8.7μF
Trans formers			
Rated power	100MUA	Voltage	132/88KV
Winding Resistance	0.001 P.u	Leakage Reactance	0.05 P.u.
Magnetizing Resistance	1000 P.u.	Magnetizing Reactance	200 P.u.
ac Filters(200MVAr,B2KV,60Hz)			
	R(Ω)	L(mH)	C(μF)
3rd	1.16	102.7	7.6
5th	0.70	37.0	7.6
7th	0.50	18.9	7.6
>9th	38.7	11.4	7.6

4. SIMULATION RESULTS:

The power which is generated by wind turbine is send to the dc bus for constant and smoothing purpose. Than, it is passed through 12-pulse inverter , it converts into low frequency and to cyloconverter is uesd to increase the lowfrequency to highfrequency according to the power grid requirement.AC filters are prvided to reduce the harmoncs. The system was simulated by using MATLAB Simulink Software.

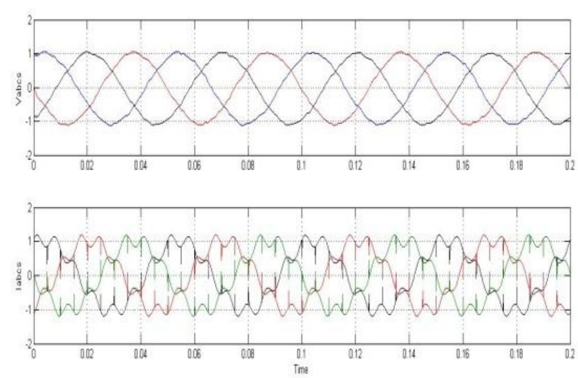

Fig 4.1 voltage and current waveforms at Sending end side

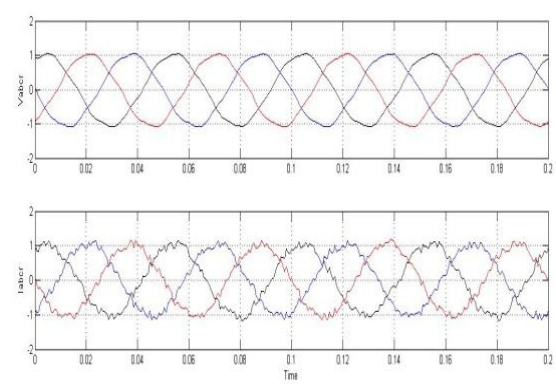

Fig 4.2 voltage and current waveforms at Recieving end side

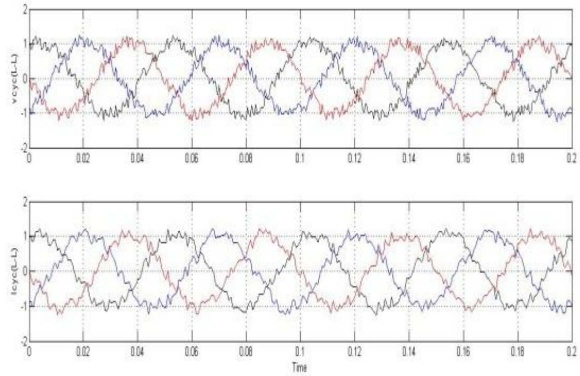

Fig 4.3 voltage and current waveforms of cycloconverter at 20Hz side

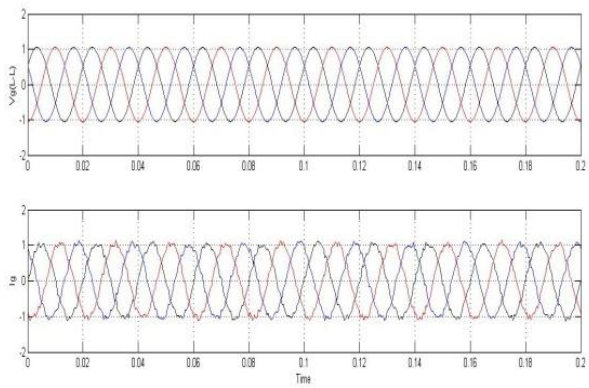

Fig 4.4 voltage and current waveforms of cycloconverter at 60Hz side

These are the final voltage and current output waveform from the ac filters which taken input from the cycloconverter. The output of the cycloconverter is having harmonics so the sine wave get distracted, by using ac filters a pure sine wave is achieved and suppress the odd current, harmonics and produce pure sine wave. And the output from the filters is connected to grid which has 60Hz frequency and these are distributed to consumers.

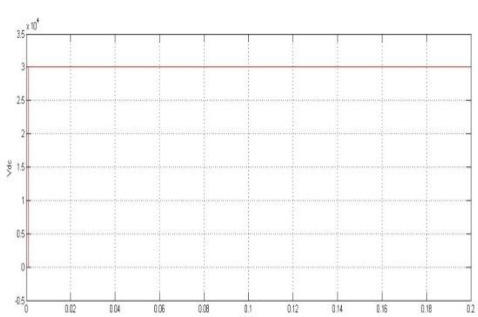

Fig 4.5 Transient waveforms during a wind power ramp event

Depicts the results of a transient simulation where the power from the wind turbines ramps from 0 to 180 MW, at a rate of 60 MW/s.

5. 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. In this project power generated at offshore is transmitted to the onshore by using LFAC Technique. Various waveforms at sending end side, receiving end side, cycloconverter and 60 Hz power grid side is shown.

Future scope:

In order to make better informed decisions, it is necessary to perform a complete technical and economic comparison among HVAC, HVDC, and LFAC evaluating factors, such as the transmission efficiency, investment and operating costs, and the performance under system transients.

REFERENCES:

[1] National Grid Electricity Transmission, London, U.K., 2011 offshore development information statement, Tech. Rep., Sep. 2011. [Online]. Available:http://www.nationalgrid.com/uk/Electricity/OffshoreTransmission/ODIS/Current Statement.

[2] S. V. Bozhko, R. Blasco-Giménez,R. Li, J. C. Clare, and G.M.Asher, "Control of offshore DFIG-based wind farm grid with line-commutated HVDC connection," *IEEE Trans. Energy Convers.*, vol. 22, no. 1, pp. 71–78, Mar. 2007.

[3] P. Bresesti, W. L. Kling, R. L. Hendriks, and R. Vailati, "HVDC connection of offshore wind farms to the transmission system," *IEEE Trans. Energy Convers.*, vol. 22, no. 1, pp. 37–43, Mar. 2007.

[4] T. Funaki and K. Matsuura, "Feasibility of the lower frequency AC transmission", in proc. IEEE Trans. Power Eng. Soc. Winter Meeting, vol. 4, (2000), pp. 2693-2698.

[5] Y. Cho, G. J. Cokkinides and A. P. Meliopoulous, "Time domain simulation of a three phase cycloconverter for LFAC

transmission system", presented at the IEEE Power Energy Soc. Transm. Distib. Conf. Expo, Orlando, FL, (2012) May.

[6] S. Lundberg, "Evaluation of wind farm layouts," presented at the Nordic Workshop Power Ind. Electron., Trondheim, Norway, Jun 2004.

[7] Ma Weimin, Wu Fangjie, Yang Yiming, Zhang Tao. Analysis of the current status and application prospect of flexible HVDC technology [J]. high voltage technology, 2014,08:2429-2439.

[8] Lu Jin Du, Wang Zhijie, Wang Haiqun, Huang Qiyuan, Wang Haoqing, Du Bin. Research on the technology and application of flexible HVDC [J]. Journal of electric power, 2015,04:293-300.

[9] H. Li, B.Ozpineci and B.K.Bose, "A Soft-Switched High Frequency Non-Resonant Link Integral Pulse Modulated DC-DC Converter for AC Motor Drive", Conference Proceedings of IEEE-IECON, Aachen/Germany, 1998, vol. 2, pp 726-732

[10] B. K. Bose, Power Electronics and Ac Drives, Prentice-Hall, New Jersey, 1986.S