A Review: Power Regulation of Multi-Phase Induction Generator based Wind Energy Conversion System

Ashima Patro[1] Prof. Romi Jain[2]
[1]PG Scholar [2]Assistant Professor
[1,2]Department of Electrical and Electronics Engineering
[1,2]UIT-RGPV, Bhopal-462036, India

Abstract— The increasing number of wind power systems connected to the grid also affects the power flow and therefore node voltage. It becomes a need to design wind farms with the ability to operate in the event of a fault. In this review, an efficient work to study the system designed for achieving the power regulation in a variable speed wind energy conversion system. The work is done with the objective to give a light for future researches in developing a system with better voltage and power regulation in a variable speed wind energy conversion system (WECS). It includes six- phase double fed induction generator providing increased efficiency and decreased losses. Use of modular multilevel converters and multi- phase generators will reduce the total harmonic distortion and will increase the overall efficiency of the WECS leading to more productivity at least possible operating and maintenance cost.

Keywords: Power Regulation, Wind Energy Conversion System (WECS), Doubly- Fed Induction Generator (DFIG), Multi- Modular Converter, Vector- Oriented Control Strategy

I. Introduction

Wind energy is the most economical, clean and pollution free energy solution in the time when the conventional sources are depleting with a considerable rate, contributing in a much-polluted environment [1]. Conversion of wind kinetic energy into electrical energy for the domestic and commercial use is what we meant by the term "Wind energy conversion system". Some of the main features of wind energy which has led it to a matured level of application is its fidelity, attainability and prolongation [2]. The competence of wind energy with other renewable sources are very remarkable for large-scale utilisation. The conversion is carried out with two steps involving, the extrication device that is, the wind turbine rotor rotates under the wind action, thus gleaning the mechanical power. The rotor drives a rotating electrical generator, which produce electrical power.

An appropriate controller is used to avoid the disturbances and protect the system or network from the faults. Also, proper wind turbine controls, maximise the generation output and also provide power factor or voltage control. The most important part of a wind energy conversion system is its turbine. The energy conversion chain is divided into four different subsystems: -

1) Aerodynamic system, comprising mainly of turbine rotor, which carries blades and turbine hub, for the support of blades.
2) Drive train, comprising of:
   a) low-speed shaft – coupled with the hub and speed multiplier
   b) high-speed shaft – which drives the electrical generator
3) Electromagnetic system, comprising mainly of the electric generator
4) Electric system, having the elements for grid connection and local grid.

The electrical power generation system combines both electromagnetic and electrical systems. Also, along with electric generator and power electronics devices, it consists of an electrical transformer to ensure the grid connection and harmony.

II. Wind Energy Generators

The three main types of wind turbine generators (WTGs) used in the different wind turbine systems are direct current (DC), alternating current (AC) synchronous and AC asynchronous generators [3]. Traditionally, each can be run at fixed or variable speed. Due to the flickering nature of wind power, it is advantageous to operate the generator at variable speed which reduces the physical stress on the turbine blades and drive train, and thus improves system aerodynamic efficiency and torque transient behaviours. There are three basic types of uses of generator in wind turbine based on megawatt ratings: -

1) Type 1: Fixed speed, induction generator connected directly to the network
2) Type 2: Variable speed, doubly-fed induction generator (DFIG) (or rotor resistance control)
3) Type 3: Variable speed, full power converter equipped generator

The DC generators can usually be used in low-voltage and low-power standalone systems in small scale wind power applications, while the alternating current generators today are most widely used for large scale WECS [4]. The greater the "load", or electrical demand placed on the generator, the more mechanical force is required to turn the rotor. This is why generators come in different sizes and produce differing amounts of electricity. There are following types of WTG used in recent times:

a) Squirrel Cage Induction Generator
b) Wound Rotor Induction Generator
c) Double-fed Induction Generator
d) Wound Rotor Synchronous Generator
e) Permanent Magnet Synchronous Generator

The best suited generator for the wind energy conversion system is merely an asynchronous and specifically, a double fed induction generator. The major advantages of this generator include compensation of reactive power and assurance of smooth grid integration, the lightest and the lowest cost solution, rugged and brushless [5] [6]. One of the disadvantages is in complying the grid fault-ride through [7] [8].

[26] The output power of the wind turbine generator can be calculated as:

$$P_t = \frac{1}{2}\rho \Pi R^2 C p(\lambda, \beta) V^3 \quad (1)$$

Where, where ρ is the air density in $kg \cdot m^3$, R is the radius of blade in m, V is the wind speed in $m \cdot s^{-1}$, and Cp(λ,β) is the power conversion coefficient as is a function of the tip-speed ratio (TSR) and the pitch angle (β) in which TSR is defined as

$$\lambda = \frac{R\omega_T}{V} \tag{2}$$

III. MULTI-MODULAR CONVERTER

After generators, one more important aspect to be considered for WECS is the converters used to convert voltage generated from the generator to make it compatible to be used in grid and utility appliances. Various converters are used according to the requirement in this system such as different types of rectifiers, inverters, choppers, cyclo-converters etc. From the view point of Wind Energy system, usually DC converters are employed [9]. Power semiconductor devices can be operated as switches by applying control signals to the gate of thyristors, base of power transistors, gate of power MOSFETs and to the gate of IGBTs. The required output voltage is obtained by varying the conduction time of these devices

Four basic topologies of switching regulators:

1) buck regulators
2) boost regulators/converter
3) buck –boost regulators/converter
4) Ćuk reguators/converter

But, the main objective nowadays, is to get efficient power in optimised cost. The economic, lossless power and the ability to overcome the fault situation are the factors which contribute to the selection of technologies used in an application. Keeping all these in mind, many methodologies are introduced which can be used according to the need of the system. One such method is “modular multilevel converter”, used in renewable energy sector for better extraction power from the resources.

Modular multilevel converter is an emerging technology for various applications including high voltage dc transmission and wind energy conversion systems [10]. This method is useful in generating multiple voltages from various dc voltage sources, by connecting single-phase converters in series and introduction of modified multilevel topologies [11]. This is able to generate high output voltages with low total harmonic distortion and they can be functioned with very low switching frequency [12]. Each submodule is consisted of two semiconductor switches, two reverse diodes and a capacitor component. The upper and lower arms of each phase of the converter include a current-limiting reactance and N submodules [13]. Current-limiting reactance plays an important role:

Firstly, DC voltage requires each phase cascade submodule voltage to support. But the capacitor voltage of each submodule has been in a change in the operation of the state. As a result, the change will lead to interphase circulation and phase circulation. while the current-limiting reactance is able to limit the circulation in a small phase range.

Secondly, when the converter internal or external malfunction happens, limiting reactance can limit short-circuit current rate. The converter includes a current-limiting reactance and N submodules [14]. The Multi-level converter is quite suitable for direct drive wind power system, because it has a lot of advantages such as smaller output harmonic content, adjustable power factor, flexible control, and weaker the voltage stress of semiconductor switch and electromagnetic disturbances [15].

IV. PULSE WIDTH MODULATION

Pulse width modulation is a method of bringing down the mean power produced by an electrical signal, by chopping it up into distinct parts. The average value of voltage and current to be fed to the load is controlled by turning on and off the switch between supply and load at a high rate. The longer the switch is on compared to the off periods, the higher the total power produced to the load. The pulse width modulation switching frequency has to be high enough not to influence the load, which is to say that the harvested waveform marked by the load must be as smooth as possible. The power loss in the switching device is very low, due to almost negligible amount of current flowing in the off state of the device and negligible amount of voltage drop in its OFF state.

Basically, they are classified into two major types, namely carrier-based modulation and carrier less modulation techniques [16].

The carrier-based modulation technique is further classified as

– Sinusoidal Pulse Width Modulation (SPWM)
– Modified Pulse Width Modulation (MPWM)
– Random Pulse Width Modulation (RPWM)
– Third harmonic injection PWM Space Vector Modulation (SVM)
– The Carrier less modulation technique is further classified as
– Delta Modulation (DM)
– Specific Harmonic Elimination (SHE)
– Wavelet Modulation (WM)

The most common type of PWM technique used nowadays is sinusoidal wave pulse width modulation (SPWM). The high frequency carrier-wave is compared with the sinusoidal modulating signals to produce the suitable gating signals for the inverters. The other PWM techniques are evolved from this basic PWM technique [17] [18].

V. SPACE VECTOR ORIENTED CONTROL METHOD

The DFIG can be controlled for its active and reactive power outputs as required by system conditions. When two or more renewable energy resources generate maximum power by controlling the active power of DFIG, the total system power can be controlled to fulfil the grid requirement [19]. Vector control, normally called the field-oriented control, is a variable-frequency drive control method in which the stator currents of a three-phase Alternating current electric machine are identified as two orthogonal components which can be pictured with a vector [20]. First component relates the magnetic flux of the motor, the other to the torque. The control system of the drive calculates the respective current components from the flux and torque references given by the drive's speed control.

Following are the main objectives of space vector pulse width modulation generated gate pulse:

- Wide linear modulation range
- Less switching loss
- Less total harmonic distortion in the spectrum of switching waveform
- Easy implementation and less computational calculations

It uses a space vector method to calculate the duty cycle of the switch which is vital implementation of digital control theory of PWM modulators. It can yield useful advantage under unbalanced conditions [21]. The three phase variables are denoted in space vectors. For a significantly small-time interval, the reference voltage vector can be approached by a set of stationary vectors generated by a converter. If this time interval is the sample time for converter control, then at the next sampling space when the reference voltage vector rotates to a new angular position, it may correlate to a new set of stationary voltage vectors. Carrying this process onwards by sampling the entire waveform of the desired voltage vector being synthesized in sequence, the average output voltage would closely emulate the reference voltage. The selected stationary vectors can also give the required phase shift between input voltage and current. The modulation process thus required, consists of two main parts: selection of the switching vectors and computation of the vector time intervals [22].

SVPWM refers to a special switching sequence of the upper three power transistors of a three-phase power converter. It has been shown to generate less harmonic distortion in the output voltages and or currents applied to the phases of a machine and to provide more efficient use of supply voltage. There are two known vectors called the zero vector and Active vector. The objective of space vector modulation technique is to estimate the reference voltage using the eight switching patterns. One simple method of approximation is to generate the average output of the converter in a small period, T to be the same as that of Vref in the same period. To apply the space vector modulation, the voltage equations in the ABC reference frame can be modified into the stationary d-q reference frame. It can be transformed into two reference frames by using Park's transformation and their relationships are shown in Equation:

$$f_{dqo} = K_s\, f_{abc} \quad (3)$$

where, $$K_S = (2/3)\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/2 & 1/2 & 1/2 \end{bmatrix}$$

where "f" is a voltage or current. In d-q reference frame, there are six sectors. Each sector is divided equally by sixty degrees. Basic Vectors are V1, V2, V3, V4, V5 and V6 [23].

A feedback linearization based nonlinear voltage and slip controller can also be employed for a DFIG based system connected to an infinite bus [24].

VI. THE POWER REGULATION SYSTEM

The recent research areas in the field of Renewable energy sources are focusing mainly on multi- phase operations [25]. It becomes a need to design wind energy systems with the ability to operate in the event of a fault. This fault forbearance is one of the main advantages of multi-phase generators compared to their three-phase equivalents. Hence in [26], authors gave an active and reactive power regulation strategy with back-to-back PWM converters connected with the permanent magnet synchronous generator (PMSG) wind turbine system. [27] proposes that in order to eradicate the zero-sequence circulating current problem, an isolated DC link with dual back-to-back PWM parallel converters are used employing carrier phase shifted technique. But, evaluating the performance of induction generator for the same case, the author in [28] proved along with some experimental results and site visit that the induction generator is best suited for the variable speed wind turbine [29]. The fault tolerance of six phase induction generators in wind energy systems is given in [30] having back to back converters. A lot of research work has been recently conducted and control approaches are suggested in this field for better regulation of active and reactive power in a grid connected WECS.

In the DFIG based WECS, the stator terminals are connected directly to the grid and the rotor across a partially rated convertor. A gearbox is required to couple the rotor with the generator due to the difference in the rotor and generator speed ranges. The main advantage of the DFIG is that only 30% of the generated power goes through the power converter and this alone may have substantial cost advantages even with low cost of future converters and power electronics [31]. An active and reactive power control strategy based on the predictive control approaches applied to grid connected Single phase wind energy systems has been proposed. To achieve the instantaneous power control, an MMC architecture has been used in combination with the predictive control [32]. By applying the feedback linearization at the machine side converter, the generator is controlled to keep the DC link voltage to follow its reference value and is maintained within variation limit of less than 1 %. A few scholars have been presented that the DC link voltage control schemes are used at the machine-side converter instead of the grid-side converter [33, 34]. The drawbacks of the naturally commutated DC- link and cyclo-converter schemes can be corrected by the use of two PWM voltage-fed current-regulated inverters connected back-to-back in the rotor circuit. The characteristics of such a scheme, in which both converters are vector controlled, are as follows:

- operation below, above and with synchronous speed with the speed range limited by the rotor- voltage ratings of the DFIG
- working at synchronous speed, with DC currents contained into the rotor with the inverter working in chopper mode
- low distortion factor of stator, rotor and supply currents control of the generator torque and rotor excitation
- Control of the displacement factor between the voltage and the current in the MSC, and thus control over the system power factor.

The induction machine is controlled in a synchronously rotating d-q axis frame, with the d-axis oriented along the stator-flux vector position. In this way, a decoupled control between the torque and the rotor current is achieved. The rotor-side PWM converter provides the actuation, and the control requires the measurement of the stator and rotor currents, stator voltage and the rotor position.

There is no need to know the rotor-induced emf, as is the case for the implementation with naturally commutated converters [35, 36]. Back to back connected voltage source converters (VSCs) are utilized for interfacing ASIG with the grid. Efficient control strategies are applied to generator side and grid side converters. Two machine side converters connected in parallel are operated with an advanced rotor field oriented control (RFOC) for MPPT. RFOC is achieved by involving six PI controllers. It mainly focuses on removal of unbalanced currents between two sets of three-phase windings. Three-level grid side converter is controlled for maintaining DC link voltage, and to regulate the flow of reactive power between grid and generator [37]. The major advantage of MMC is its ability to realize transformer less connection between medium voltage system and grid. The primary building block of an MMC is submodule, which facilitates the characteristic like scalable voltage level leading to staircase output waveforms, modularity, reduced harmonics and electromagnetic losses, high power quality [38, 39].

The PWM converter is current regulated, with the direct axis current used to regulate the DC link voltage and the quadrature axis current to regulate the reactive power. Thus, supply-side converter is used to control the reactive power of the system. The control scheme utilizes current control loops for the d axis and q axis grid current with the d axis current demand being derived from the DC-link voltage error through a standard PI controller. The q axis current demand determines the displacement factor on the supply-side of the inductors. Since the stator is connected to the grid, and the influence of the stator resistance is small, the stator magnetising current can be considered constant. It is shown that with variations in wind speed the system automatically captures the maximum power possible for tat speed and the regulatory control is done within milliseconds. During change over between super synchronous and sub synchronous operations the back to back converters automatically shift between their operation as inverters and converters [40].
Analysis of a system for power regulation of a grid connected Wind energy conversion system with six- phase DFIG has been presented for varying wind speeds. The most compatible control system consists Back to back modular multi- level PWM converters employed between the wind turbine driven DFIG and the grid in order to regulate the power flow from the turbine to the grid. Stator flux- oriented vector control is employed in the rotor side converters to decouple the active and reactive power control of the DFIG. Grid voltage-oriented vector control is employed in the grid side converters to maintain constant DC link voltage for effective power flow and to maintain overall system power factor as unity. It consists of regulating the reference value of the vector control system in order to influence the wind energy conversion system's reactive power. Clear disadvantage of the recent topologies lies in the complex gearbox system, which can significantly increase the price, and maintenance cost of the system. Furthermore, complex gearbox system can contribute to major decrease in WECS reliability. Hence, it is proved in recent researches to use feedback linearization technique in the stator of DFIG to control its speed and torque and in this way, we can avoid the gearboxes.

VII. SURVEY

Different researches have been carried out before in the field of power regulation in variable speed wind turbine power system. We can observe an explosion of interests in the area of control approaches, generators and PWM techniques.

AUTHORS	YEAR	TITLE	JOURNAL/CONFERENCE NAME	OBJECTIVE
Bindhu Babu1, Divya S	2017	Comparative study of different types of generators used in wind turbine and reactive power compensation [3]	IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)	A comparative study is discussed about the selection of the generators used in the WECS. And two methods for reactive power control is shown that i.e. power factor control and voltage control. It showed that the doubly-fed induction generator (DFIG) is the the best suited generator due to its advantages over others.
Alin Pantea, Amine Yazidi, Franck Betin, Sébastien Carriere, Bruno Vacossin, Humberto Henao, Gérard Capolino	2017	Low Speed Six-Phase Induction Generator Model for Wind Turbines	Institute of electrical and electronics engineering (IEEE)	A squirrel cage six-phase induction generator model based on the circuit-oriented approach suitable for simulation of electrical faults is presented. The rated values of the SCIG is compared to results to prove the capabilities.
A. Chih-Chiang Hua, B. Chien-Hung Cheng	2010	Design and Implementation of Power Converters for Wind Energy Conversion System	The 2010 International Power Electronics Conference	This paper gives the design and implementation of power converters for WECS. The presented system employs a permanent magnet synchronous generator (PMSG), a DC/DC boost converter, a bi-directional

				DC/DC converter and a full-bridge DC/AC inverter.
Sandeep Kumar Singh, Harish Kumar, Kamal Singh, Amit Patel	2014	A survey and study of different types of PWM techniques used in Induction motor drives [16]	IJESAT [International Journal of Engineering Science & Advanced Technology]	The different PWM techniques such as Single-pulse modulation, Multiple pulse modulation and Sinusoidal pulse width modulation (Carrier based Pulse Width Modulation Technique) are discussed. The advantages of the switching techniques are also presented.
Ankit Yadav,S N Singh and S P Das	2017	Modular Multi-level Converter Topologies: Present Status and Key Challenges [12]	2017 4th IEEE Uttar Pradesh Section International Conference on Electrical, Computer and Electronics (UPCON) GLA University, Mathura	This paper presents a complete review of MMC topology and its submodules. Different sub modules and their advantages are discussed. MMC is an emerging technology for HVDC transmission.
Puneet Singh Ghuman, Ms. Rachna	2016	Maximum Power Point Tracking in Wind Energy Generation System using DFIG	International Journal of Engineering Trends and Technology (IJETT)	This paper depicts that the unbalances in the wind energy can be eliminated by using the DFIG. It gives an efficient MPPT control for matrix converters. Here, the total system power is managed by back to back converters connected to the DFIG.
Rakesh Sharma, Kuldeep Sahay, Satyendra Singh	2014	Effects of Varying Load on DC- Link Voltage in DFIG Based Wind Energy Conversion System	International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering	The study proposes that the DC link acts as the source or sink for the active power. The work gives the idea of the DC-link voltage fluctuations for a back to back PWM converter in DFIG for wind turbine systems. For this, two cases are considered (i) At fixed speed, effect of load variation on dc link voltage (ii) At variable speed, effect of load variation on dc link voltage.
Seung-Ho Song, Shin-il Kang, Nyeon-kun Hahm	2003	Implementation and Control of Grid Connected AC-DC-AC Power Converter for Variable Speed Wind Energy Conversion System	Institute of electrical and electronics engineering (IEEE)	It models a WECS with synchronous generator. As the voltage and frequency of generator vary along the wind speed variation, a dc-dc boosting chopper is utilized to maintain constant dc link voltage. A PWM inverter is applied in the line side to supply the current to the grid by regulating the dc link voltage. The proposed model gives a low cost and high efficiency power conversion.
K.Kerrouchea, A. Mezouarb, Kh. Belgacem	2013	Decoupled Control of Doubly Fed Induction Generator by Vector Control for Wind Energy Conversion System [22]	ELSEVIER- Energy procedia	A sophisticated model of a DFIG-based WECS that also grid connected in the d-q synchronous reference frame and the inverters controlled by vector- oriented control approach. The stator flux orientation is used to measure active and reactive power equal to the reference values. An

				appropriate fitness function is also derived to express the time domain evolution of DFIG, with the objective to assure the DFIG continuous operation even under a fault condition.
Bidyadhar Subudhi1, Pedda Suresh Ogeti1	2017	Optimal preview stator voltage-oriented control of DFIG WECS [23]	IET Generation, Transmission & Distribution Research Article	A new optimal preview control (OPC) is proposed for power regulation of DFIG- based WECS. This OP controller is designed on the basis of linear quadratic regulator (LQR) approach. The proposed OPC is designed in order to minimise the error due to cross-coupling-induced electromotive force (emf) and emf-induced due to stator flux using feedforward compensation loops.
Mohamed Amin M.A. Moftah, Gaber El-Saady A. Taha & El-Noby A. Ibrahim	2016	Active Power Filter for Variable-Speed Wind Turbine PMSG Interfaced to Grid and Non-linear Load via three Phase Matrix Converter	Institute of electrical and electronics engineering (IEEE)	This paper aims to propose a shunt active power filter (APF) for harmonic cancelation of grid-connected wind turbine (WT). The model employs a matrix converter to interface the generator and the grid. The MC controls the wind maximum power point tracking (MPPT) via perturbation and observation (P&O) technique. The system responses proved that the system works significantly irrespective of wind speed values and load demand.
Yijing Chen, Gilney Damm, Abdelkrim Benchaib, Franc¸oise Lamnabhi-Lagarrigue	2014	Feedback Linearization for the DC Voltage Control of a VSC-HVDC Terminal	2014 European Control Conference (ECC)	The paper investigates the feedback linearization method to develop a system for power regulation in variable speed turbines. A d-q state space model for the system is developed. Feedback linearization can be applied when the VSC terminal operates in inversion mode but, the system is not feedback linearizable when the VSC works in rectification mode. A new dynamic model is introduced in the paper by using an additional control variable which yields a higher order system, allowing the terminal to operate in rectification mode also.

Table 1: The Survey on Recent Development Related To Power Regulation in Wind Farms

VIII. Conclusion

The research trend in past decade can be seen shifting towards renewable energies solution. Among them the most reliable is wind energy. But certain control strategies should be adopted to maintain the magnitude of the speed and the output parameters. The best suited system for this purpose as concluded by the survey is applying a six-phase double fed induction generator for wind energy with back to back multi modular converter using carrier phase shifting PWM technique controlled by vector-oriented stator control approach. This review will help the future researchers by throwing light towards every expect to be considered for a better technological approach towards the issue.

Acknowledgment

I would like to express my warm gratitude towards my advisor Prof. Romi Jain for her valuable guidance and department of electrical and electronics engineering, University Institute of technology, Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal for the support I got during this work. I also like to thank my family who continuously motivated and helped me whenever needed throughout the tenure.

REFERENCES

[1] T. Shanker and R. K. Singh, "Wind Energy Conversion System: A Review," 2012.
[2] M. El-Shimy, "Wind Energy Conversion Systems: Reliability Perspective," 2015.
[3] D. S. Bindhu Babu, "Comparative study of different types of generators used in wind turbine and reactive power compensation," 2017.
[4] Beainy, C. Maatouk and F. K. Nazih Moubayed, "Comparison of Different Types of Generator for Wind Energy Conversion System Topologies," 2016.
[5] Beainy, C. Maatouk, N. M. and F. Kaddah, "Comparison of Different Types of Generator for Wind Energy Conversion System Topologies," 3rd International Conference on Renewable Energies for Developing Countries (REDEC), 2016.
[6] De Battista, ""Sliding mode control of wind energy systems with DOIG-Power efficiency and torsional dynamics optimization"," IEEE Transactions on Power Systems, vol. 15, no. 2, pp. 728-733, 2000.
[7] J. M. F. Iov, ""Grid code compliance of grid-side converter in wind turbine systems,"," Proc. IEEE PESC, pp. 1-7, 2006.
[8] ON Netz, ""Grid Code. High and Extra High Voltage," www.eon-netz.com, Germany .
[9] Vinay Kumar Dwivedi, "Power Electronics Converters for a Wind Energy Conversion System: Review," vol. 4, no. 6, 2013.
[10] H. Akag, " "Control and experiment of pulsewidthmodulated modular multilevel converters,"," IEEE Trans. Power Electronics, vol. 24, no. 7, p. pp. 1737–1746, 2009.
[11] N. L.Angquist, " "Open-loop control of modular multilevel converters using estimation of stored energy,"," IEEE Trans.Ind.Application, vol. 47, no. 6, p. pp. 2516–2524, 2011.
[12] Ankit Yadav, "Modular Multi-level Converter Topologies: Present Status and Key Challenges," 2017.
[13] Yan Gangui, "Research on Modular Multilevel Converter Suitable for Direct-drive Wind Power System," 2012 International Conference on Future Electrical Power and Energy Systems , vol. 17, p. 1497 – 1506 , 2012.
[14] Reusser, "DC-Link Control Schemes in Multilevel Converters for WECS," IntechOpen, pp. 95-119, 2018.
[15] Micheal Sztykiel, "Modular Multilevel Converter Modelling ,Control and Analysis under Grid Frequency Deviations," Proceedings EPE Joint Wind Energy and T&D Chapters Seminar, 2012.
[16] Sandeep Kumar Singh, "A SURVEY AND STUDY OF DIFFERENT TYPES OF PWM TECHNIQUES USED IN INDUCTION MOTOR DRIVE," [IJESAT] [International Journal of Engineering Science & Advanced Technology, vol. 4, no. 1, pp. 18-22, 2014.
[17] V. k. chinnaiyan, D. J. Jerome, J. Karpagam and T. Suresh, "control techniques for multi level voltage source inverrters," The 8th InternationalPower Engineering Conference (IPEC 2007), pp. 1023-1028, 2007.
[18] Neha Kaushik, "Comparison and Implementation of Different PWM Schemes of Inverter with Induction Generator for Wind Generation," International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering , vol. 3, no. 5, pp. 9513 - 9520 , May 2014 .
[19] Tanvir and A. M. a. R. Beguenane, "Real-Time Control of Active and Reactive Power for Doubly Fed Induction Generator (DFIG)-Based Wind Energy Conversion System," Energies , vol. 8, pp. 10389-10408, 2015.
[20] K.Kerrouchea, "Decoupled Control of Doubly Fed Induction Generator by Vector Control for Wind Energy Conversion System," Overview of renewable energies exploitation in Algeria , Elsevier, vol. 42, p. 239 – 248 , 2013.
[21] M. G. S and N. A. Divya, "Rotor Side Converter Control of DFIG based Wind Energy Conversion System," International Journal of Engineering Research & Technology (IJERT) , vol. 4, no. 8, pp. 607-612, 2015.
[22] K.Kerrouchea, "Decoupled Control of Doubly Fed Induction Generator by Vector Control for Wind Energy Conversion System," Elsevier, vol. 42, pp. 239-248, 2013.
[23] P. S. O. Bidyadhar Subudhi, "Optimal preview stator voltage-oriented control of DFIG WECS," IET Generation, Transmission & Distribution, vol. 12, no. 4, pp. pp. 1004-1013 , 2018.
[24] Balogun, O. Ojo and F. Okafor, " Decoupled direct control of natural and power variables of doubly fed induction generator for extended wind speed range using feedback linearization," IEEE J. Emerg. Sel. Top. Power Electron., vol. 1, p. 226–237, 2013.
[25] F. J. Rodas, ""Multimodular matrix converter topology applied to the six-phase wind energy generator,"," Proc. 50th UPEC, pp. pp 1-6, 2015.
[26] Tan Luong VAN, "Advanced Control Strategy of Back-to-Back PWM Converters in PMSG Wind Power System," POWER ENGINEERING AND ELECTRICAL ENGINEERING, vol. 13, no. 2, pp. 81-95, 2015.
[27] Li Jian-lin, "Research on the Application of Parallel Back-toBack PWM Converter on Direct-Drive Wind Power System," DRPT, pp. 2504-2508, 2008.
[28] Jitendra Singh Shakya, "PERFORMANCE EVALUATION OF SEIG FOR VARIABLE SPEED WIND ENERGY CONVERSION SYSTEM," IJRRAS, vol. 24, no. 1, pp. 21-51, 2015.
[29] G. M. Asher, "Doubly fed induction generator uising back-to-back PWM converters and its application to variable- speed wind-energy generation," IEE Proceedings, vol. 143, no. 3, pp. 231-241, 1996.
[30] Gonzalez, "Fault-tolerant efficient control of six-phase induction generators in wind energy conversion systems with series-parallel machineside converters".

[31] R. Spée et S. Bhowmik, “, “Novel control strategies for variable speed doubly fed power generation systems”,” Renewable Energy, vol. 6, no. 8, pp. pp. 907-915, 1993.
[32] CABALLERO, “"Active and Reactive Power Control Strategy for Grid-Connected Six-Phase Generator by using Multi-Modular Matrix Converters,” SYSTEMICS, CYBERNETICS AND INFORMATICS, vol. 4, no. 6, pp. pp. 57-61, , 2016.
[33] R. B. YUAN, “ DC-link voltage control of a full power converter for wind generator operating in weak-grid systems,” IEEE Transactions on Power Electronics, vol. 24, no. 9, p. p. 2178–2192, 2009.
[34] HANSEN, “"Multipole permanent magnet synchronous generator wind turbines’ grid support capability in uninterrupted operation during grid faults,” IET Renewable Power Generation, vol. 3, no. 3, p. p. 333–348, 2009.
[35] BOGALECKA, “‘Power control of a double fed induction generator without speed or position sensor,” EPE, vol. 8, no. 377, pp. pp. 224-288, 1993.
[36] L. TANG, “Stator field oriented control of doubly excited induction machine in wind power generating system,” 35th Mid-West Symp. on Circuits and systems, Washington, DC, p. pp. 14461449, 1992.
[37] K. Chinmaya and G. Singh, “Modeling and experimental analysis of grid-connected six-phase induction generator for variable speed wind energy conversion system,” Electric Power Systems Research Elsevier, no. 166, pp. 151-162, 2019.
[38] M. Hagiwara, “"Control and Analysis pf the Modular Multilelve Cascade Converter Based on Double-Star Chopper-Cells (MMCC-DSCC),” IEEE Transaction on Power Elelctronics, vol. 26, no. 6, pp. pp. 1649-1658, 2011.
[39] M. A. Perez, “Predictive Control of AC-AC Modular Multilevel Converter,",,” " IEEE Transaciton on Industrial Electronics, vol. 59, no. 7, pp. pp. 2832-2839, 2012.
[40] Aishwarya Devi Rai, “"Active and Reactive Power Regulation of a Grid Connected Wind Energy Conversion System with Doubly Fed Induction Generator,” International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, vol. 3, no. 2, pp. 16-23, 2014.