Methods for Reducing Harmonics in Wind Energy Conversion Systems: A Review

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Manuscript Received: Manuscript Accepted:

Abstract: *As renewable energy is unlimited, pollution-free, and abundant, the world is slowly but surely heading toward it. Wind energy is one of the most renowned renewable energy sources since wind will never die until the end of time. We used to use fixed-speed wind turbines in our wind energy conversion system (WECS), but we switched to variable-speed wind turbines due to various disadvantages of fixed-speed wind turbines. Power electronic converters are used in variable speed wind turbines to extract maximum power, although they are a source of harmonics due to their switching operation. The power quality of wind power is deteriorated by this harmonic in the voltage and current. So, in order to reduce the harmonic in variable speed WECS, numerous solutions have been presented over the years to lessen the harmonic problem caused by variable speed WECS. This paper provides an overview of some of the harmonic mitigation techniques that have been developed in recent years to improve power quality.*

Keywords: *Power quality, Variable speed wind turbine, WECS, Fixed speed wind turbine.*

I. Introduction

From 2011 to 2030, global primary energy consumption is expected to increase by 1.6 percent each year, adding 36 percent to the amount from 2011. Coal (41%) was the primary source of energy in 2011, followed by gas (22%), and oil (8%). (4 percent) The total contribution of fossil fuels was 67%, nuclear energy was 13%, and renewable energy was 20%. Renewable energy will grow at a rate of 7.6% per year between 2011 and 2030, the greatest among all energy sources [1]. However, because fossil fuels deplete more faster than they are formed, there will be a significant scarcity of fossil fuel in the future. Every year, the world produces 21.3 billion tonnes of carbon dioxide, and natural processes may absorb half of it, leaving the other half in the atmosphere [2]. Carbon dioxide concentrations grow by 40% when fossil fuels are burned [3,4]. Because of the rise in carbon dioxide emissions, the Kyoto Protocol was established in 1997 in Japan to stabilise carbon dioxide emissions [5].

Variable speed wind turbines were developed as a result of reactive power regulation and high mechanical stress. Variable speed wind turbines provide the advantages of keeping generator torque relatively constant regardless of wind speed, capturing maximum power for maximum energy, reducing mechanical stress, and reducing electrical power variance, among other things[6,7]. However, because of the fluctuating wind speed, variable wind turbines produce varying frequency and voltage, making them non-grid compliant. As a result, a power electronic converter was used to connect with the wind system in order to supply the grid with frequency and voltage matching. However, due to the switching action of power electronic converters used in variable speed wind turbine systems, they are a source of harmonics [8], and these harmonics in wind power voltage and current degrade the power quality provided by WECS.

Several techniques have been presented in recent years to solve the harmonics problem. This research examines some of the previously discovered strategies for mitigating harmonic difficulties in variable speed wind energy conversion systems, with the goal of improving wind energy power quality.

II. Wind Energy Conversion System

Because of the great achievement of variable speed wind turbine systems, they are presently adopted by the majority of WECS [20]. Variable speed wind turbines with a double-fed induction generator (DFIG) and a permanent magnet synchronous generator (PMSG) are becoming increasingly popular. Figures 2 and 1 show the diagrams of WECS-based DFIG and PMSG, respectively. In DFIG, the stator is connected to the grid, and the rotor circuit is controlled by the power electronic converter. It can maintain an operational speed of around 30% of synchronous speed, allowing for reactive power control, which is critical for maintaining voltage stability during some disturbances. DFIG has control over the rotor voltage and current, which allows it to stay synchronised with the grid even when the wind speed changes. Because the converter only handles 25-30% of mechanical power to the grid and the rest is connected directly to the grid by the stator, the converter's cost is lower and its efficiency is higher [22]. However, in the case of PMSG, it is fully connected to the grid via a power electronic converter, and PMSG can even do away with the complex gearbox system. The pulse width modulation converter regulates the speed of the PMSG. The generator side converter and grid side converter are used to feed the PMSG's output electricity into the grid[23]. To increase power quality, the harmonic reduction approach can be applied to any variable speed wind turbine system.

This review paper mentions a new generator known as a Split Winding Alternator, which has been utilised in the past and is connected to the grid via a power electronics instrument. In terms of operation, this generator differs from the DFIG and PMSG generators.

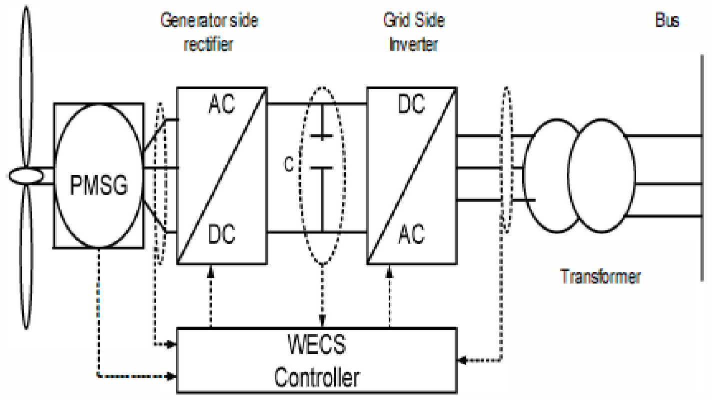

Figure.1 Wind energy conversion based on PMSG.

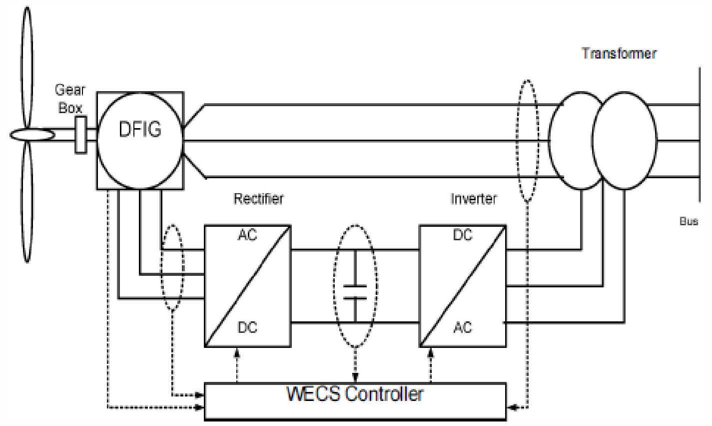

Figure.2 Wmd energy conversion based DFTG wind turbine connection system.

III. Harmonic Mitigation Methods

Following methods are used in the past to reduce harmonics in the wind energy conversion system.
A. Shunt active filter.
B. Unconventional power electronic interface.
C. Synchronous active front ends.
D. Cascaded multi level inverter.
E. Predictive current control based multi pulse flexible topology.
F. Power factor corrector.

A. *Shunt active filter*

Shunt Active power filter-generally an active filter has three parts.
1. Identification.
2. Inverter.
3. Modulation.

1. *Identification:* The techniques for extracting harmonics from line current and determining the filter reference current are critical during filter design and implementation. The accuracy of the shunt active filter and the speed of response are also influenced by the above-mentioned approach [24-26]. Two excellent methods for obtaining reference current are time domain and frequency domain analysis[27-29]. Both methods have benefits and drawbacks. For example, time-domain analysis is faster, whereas frequency domain analysis is more accurate. In the presence of source harmonics, time-domain methods such as instantaneous reactive power cannot provide good performance, however frequency domain methods that use frequency Fourier transfer can fix the problem.

It is better to employ a Band Reject Filter in an active filter, where the line current signal is passed and the output signal contains all harmonics except the fundamental frequency, making correction simple. When opposed to the instantaneous reactive power approach, a Band Reject Filter has the advantage of not requiring a voltage sensor.

2. *Inverter:* There are two types of inverters in use: voltage source and current source inverters. However, because a shunt active filter is used to compensate current, a current source inverter (CSI) is suitable here; however, this system uses a current sensor, which is expensive, so we use a voltage source inverter instead (VSI). However, a method must be used to transform the current reference signal into a voltage reference signal, and VSI will generate a signal for this approach.

3. *Modulation:* Shunt active filter (SAF) uses pulse width modulation (PWM) technique, in which the reference signal is compared with a triangular signal, but this triangular signal has no information. However, in VIPWM method, the triangular signal is derived from the integral of the reference signal, and it has many advantages, such as it contains the information of the output signal and its amplitude varies in proportion to the amplitude of the output signal.

B. *Unconventional power electronic interface*

The unconventional power electronic interface has consists of three parts

1. Rotor side converter.
2. DC to DC intermediate circuit.
3. Grid side converter system.

C. *Synchronous Active Front ends*

At the grid side converter end system, active front ends are the parallel of converters. Its bi-directional characteristic provides numerous power quality advantages in both directions of conversion. A Synchronous active front end (SAFE) system is made up of n identical parallel linked converters connected by a common DC link. Each parallel converter has the same switching frequency, and each one's sizing is based on the plant's nominal power, thus each converter has a higher switching frequency. The pulse width modulation (PWM) interlaced control mechanism that operates the system, however, is the true SAFE benefit. It is made up of n shifted PWM current controllers, one for each active front end (AFE) that uses the same current reference.

D. *Cascaded multilevel inverter*

The suggested inverter combines an internal current control mechanism with external control of the dc input voltages, resulting in increased control flexibility. After each diode bridge rectifier (DBR), a dc-link capacitor was utilised to hold the dc input voltages to the cascaded H-bridge multi level inverter (CHBMLI). On the ac side, the three H-bridge cells per phase are connected in series, and the output is directly connected to the medium-voltage distribution grid, eliminating the need for an interface transformer.

E. *Multi pulse flexible topology thyristor converter(MPFTTC)*

There is a description of 24 pulses in this method. It has a phase-shifted transformer with a single main winding and four isolated secondary windings, as explained in the multi pulse flexible topology. The phase shifting angle for harmonic cancellation has been set to 15 degrees. Each secondary winding feeds a typical 6-pulse thyristor rectifier, with six extra diodes and three GTOs connecting the four 6-pulse rectifiers (functioned as switches).

F. *Power Factor Corrector*

In most WECS-used variable speed wind turbines, there is a boost converter between the bridge rectifier and the voltage source current controlled inverter (VS-CCI). Its control of DC output power is simple, and the transistor operates at a constant switching frequency, but it has a serious problem of high switching losses when compared to three phase AC-DC converters, and an input filter is required.

IV. Comparisons of Different Methods

Table I: ADVANTAGE AND DISADVANTAGE OF METHODS

Methods Used Merits Demerits	**Methods Used Merits Demerits**	**Methods Used Merits Demerits**
Shunt active filter	➢ Does not create parallel resonance with the system impedance at a frequency below tuned frequency like passive filter. ➢ Able to compensate harmonic without fundamental reactive power concerns. ➢ If shunt active filter uses time domain	➢ Time domain method possesses lack of accuracy and multiple harmonic load currents detection. ➢ Frequency domain method possesses lack of fast response. ➢ Time domain methods like instantaneous

	method then it will provide fast response. ➢ If uses frequency domain method then it will provide more accuracy and mUltiple harmonic load currents detection. ➢ Frequency domain approach based on band reject filter does not require any voltage sensor so economical. ➢ Shunt active filter which employs Voltage source inverter does not require any current sensor. ➢ This method is more efficient in reducing current harmonics.	reactive power theory method suffer from dependency on source voltage harmonics. ➢ Instantaneous reactive power theory not suitable where source is non-sinusoidal. ➢ Instantaneous reactive power theory method required voltage sensor which make system economical. ➢ Less efficient in reducing voltage hannonics.
Unconventional Power Electronic interface	➢ Low total harmonic distortion. ➢ Long distance between generator and converter. ➢ Able to stand wide transients of grid Voltage and current. ➢ Regulation of generator speed to I p. u. ➢ Regulation of reactive power to zero. ➢ Regulation of pitch angle to zero degree. ➢ UPEI uses pitch angle control hence pitch angle has advantages like good power control, emergency stop.	➢ System uses LC filter which is bulky. ➢ Extra system complexity. ➢ Higher power fluctuation at higher wind speed.
Interlaced active front ends	➢ A reduced sizing of each AFE unit, which manages a portion of the whole normal power. ➢ A reduced ripple in the injected current which improves the power quality of PCC voltage too. ➢ An increased equivalent switching frequency, which makes smaller the passive filters on AC side. ➢ A possible reduction of switching losses.	➢ As it employs inverter in parallel hence cost of AFE is more.
Cascaded multi level inverter	➢ Not uses excessive transfonner that uses by multi pulse inverter. ➢ Will be able provide equal switching stress and power handling for all the cascaded H bridge cells. ➢ Multilevel inverter are applicable for high wind power application. ➢ Applicable where high power and power quality needed. ➢ Since switch stress is reduced, switch ratings are low. ➢ Cost is reduced as switch is reduced. ➢ Using a large number of DC sources provide an advantage.	➢ Require more devices than traditional converter. ➢ Using more devices may increase failure chance more. ➢ Controlling more no of switches will result in complicated control.
Predictive current controlled based multi Pulse Flexible Topology	➢ Predictive current control provides fast transient as well as good steady state response, simple conception, easy implementation. ➢ The mention MPFTTC can operate over a wide voltage range while maintaining improved power factor when feeding light load. ➢ Depending upon the load voltage multi pulse flexible topology may be act in series or parallel mode in order to improve THD and power factor.	➢ THO and Power Factor are good when feeding light load only so not effective for heavy load. ➢ Use many transformers so system is not economical
Power Factor Corrector	➢ Boost topologies can provide continuous input currents and higher output voltage. ➢ Very suitable for low cost power ac-dc application. ➢ High efficient due to reverse recovery related losses of the boost diode are	➢ Cascading three phase PFC circuits require the use of additional diodes. ➢ Increased component count. ➢ Complicated input synchronization logic.

	eliminated. ➢ Low THD in the input current. ➢ Simple structures use one controlled device.	

V. CONCLUSION

This work examined and described numerous harmonic reduction approaches for the WECS, which are still under investigation. Because the power quality of WECS is fast deteriorating due to the harmonic problem, researchers have expressed a strong desire to find a solution. In this work, many harmonic reduction approaches are discussed with a clear and concise graphic. In this work, the advantages and disadvantages of several approaches are compared.

References

[1] Renewable global status report 2013, http://www.ren21.netlportals/0/documents/resources/ . . . IGSR2013.

[2] What are greenhouse gases, US department of energy, http://www.eia. gov/oiaIl1605/ggccebro/chapterl.htm!.

[3] T. J. BIasing "current green house gas concentration" ,http://www.eia. gov/cfapps/ipdbprojectlTEOlndex3.cfm.

[4] E. Olugokencky and P. Trans, "The most recent preliminary estimates of global monthly mean C02 concentration is 396.71 ppm", http://www.eia. gov/countries/.

[5] M. Grubb, "Kyoto and the future of international climate change responses: from here to where" 2004, http://www.econ.cam.ac. uk/rstaff/grubb/publications/J37.pdf.

[6] Li. J, N. Samaan and S. Williams, "Modeling of large wind firm systems for dynamic and harmonic analysis" Transmission and Distribution conference and Exposition, pp.I-7, 2008.

[7] F. S. Dos reis, FD. Adegas, R. Tonkoski, S. Slan and K. Tan, "Active shunt filter for harmonic mitigation in wind turbine generator", Power electronic special conference, pp.I-6, june 2006.

[8] J. M. Carrasco, J. T. Bialasiewicz, R. C. P. Guisado and J. T. Leon, "Power electronic system for grid integration of renewable energy sources: A survey" IEEE transactions on industrial electronics , Vo1.53, no.4, August 2006.

[9] R. Zahira, A. Peer Fathima, Ranganath Muthu “Harmonic Reduction in Wind Power Generating System Using Shunt Active Filter with SPWM Technique”Scientific Research Publishing, Circuits and Systems, 2016, 7, 157-165

[10] Gawain, L., Tiwari, H. and Bansal, R.C. (2013) Improving Power Quality of Wind Energy Conversion System with Unconventional Power Electronic Interface. International Journal of Electrical Power & Energy Systems, 44, 445-453.

[11] Emmanuel Hernández Mayoral, Miguel Ángel Hernández López, Hugo Jorge Cortina Marrero and Reynaldo Iracheta Cortez “Harmonic Analysis of the Wind Energy Conversion System Connected with Electrical Network”IntechOpen, 2018.