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Mitigation of Harmonics in a grid connected DFIG Wind Power System

Mirza Tanweer Baig[1], Abrar Ahmad[2], Dr.Mohammad Muazzam[3]

[1]M.Tech,Noida International University,Greater Noida,India
[2]Assistant Professor,Department of EE,Jamia Millia Islamia,New Delhi
[3]Prof & HOD,Department of EE,Noida International University

ABSTRACT

The inevitability of power electronics devices for reliable performance of renewable energy sources in general and wind power system in particular has brought various power quality issues including harmonics. In this paper a single tuned notch LCL filter derived from Butterworth and Chebyshev I filters is designed to detect the presence of harmonics in a doubly fed induction generation wind power system (DFIG) in order to mitigate the same. We analyzed that power quality has been substantially improved by employing the designed filter. The designed filter is made to achieve optimal control for harmonics alleviation problems in wind environment. In this paper, high order harmonics cases have been suppressed by employing variants of filters. MATLAB/SIMULINK DFIG (Doubly feed induction motor) wind farm model is used to generate and analyze the different harmonics magnitude and frequency.

Keywords: Harmonics, micro distributed generation, wind power, DFIG

INTRODUCTION

Renewable energy sources are fast shedding their 'alternative' or 'secondary source' tag due to aggravation of global warming and alleviation of fossil fuels attributed to conventional sources of energy. Also the ubiquitous presence of semiconductor devices has led to a revolution in energy but at the same time it has posed significant challenges to power quality considerations. Devices like UPS, converters, inverters, adjustable-speed motor drives (ASDs), direct current (DC) motor drives, battery chargers, and electronic ballasts etc are gaining more and more employability in power system arena. The presence of harmonics and distortion in the current is mainly due to nonlinearity of the loads where current is not always proportional to voltages thus creating harmonic in the system. These harmonics can interact negatively with a broad range of power equipments especially transformers and motors that in turn produces more loss, trigger the problem of overheating and overloading. Harmonics also adds up to overall reactive power demanded by equivalent load. Figure 1.1 shows a typical understanding of power quality when electrical parameters pass through non linear loads such as power electronics devices.

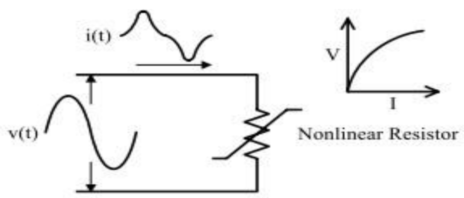

Figure 1.1. *Nonlinear behavior of current*

There are some conventional methods to solve the harmonic distortion problems which have existed for a long time. Passive filtering is the simplest conventional solution to mitigate the harmonic distortion [1]. They are known such as because they are not dependent on an external power supply and/or they do not include active component such as transistors. These conventional solutions that use

Address for correspondence:

Aahmad15@jmi.ac.in

passive elements are simple but they do not always respond correctly to the dynamics of the power distribution systems. In near future the technique such as wave digital filter (WDF) or circulator-tree wave digital filter (CTWDF) are expected to be used more commonly for the renewable energy applications to mitigate harmonics [2-5].

WIND POWER SYSTEMS

There are broadly two generation concepts in wind energy systems, one with asynchronous generator and other with synchronous generator. Both are based on variable-speed generators and use blade angle adjustment (pitch control) as power limiters. The variable speed rotor drives a double-fed asynchronous generator via a gear box. The generator rotor is connected to the network through a frequency converter, which permits both an over synchronous and under synchronous operation compared to the line frequency. As a result, the generator is variable speed. Only part (approx. 30 – 40%) of the output power or current has to be adapted to the desired line frequency through the converter [6].

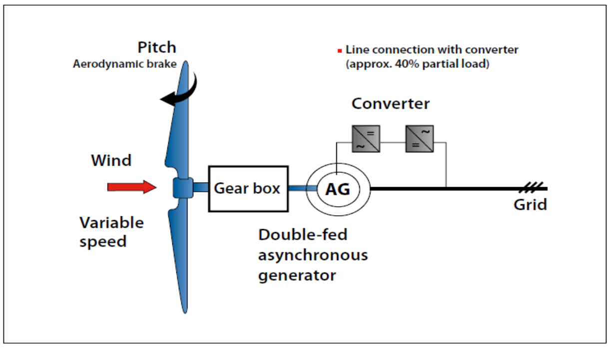

Figure 2.1. *Double-fed asynchronous generators*

Through the variable rotor speed, wind energy systems with synchronous generators can adapt themselves optimally to changing wind speeds and thus achieve a high degree of efficiency. The synchronous generator converts mechanical energy into electrical energy from variable rotation speed and thus frequency. The full generator output must be adapted via a frequency converter to the desired voltage and line frequency.

Systems with separately excited synchronous generator ("full conversion") or permanently excited synchronous generator ("full conversion")

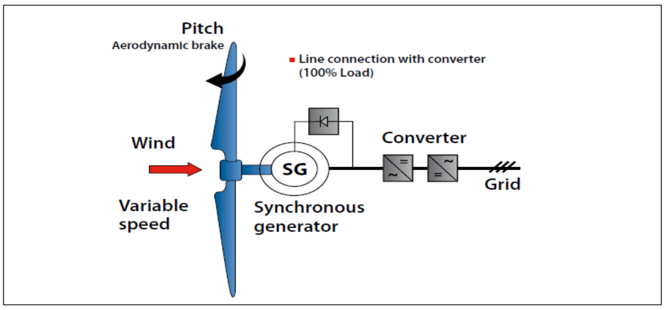

Figure 2.2. *Separately excited synchronous generator*

Permanently excited synchronous generators achieve a higher efficiency in the partial load operational range. Gearless systems are equipped with slow-running generators that have a higher number of poles. In this case, the design of the frequency converter is particularly demanding. Since efficiency optimization and component reduction are at the forefront when it comes to offshore systems, the wind energy systems tend to be gearless and with full power converters.

It has a wide speed range than that of any of the other types of WPP, thereby optimizing energy extraction from the wind. Absence of gearbox failures in direct drive WPPs and no oil cooling /monitoring systems required. It has large air gap leading to higher overloading capacity. These slow rotating WPPs produce lesser tip noise at low wind speed. Whenever a fault occurs, to maintain the needed grid voltage, the synchronous generator can provide requisite VARs to the grid within certain limits. The WRSG can be operated both in capacitive and inductive mode, which is especially useful in the case of large WPPs or weak grids.

Compared to an IG of a similar size, the synchronous generator is mechanically and electrically more complicated and all the more expensive[7]. In the direct drive WPP, no gearbox is needed, but this advantage must be paid for by a larger PEC (requiring greater cooling arrangement) with more complicated electronic circuits for which expert maintenance personnel required. Synchronous generator can only be connected to the grid, when frequency, phase position and voltage of the power produced are in synchronism with the grid.The WRSG is not as rugged as the squirrel cage machine.

HARMONICS FILTER DESIGNING

Any periodic or distorted waveform can be illustrated as a sum of pure sinusoids as shown in Fig 3.1. The Fourier analysis allows a periodic distorted waveform to be decomposed into an infinite series containing DC component, fundamental component (50 Hz in case of India) and its integer multiples called the harmonic components. The harmonic number usually expressed by symbol (h) is the ratio of its frequency to the fundamental frequency [8].

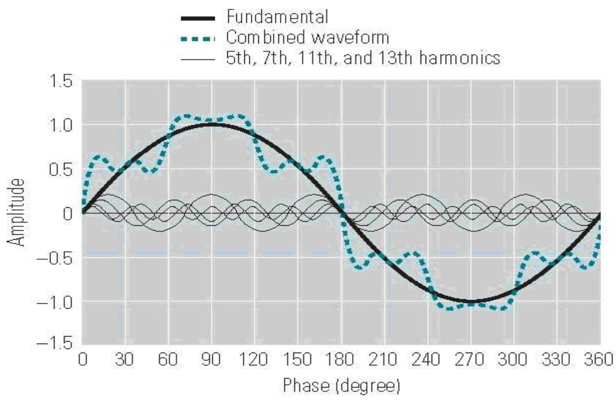

Figure 3.1. *typical harmonics representation*

To measure the extent of harmonics distortion, total harmonic distortion (THD) is used it applies to both current and voltage waveforms and is defined as in following equation:

$$THD = \frac{\sqrt{\sum_{h>1}^{hmax} M_h^2}}{M_1} \times 100 \quad (1)$$

Where M_h is the RMS value of the harmonic component h of the quantity M.

THD may vary from fee percentage to more than 100% but generally upto 5% is acceptable range however the value beyond 10% is not acceptable in any case. [8].

Harmonics Mitigation and Filters

Harmonic filters are designed to the customized need of any particular power system. The interaction between harmonics producing sources and power system is important to asses for designing of an effective filter. The filter should have ability to find the nonlinear loads and reduce the harmonic current, or block the harmonic current from entering to the system and modify the system frequency response to avoid harmful interference with harmonic current.

Figure 3.2 shows configuration of the filter, equivalent circuit of the filter and the frequency response of the filter. This filter has two advantages, it suppresses the harmonics and increases power factor. This filter is tuned to a little bit lower than the intended harmonic to be filtered so that if there is some change in the system parameters then it may raise the notch frequency.

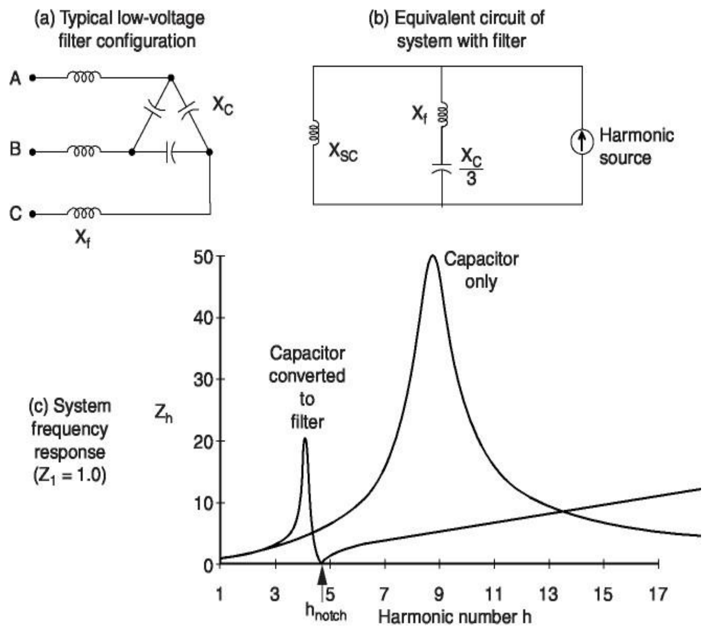

Figure3.2. *Fifth-harmonic notch filter and its effect on the system response*

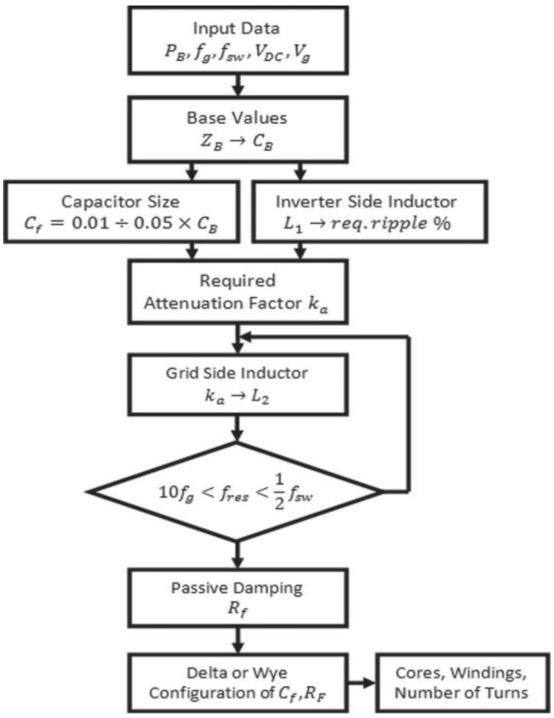

Figure3.3. *LCL filter design algorithm*

A single tuned notch filter is designed and applied at 480 V bus at 1200kVA load and 0.75 lagging power factor. The total harmonic current produced by the load is 30% of the fundamental current and has maximum of 25% of 5th harmonic. This model has 1500kVA transformer with 6% of impedance. The 5th harmonic voltage distortion on the utility side of the transformer is 1.0% of the fundamental when there is no load [6].

MODELING OF DFIG WIND FARM

Here we have considered DFIG wind farm technology that harness maximum energy from the wind at low wind speeds by optimizing turbine speed and minimizing mechanical stresses during gusts of wind. The optimum turbine speed producing maximum mechanical energy for a given wind speed is proportional to the speed at which wind is flowing. The output power of the turbine is given by the following equation (2)

$$P_m = 0.5\rho A C_p(\lambda,\beta) v_{wind} \quad (2)$$

Where

Pm Power from the wind,

ρ Air density, (approximately 1.2 kg/m3 at 20 0C at sea level)

A swept area of blade.

Cp The power coefficient which is a function of both tip speed ratio (λ), and blade pitch Angle (β) (deg.

Figure 4.1 shows a Simulink block diagram of 10 MW wind farm consisting of five 2 MW wind turbines is connected to a 25 kV distribution system. The generated power through wind is transmitted to a 120 kV grid through a 30 km long 25 kV feeder along with necessary assortments. DFIG wind turbine here is consisting of a synchronous generator connected to a diode rectifier, a DC-DC IGBT-based PWM boost converter and a DC/AC IGBT-based PWM converter. In this paper the wind speed is considered constant at 15 m/s for the sake of simplicity. The control system of the DC-DC converter is used to maintain the speed at 1 p.u. The reactive power produced by the wind turbine is regulated at 0 Mvar. The model is discretized at a relatively small time gap of 5 microseconds. This model is suitable for dynamic monitoring and control over relatively short periods of times (typically hundreds of milliseconds to one second).

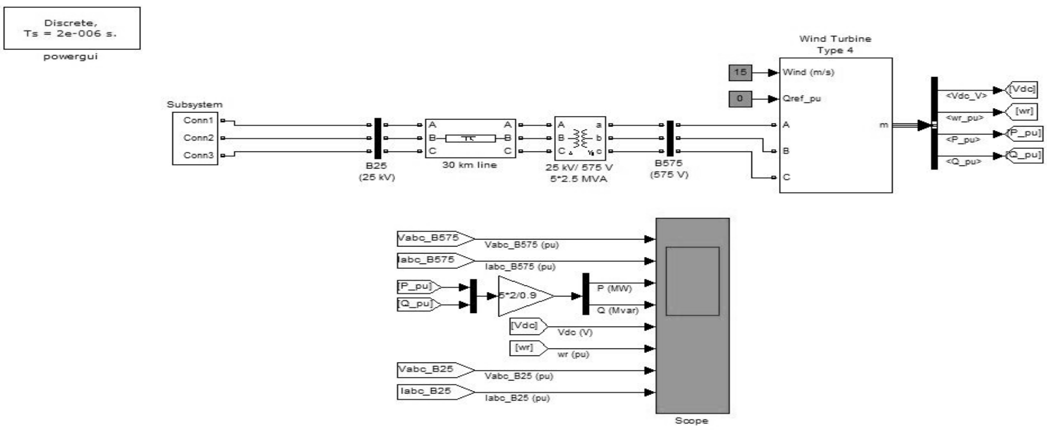

Figure4.1. *Simulink model of wind farm.*

SIMULATION AND RESULTS

We observe the steady-state operation of the DFIG wind turbine and its dynamic response to voltage sag as a remote fault takes place on 120-kV system. By opening the “120 kV” block modeling on Simulink we set six-cycle 0.25 pu voltage drop at t=0.03 s. We can observe the voltage and current waveforms on the scope connected on Simulink platform. At starting we see that the Type 4 wind farm produces 10 MW while the corresponding turbine speed is 1 pu of generator synchronous speed. The DC voltage is regulated at 1100 V and reactive power is kept at 0 Mvar. At t=0.03 s the positivesequence voltage suddenly drops to 0.75 pu causing an increase on the DC bus voltage and a drop on the DFIG wind turbine output power. While the voltage sag takes place the control system tries to regulate DC voltage and reactive power at their set points (1100 V, 0 Mvar). The system recovers after fault elimination.

Simulation results are taken before the 575V bus bar with and without the filter as shown in above figure 4.1. To suppress the harmonics a single tune high pass filter is designed das used. In addition the Single tune filter is derived from Butterworth and Chebyshev I filters mainly because they are based on poles and zeros. In Butterworth and Chebyshev filters the numerator is constant because there are no finite zeros. Single tune High-pass filters are best for harmonics of higher order which also cover wide range of frequencies. C-type high-pass filter (A special type of high-pass filter) is used to provide reactive power and also to get rid of parallel resonances. C type high pass filters also allows filtering of low order harmonics (such as 3rd), while keeping zero losses at fundamental frequency.

CASE 1: Voltage and current response without Filters

Figure 5.1 and 5.3 represents the voltage and current waveforms before the bus B575. From graphs we can clearly see the presence of different harmonics in the wind farm due to power electronics devices that are used to extract maximum energy from the wind. These power electronics devices are nonlinear in nature and this non linearity is the source of harmonics. The graph is representing the noise and presence of harmonics due to same.

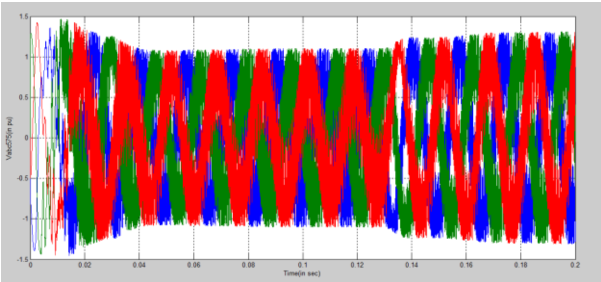

Figure5.1. *Voltage waveform without filter (Voltage vs Time)*

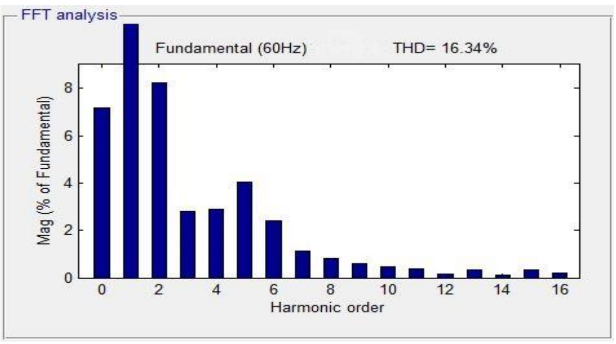

Fig5.2. *FFT voltage waveform without filter*

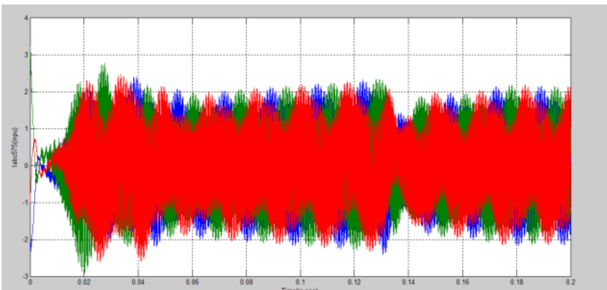

Figure5.3. *Current waveform without filter (current vs time)*

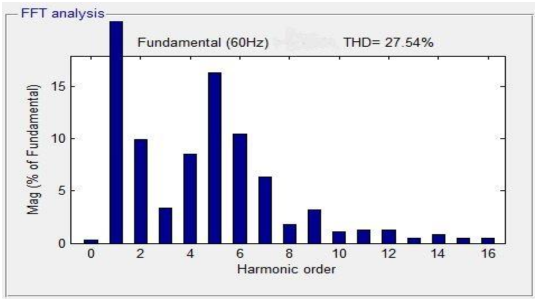

Fig 5.4. *FFT current waveform without filter*

CASE 2: Voltage and current response with Filters

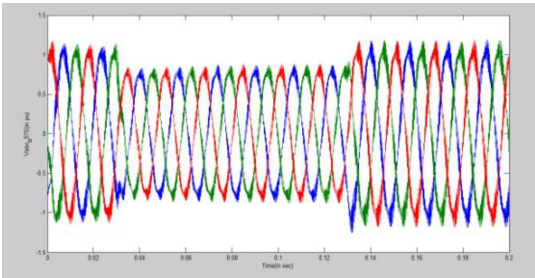

Figure5.5. *Voltage waveform with filter (voltage vs time)*

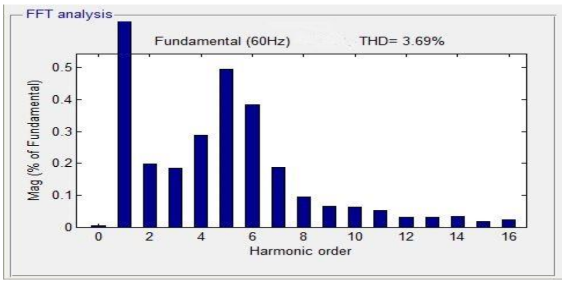

Figure5.6. *FFT voltage waveform with filter*

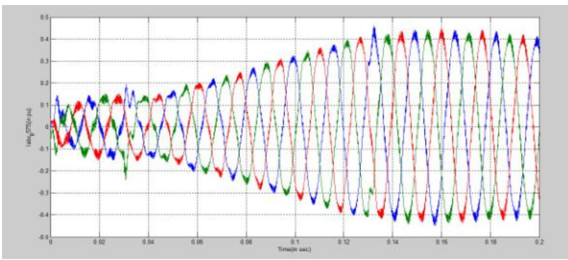

Figure5.7. *current waveform with filter (current vs time).*

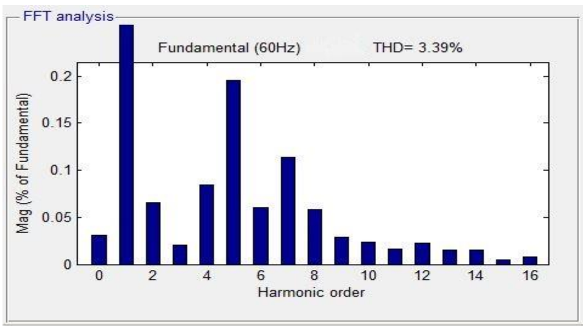

Fig5.8. *FFT current waveform with filter*

We can also observe from the above simulation result that distortion level in the figure 5.1(voltage response without filter) is higher than the figure 5.5 (voltage response with filter). From the graph we observe that with use of filter we can successfully eliminate the harmonics and bring it harmonics according to the IEEE standards. To explain the harmonics presence in wind power system we also used FFT analysis of the harmonics. With the help of FFT, we can show the harmonic order in bar graph representation. THD is the parameter to show content of harmonics. Here FFT analysis is done on current and voltage waveform with and without filter.

From above bar diagrams it is manifested that with filter total harmonic order (THD) value is under 5% which is acceptable by IEEE standards. With filter the value of THD of current and voltage is 3.69% and 3.29% respectively. Without filter the value current and voltage is 27.54% and 16.34% respectively. With using filter the value of THD decreases.

CONCLUSION

For a DFIG based wind power system, harmonics and power quality are analyzed while the wind farm was connected to a grid. Form the simulation results it is clear that the amplitude of the harmonics is smaller than the fundamental frequency but the harmonics frequency is greater than the fundamental frequency. The results from waveforms show that high-pass filter is suppressing high frequency component of the combined signal. The LCL filter is clearly reducing the switching frequency ripples and therefore suitable for coupling to utility grid. From the results it was found that the proposed design meets industry standards and allows a total harmonic distortion (THD) within a prescribed range of 5%.

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AUTHOR'S BIOGRAPHY

Mr. Abrar Ahmad, obtained his B.Tech (Electrical Engineering) and M.Tech (Electrical Power System Management) from JMI, New Delhi, both with First division in 2003 and 2009 respectively. He is pursuing his Ph.D. from Jamia Millia Islamia (Central University) New Delhi since 2011. He has been teaching and guiding research for about 10 years at different institutions such as MDU, UPTU and Jamia Millia Islamia at undergraduate and post graduate level. His research interests include Renewable Energy, Power System operation, control and management. He has around 10 research papers published in different international and national journals and conferences of repute