

HARMONIC MITIGATION IN WIND TURBINE ENERGY CONVERSION SYSTEMS USING DFIG

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Abstract: *Doubly Fed Induction Generator (DFIG) applied to wind energy conversion system (WECS) using variable speed operation is being used more frequently in wind turbine application. Variable speed systems have several advantages over the traditional method of operating wind turbines, such as the reduction of mechanical stress and an increase in energy capture. AC-DC converter is used to convert variable voltage from the DFIG to DC voltage, thereby producing DC power. The DC is converted back to AC that is appropriate for electrical utilizations in the grid. However, the use of converters introduces high intensity of low frequency current harmonic content into the power system. This leads to reduction in efficiency in WECS and also decreases the life span of the generator. A case study on a 9 MW wind turbine is used to explain Harmonic Mitigation in Wind Turbine Energy Conversion Systems. In this paper, harmonic voltage and current measurements performed at different points of a wind farm comprising six DFIG wind turbines are analyzed and their most important characteristics are discussed. It presents a comparative simulation study between with and without three phase harmonic filters applied to power system model connected to wind farm.*

Keywords: Harmonic Mitigation, Wind Energy Conversion systems, DFIG, Harmonic filters.

1. Introduction

The increasing demand of energy from the growing modern society has created a concern in the last few decades. This is made worse by the fact that most of the current energy sources are exhaustible

and depleting rapidly. Moreover, the combustion process of most of the current energy sources such as coal and fuel produces a high level of air pollution that fuels global warming, which is a currently emerging problem. These prompted the rapid development of many renewable energy sources over recent years, particularly the clean and pollution free wind energy that has an eligible rate of depletion. Thus, many efforts are dedicated to efficiently integrating wind energy into the current power system [1-2].

Power quality has also been a growing concern in recent years with many researches done in this area [3-4]. Harmonic emissions are recognized as a power quality problem for modern variable-speed wind turbines (WTs). For this reason, relevant standards [5] require the measurement of harmonics and their inclusion in the power quality certificates of WTs, and grid interconnection assessment procedures always comprise provisions for their control, [6]. Yet, although a vast number of wind power stations are already in operation worldwide, relatively scarce literature exists to provide field-measurement-based information on the expected harmonic emission levels of real machines or to analyze their characteristics [7-8]. Understanding the harmonic behavior of WTs is essential in order to analyze their effect on the grids where they are connected. Further, the statistical analysis of the harmonic emissions of individual WTs, presented in this paper, forms the

basis for a more thorough investigation of the important issue of the summation of harmonics in wind farms, which was preliminarily addressed in [9].

Power electronic devices usually inject harmonic and reactive current into the utility system. Harmonics increase power system losses, damage sensitive loads, cause excessive heating in rotating machinery, create significant interference with communication systems, and generate noise on regulating devices and control systems. Therefore, harmonic-compensation has become a major concern for power system specialists. Detection and precise extraction of the compensating signal are the most important parts of a grid connected converter's control [10-11]. In high power applications, the harmonic content of the output waveforms has to be reduced as much as possible in order to avoid distortion in the grid and to reach the maximum energy efficiency. On such applications, the thermal

losses in the power semiconductors limit the maximum switching frequency to a few hundreds of Hertz and multilevel converters are the most suitable power systems to be used. Many recent works with different multilevel converter topologies have been recently presented showing their good performance for high power applications [12-13].

In order to investigate and mitigate the harmonic content in the WECS; a 9 MW DFIG model was simulated and connected with power system model having voltages ranging from 220KV to 440V and three phase harmonic filters are connected to power system model at various busbars. The paper is divided into five sections. In Section 2, wind farm model using DFIG and power system model simulations are discussed. Harmonic filter models are discussed in Section 3 and results and discussions are presented in Section IV. Conclusions are outlined in Section 5 and references are shown in Section 6.

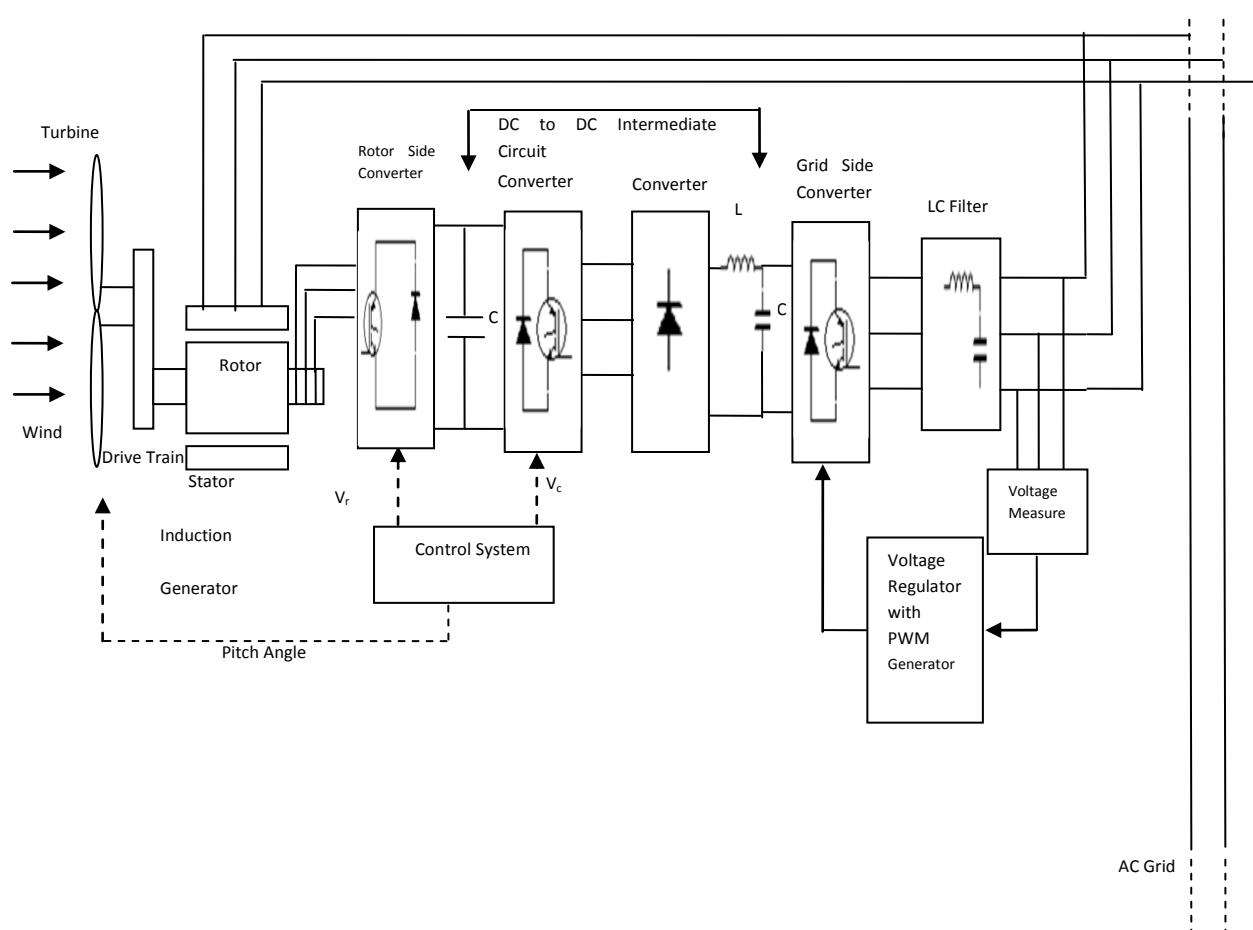


Fig. 1. Wind Energy Conversion System with DFIG and Controlled Efficient Power Electronic Interface

2. Power System Model Integrated with Wind Farm using DFIG

The WECS considered for analysis consist of a DFIG driven by a wind turbine, rotor side converter, DC to DC intermediate circuit and grid side converter. Fig.1 shows a schematic of the wind energy conversion system having DFIG and power electronic interface that will be discussed in this paper. The turbine output power is controlled in order to follow a pre-defined power-speed characteristic, named tracking characteristic. The electrical output power at the grid terminals of the wind turbine is added to the power losses and is compared with the reference power obtained from the tracking characteristic.

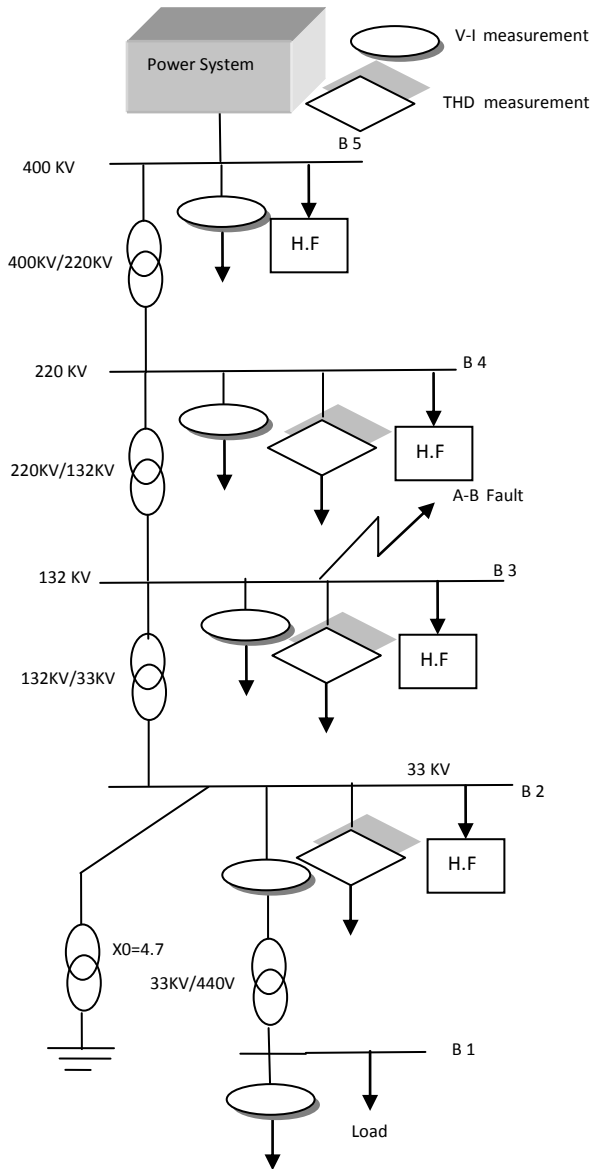


Fig. 2. Power System Model Considered

In rotor side converter system, AC voltage and VAR are regulated. DC to DC intermediate circuit consists of two converters: Converter 1 (DC to AC) and Converter 2 (AC to DC). The control system of DC to DC intermediate circuit consists of DC voltage and current regulation and pitch control system. The pitch angle is regulated at zero degree by pitch angle regulator until the speed reaches desired speed of the tracking characteristic. The DC voltage output from intermediate circuit is applied to grid side converter, which consists of an Insulated Gate Bipolar Transistor (IGBT) two-level inverter, generating AC voltage at 50 Hz. The IGBT inverter uses Pulse Width Modulation (PWM) at 2000 Hz carrier frequency.

A 9 MW wind farm consisting of six 1.5 MW wind turbines connected to 440V distribution system through power electronic interface. The wind speed is maintained constant at 15 m/s. The reactive power produced by the wind turbine is regulated at 0 MVAR. This model is well suited for observing harmonics and control system dynamic performance over relatively short periods of times. Fig.2 shows power system model used. The harmonic filters are connected to buses B1 to B4 as shown in Fig.2. A transient phase to phase to ground fault is simulated on B3 (as shown in Fig.1), which lasts for 3m secs.

3. Harmonic Mitigation by Harmonic Filters

Harmonic filters reduce distortion by diverting harmonic currents in low impedance paths. In order to achieve an acceptable distortion, several banks of filters of different types are usually connected in parallel. The total harmonic distortion (THD) can be calculated as follows [9]:

$$THD = \frac{I_{an}}{I_{a1}} \quad (1)$$

$$I_{an} = \sqrt{I_2^2 + I_3^2 + \dots + I_n^2} \quad (2)$$

where,

I_{an} Phase RMS of the n^{th} Component and

I_{a1} Fundamental Component of Phase RMS

The filter set is made of the following four components:

- One Capacitor Bank of 100 MVAR,
- One C-Type High-Pass Filter Tuned to 3rd harmonic of 100 MVAR,

-One Double-Tuned Filter to 11/13th harmonic of 100 MVAR and

-One High-Pass Filter Tuned to the 24th harmonic of 100 MVAR

The total MVAR rating of the filters set is then 400 MVAR. Fig.3 shows three phase harmonic filters connected to grid, which are used to improve power quality and reduce harmonic distortion. The entire harmonic filter set, 1st, 3rd, 11th/13th and 24th, are connected to bus B1 and B2. Harmonic filters 1st, 3rd and 11th/13th are connected to B3. Only harmonic filter 3rd is connected to B4. This is done because it is observed that connection of other harmonic filters i.e. 24th to B3 and 1st, 11th/13th and 24th to B4 distort the results or harmonic distortion is increased.

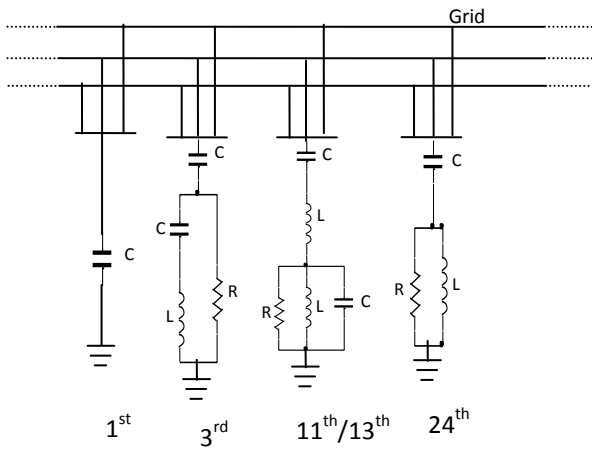


Fig. 3. Three Phase Harmonic Filters Considered

4. Results and Discussions

In this section the simulated results for the grid connection of three phase harmonic filters described above are presented. Two cases are considered to investigate the impact of harmonic filters on power grid connected with wind energy. One case (Case 1) is that harmonic filters are not connected to power grid and another case (Case 2) is taken as harmonic filters connected to AC power grid.

The comparison of magnitude of voltage THD having range 0-1 is presented in Fig.5-Fig.8. Table 1 shows the effect of adding harmonic filters in terms of voltage THDs in the existing integrated wind

energy power system model. The %reduction in peak value of voltage THD with harmonic filters at busbar locations B1, B2, B3 and B4 are 80%, 80.36%, 90% and -0.8% respectively. Thus reduction in THD is significant at B1, B2 and B3. Although peak value of voltage THD rises at B4, but it is clear from Fig.8 that values of voltage THD is less in Case 2 as compared to Case 1 at other times. Table 2 presents the effect of adding harmonic filters in terms of current THDs in the existing integrated wind energy power system model. The %reduction in peak value of current THD with harmonic filters at busbar locations B1, B2, B3 and B4 are 76.5%, 35.5%, 28.6% and 95.7% respectively. The peak value at B4 with harmonic filters increase or % reduction is -0.8% because as we keep on adding harmonic filters in power system starting from lowest voltage, a stage will come when it will cause increase in harmonic level.

Table1: Effect of Adding Harmonic Filters in Terms of Voltage THDs

Busbar Location / Voltage THD	Peak Value Without Harmonic Filters	Peak Value With Harmonic Filters	% Reduction
B1	0.8	0.16	80%
B2	0.82	0.161	80.36%
B3	1.5	0.15	90%
B4	0.253	0.255	-0.8%

Table 2: Effect of Adding Harmonic Filters in Terms of Current THDs

Busbar Location/ Current THD	Peak Value Without Harmonic Filters	Peak Value With Harmonic Filters	% Reduction
B1	0.98	0.23	76.5%
B2	0.4	0.258	35.5%
B3	0.7	0.5	28.6%
B4	3.5	0.15	95.7%

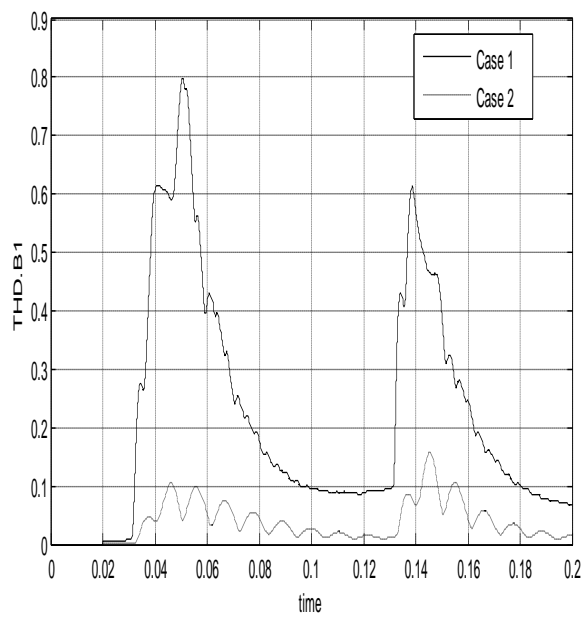


Fig. 5. Comparison of Voltage THD at Bus B1

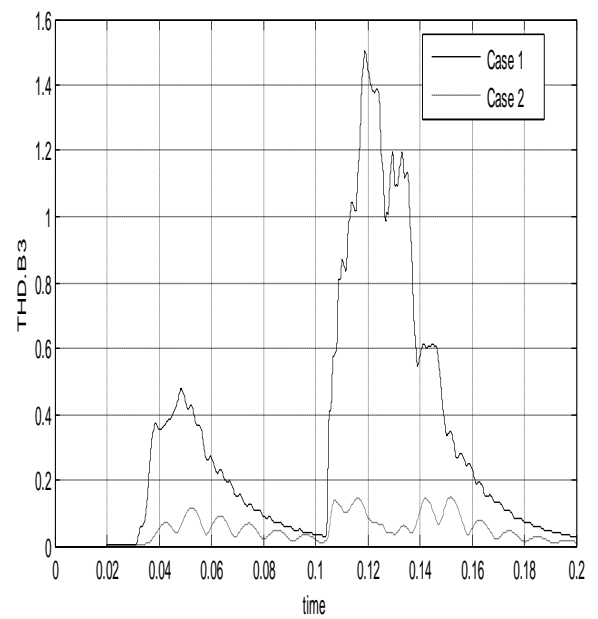


Fig. 7. Comparison of Voltage THD at Bus B3

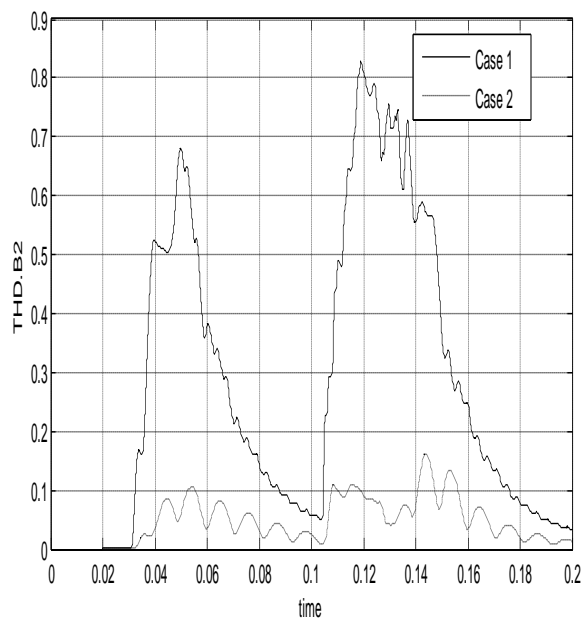


Fig. 6. Comparison of Voltage THD at Bus B2

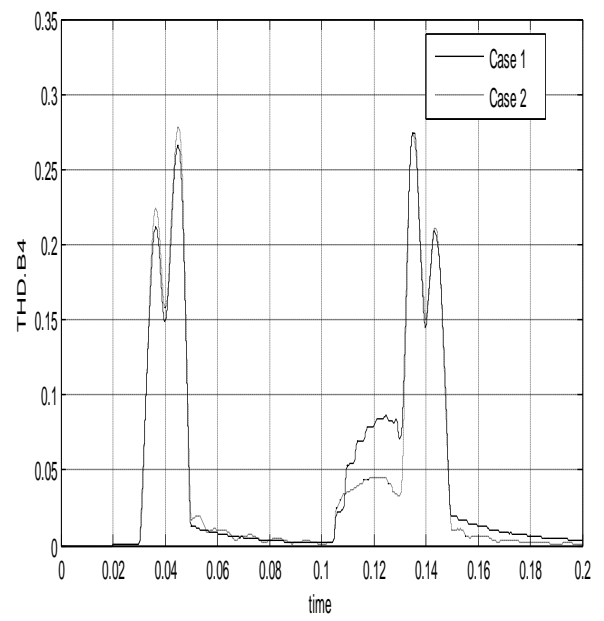


Fig. 8. Comparison of Voltage THD at Bus B4

5. Conclusions

Harmonics analysis is an essential part of the grid impact studies needed for new wind farms. That can lead to the earlier detection of potential series and parallel resonance problems. Consequently, a harmonics mitigation solution is examined in this paper. The simulated results on transients of a power system grid integrated with wind power are presented. In this paper, we attempted to compare the impact, in terms of voltage THDs and currents THDs, of adding three phase harmonic filters to wind integrated power system consisting of DFIG. Two different cases are considered examining the influence of adding harmonic filters. The results have clearly demonstrated the ability of harmonic filters to reduce transients and harmonic distortion in power system. It has been proven that with the inclusion of harmonic filters THD reduces noticeably and hence power quality improves significantly.

6. References

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