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Improving Power quality by Fed DFIG Converter with Various Switching Techniques

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***Abstract*— In this paper, an integrated system of wind farm based on doubly fed induction generators (DFIGs) is modeled and simulated in Matlab/Simulink environment. To connect the wind farm based on DFIGs to the electrical grid, the grid code requirements should be achieved and as a result of the use of back-to-back converter interfacing the rotor winding with the grid causes harmonic distortion for voltage and current of this generator. Therefore, the waveforms of voltage and current of DFIG wind farm are investigated and improved from view point of power quality at all wind speeds using two different topologies of back-to-back converter connecting the rotor with the grid, namely two-level and three-level neutral point clamped (NPC), and also using several types of switching techniques including third-harmonic injection carrier-based PWM (THIPWM), offset addition carrier-based PWM (OAPWM), flat top carrier-based PWM (FTPWM) and space vector modulation (SVM). On comparison with Simple PWM, the switching techniques of THIPWM, OAPWM, FTPWM and SVM have many advantages such as lower total harmonic distortion (THD), minimal number of switching to decrease switching losses and the output fundamental voltage is increased. All of these systems are compared from view point of power quality and the limits of IEEE 519 standard are taken into account.**

***Index Terms*—** Doubly fed induction generator (DFIG), switching techniques of THIPWM, OAPWM, FTPWM and SVM, total harmonic distortion (THD).

I. Introduction

According to the numbers and studies dealing with start entering the circle of running out of conventional energy and fossil fuels of petroleum and its derivatives, and due to the increasing of CO2 emissions, the frantic search comes by countries and companies, scientists and researchers to obtain so-called "alternative energy", or renewable and clean energy. It is energy available, durable and low cost, risk and damage, what keeps the economy and the purity of the earth and the human life. Wind power is the fastest growing renewable energy source. It is forecasted that the cumulative wind capacity growth rate will be between 11% - 16% and the cumulative installed wind capacity will reach about 666 GW in the 2019.According to the global wind energy outlook, by green peace international and the global wind energy council (GWEC), wind energy could provide between 17-19% of global electricity by 2030 and 25-30% by 2050, [1].

Nowadays, the variable-speed wind turbines based on doubly fed induction generators are the most widely used technology for wind farms due to some advantages such as the rating of the power electronic converter is only 25–30% of the generator capacity, which makes this concept attractive and popular from an economic point of view, reduced losses with an improved efficiency, does not need either a soft starter or a reactive power compensator, and the stator active and reactive power can be controlled independently in four quadrants, [2].

Power Converters are widely used in wind energy conversion systems (WECS). In fixed-speed WECS, the converters are used to reduce inrush current and torque oscillations during the system start-up, whereas in variable-speed WECS they are employed to control the speed/torque of the generator and also the active/reactive power to the grid [3].

The converter switching concepts are an important part of the control structure in variable-speed WECS. It should provide features like, [2], Wide range of linear operation, increase DC voltage utilization (higher output voltage), low content of higher harmonics in voltage and current, low frequency harmonics, operation in over-modulation, Reduction of generated common mode voltage, minimal number of switching to decrease switching losses.

This paper investigate several techniques of switching to be applied for the gate of the IGBTs of back-to-back converter of doubly fed induction generator (DFIG) such as carrier-based sinusoidal PWM (SPWM), [4], third-harmonic injection carrier-based PWM (THIPWM), [5], offset addition carrier-based PWM (OAPWM), [3], flat top carrier-based PWM (FTPWM) and space vector modulation (SVM), [6-8]. Also two different converter topologies, namely two-level and three-level NPC converters are presented in this paper. These converter topologies with proposed switching techniques are carried out and simulated in Matlab/Simulink to be used with DFIG wind power system, [9]. And, the focus on the harmonics problem in voltage and current caused by partial scale frequency converter interfacing the rotor with the grid. In this way, the quality of power generated by DFIG wind system is improved by varying switching techniques and topologies of

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this converter to obtain the THD of current and voltage at the point of common coupling (PCC) within the limit of IEEE 519 standard which is 5 % for voltage and 12 % for current.

II. DFIG Wind Energy

The simplified circuit diagram for the system is illustrat in Fig. 1. The converter has been widely used in industry for many different applications. Whether it serves as an inverter or its DC rectifier, the power flow in the converter circuit is bidirectional: the power can flow from side to the AC side, and vice versa. In DFIG wind energy system, the rotor connection to the grid is done through power converters and harmonic filters. The stator of the generator delivers power from the wind turbine to the grid and, therefore, the power flow is unidirectional. However, the power flow in the rotor circuit is bidirectional, depending on the operating conditions. The power can be delivered from the rotor to the grid and vice versa through rotor-side converter (RSC) and grid-side converter (GSC).

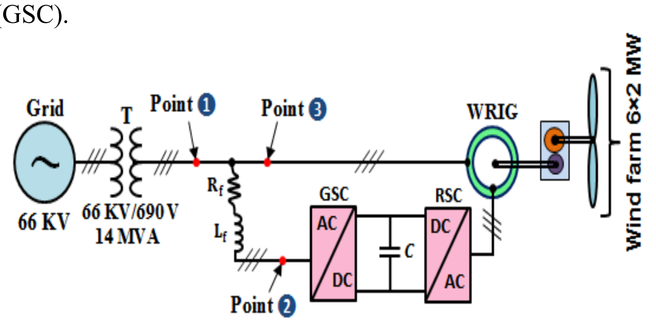


Fig. 1: DFIG wind farm measurement points.

III. Investigation System

When the wind speed changes, the rotor speed will change, and hence the rotor injection frequency should also be adjusted. A key requirement of a DFIG is to have its three-phase rotor circuit injected with a voltage at a controllable frequency and magnitude. This three-phase ac voltage can be synthesized using various switching techniques, including SWPM, THIPWM, OAPWM, FTPWM and SVPWM.

In this paper, the harmonic content is reduced using three-level NPC topology with varying switching techniques of semiconductor devices for converter connected with DFIG wind power system.

On comparison with simple PWM, the switching techniques of THIPWM, OAPWM, FTPWM and SVPWM have many advantages: wide linear modulation range, less switching loss, and lower THD.

IV. Simulation Results

In the following case studies two-level and three-level NPC, and using five types of switching techniques, to improve the waveforms quality of voltages and currents of DFIG wind farm are evaluated at all wind speeds using two different topologies of back-to-back converter connecting the rotor with the grid, namely two-level and three-level NPC, and also using five types of switching techniques. These switching techniques are SWPM, THIPWM, OAPWM, FTPWM and SVM. The value of current and voltage THD (phase a) is taken at three points for wind farm using Matlab/Simulink tool of Fast Fourier Transform (FFT). The measurement points are shown in Fig. 1. The three points are as the following:

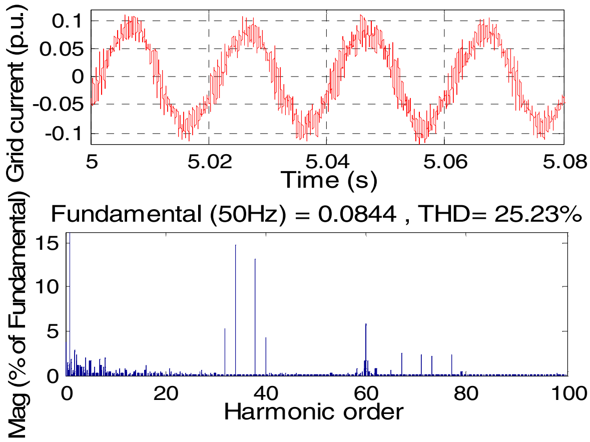
- Point 1, for the measurement of fundamental and THD for grid voltage and current at low side of transformer (PCC).
- Point 2, for the measurement of fundamental and THD for AC GSC voltage and current.
- Point 3, for the measurement of fundamental and THD for stator current.

The harmonics analysis considers a steady state operation under 10 cases during the wind speeds of 5, and 12 m/sec.

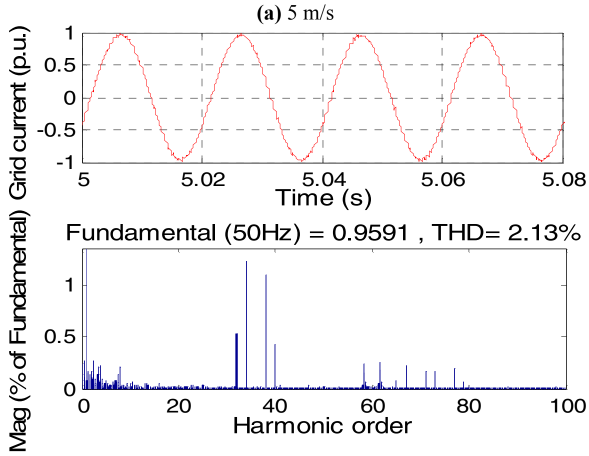
A. Case (1)

This case study the performance of the DFIG wind farm shown in Fig. 1 from point of view of waveforms quality using two-level topology with FTPWM switching technique for GSC and RSC. Figure 2 a and b display grid current and its harmonic spectrum, also Figure 3 a and b show grid voltage and its harmonic spectrum.

Figure 4 show stator current and its harmonic spectrum. However, Figs. 5 show GSC AC current and its harmonic spectrum, also Figs. 6 show GSC AC voltage and its harmonic spectrum.

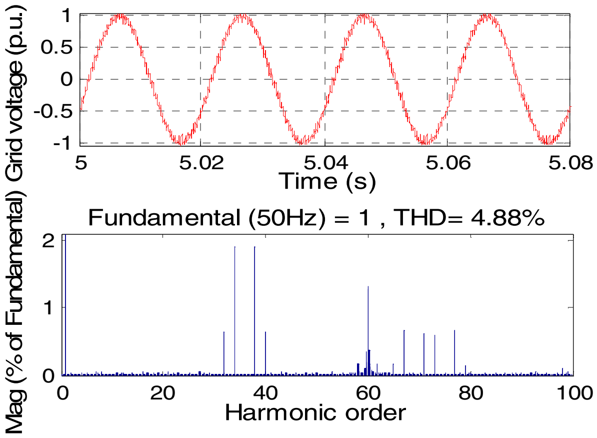


(a) 5 m/s

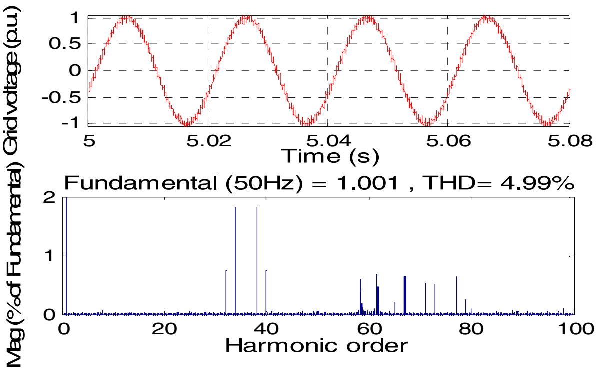


(b) 12 m/s

Fig. 2: Grid current and its harmonic spectrum for two-level FTPWM at wind speed

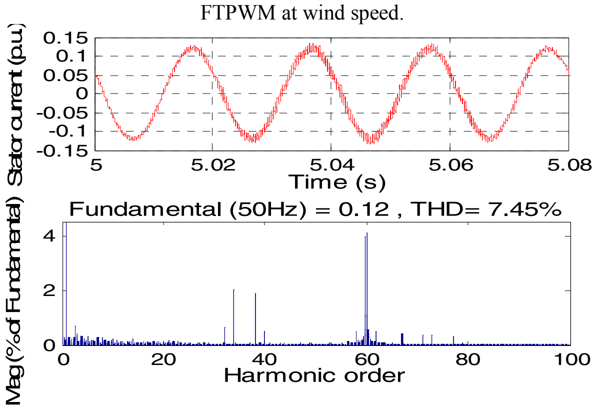


(a) 5 m/s

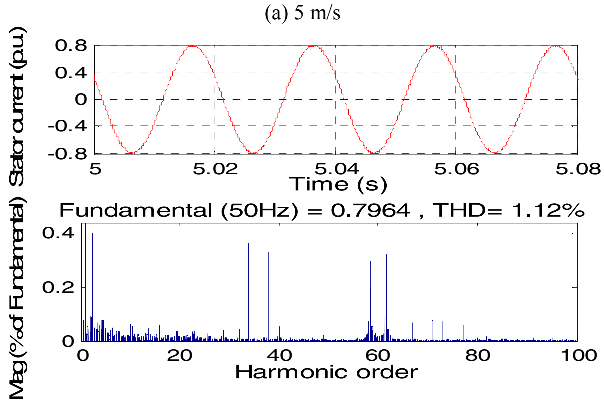


(b) 12 m/s

Fig. 3: Grid voltage and its harmonic spectrum for two-level FTPWM at wind speed.

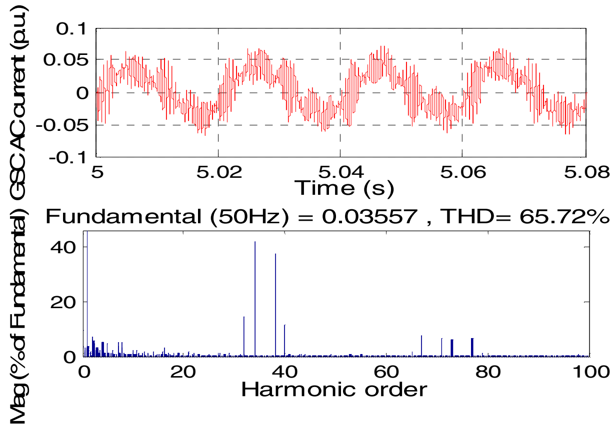


(a) 5 m/s

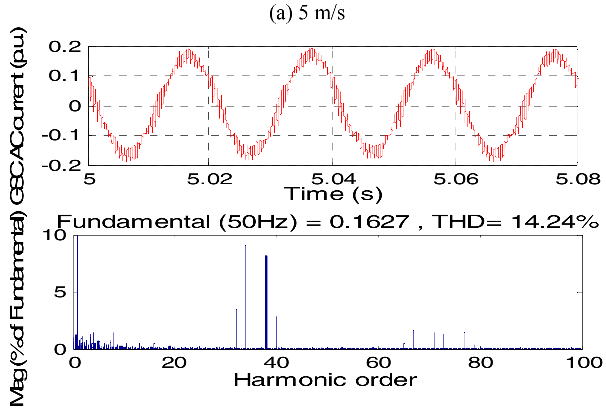


(b) 12 m/s

Fig. 4: Stator current and its harmonic spectrum for two-level FTPWM converter at wind speed.

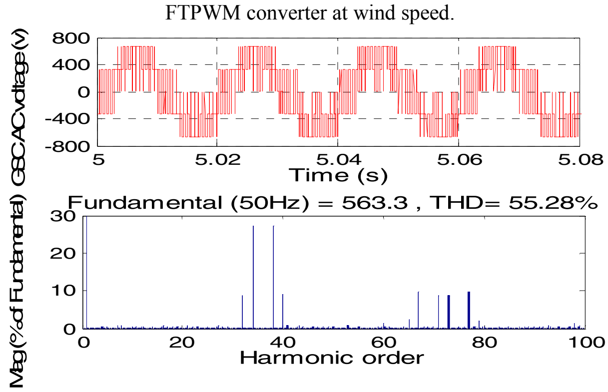


(a) 5 m/s

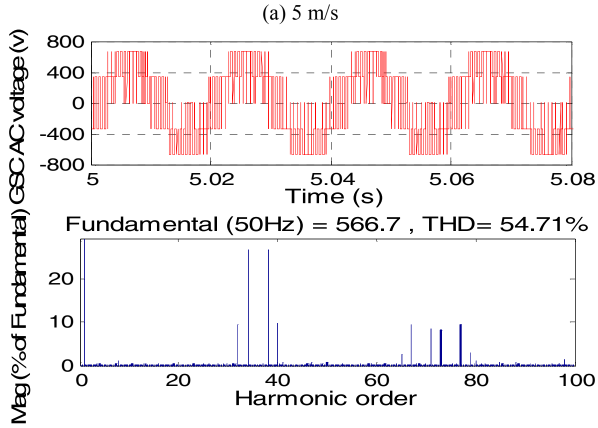


(b) 12 m/s

Fig. 5: GSC AC current and its harmonic spectrum for two-level FTPWM converter at wind speed.



(a) 5 m/s

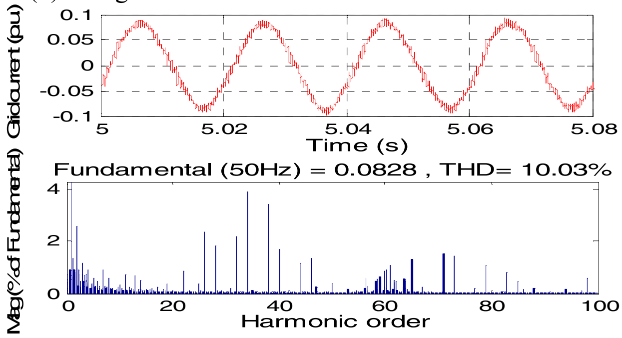


(b) 12 m/s

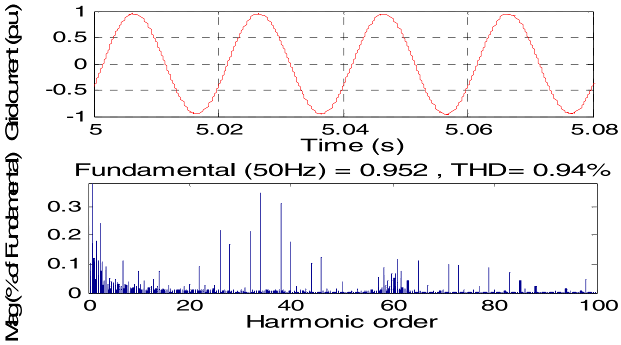
Fig. 6: GSC AC voltage and its harmonic spectrum for two-level FTPWM converter at wind speed

B. Case (2)

This case investigates the performance of the DFIG wind farm shown in Fig. 1 from point of view of waveforms quality using three-level topology with SVPWM switching technique for GSC and RSC. The same results in case (1) are repeated for case (2) in Figs. 7 to 11.

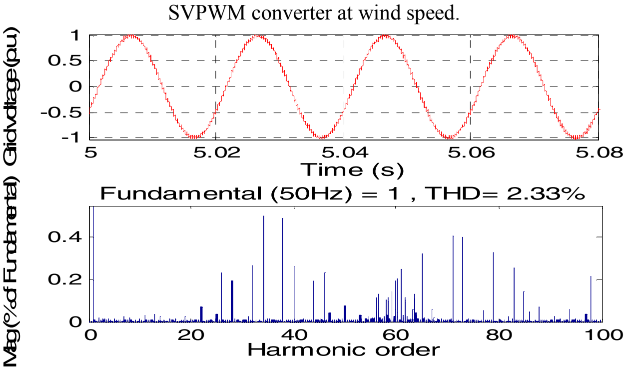


(a) 5 m/s

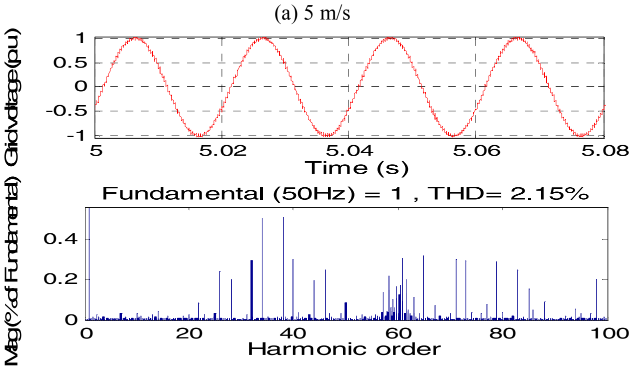


(b) 12 m/s

Fig. 7: Grid current and its harmonic spectrum for three-level SVPWM converter at wind speed.

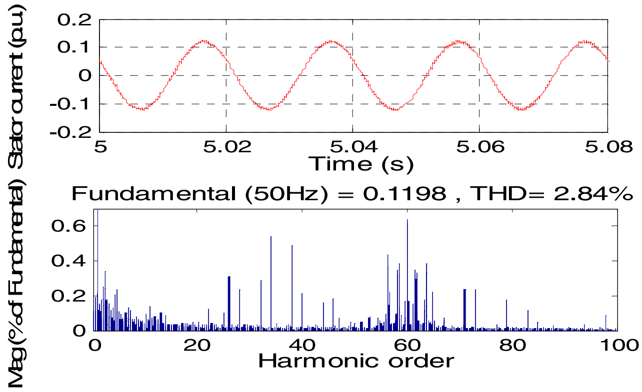


(a) 5 m/s

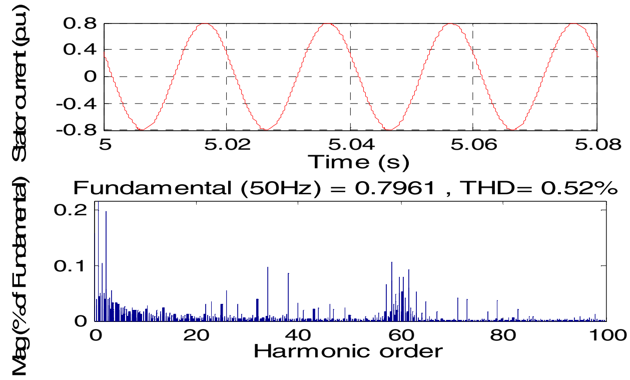


(b) 12 m/s

Fig. 8: Grid voltage and its harmonic spectrum for three-level SVPWM converter at wind speed.

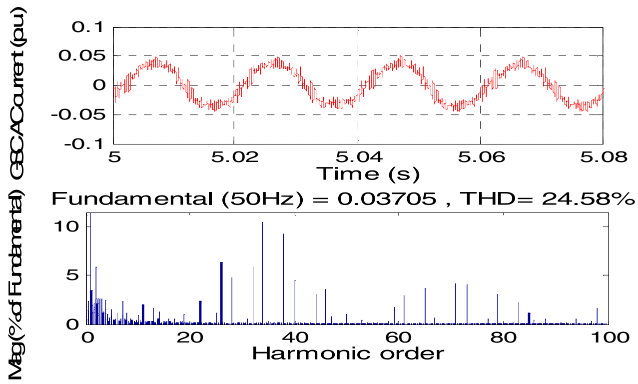


(a) 5 m/s

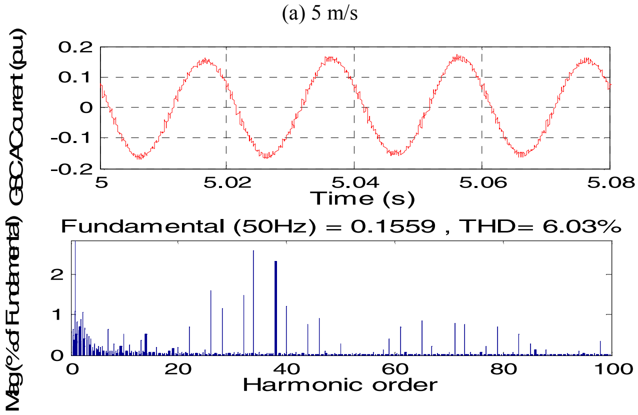


(b) 12 m/s

Fig. 9: Stator current and its harmonic spectrum for three-level SVPWM converter at wind speed.

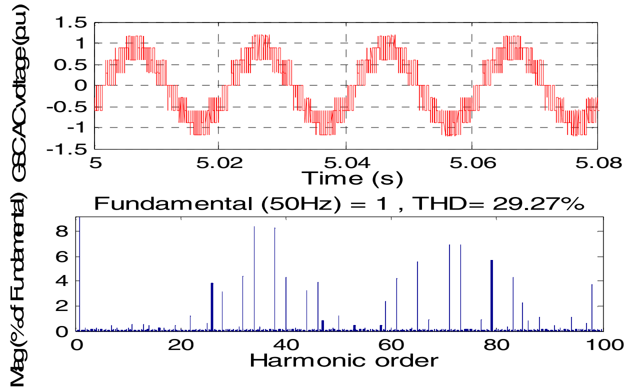


(a) 5 m/s

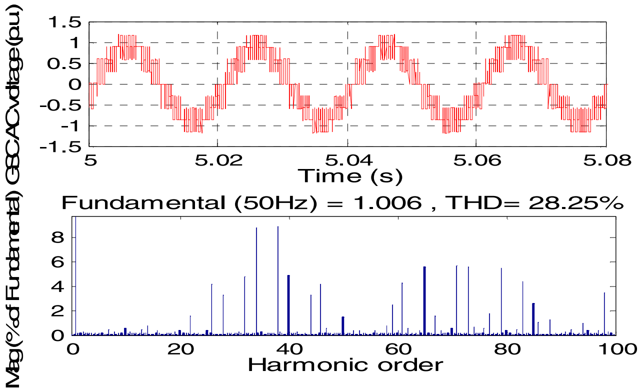


(b) 12 m/s

Fig. 10: GSC AC current and its harmonic spectrum for three-level SVPWM converter at wind speed.



(a) 5 m/s



(b) 12 m/s

Fig. 11: GSC AC voltage and its harmonic spectrum for three-level SVPWM converter at wind speed.

V. Comparative Evaluation at Various Switching Techniques

Figures 12 and 13 show comparison of THD for grid current and voltage respectively between two-level and three-level topologies of converter connected to DFIG wind system with various switching techniques at all wind speeds. It is noted that two-level PWM for GSC and RSC produces the highest THD of grid current and voltage while three-level SVPWM for GSC and RSC produces the lowest THD of grid current and voltage at all operating points. The harmonic content decreases by changing switching techniques and converter topologies. For example, at sub-synchronous speed 0.7061 p.u corresponding to wind speed 5 m/sec, the THD of grid current decreases from 29.08% for two-level PWM to 10.03% for three-level SVPWM, while the THD of grid voltage decreases from 6.22% for two-level PWM to 2.33% for three-level SVPWM. This is roughly a 65% decrease in grid current harmonics and 62% decrease in grid voltage harmonics. Also, at super-synchronous speed 1.21 p.u corresponding to wind speed 12 m/sec, the THD of grid current decreases from 2.37% for two-level PWM to 0.94% for three-level SVPWM, while the THD of grid voltage decreases from 6% for two-level PWM to 2.15% for three-level SVPWM. This is roughly a 60% decrease in grid current harmonics and 64% decrease in grid voltage harmonics. The generation of grid current harmonics decreases with increasing rotor speed (i.e., increasing wind speed) as shown in Fig. 12, where by increasing rotor speed, the magnitude of grid current increases. Using either OAPWM or THIPWM or SVPWM with three level topology for GSC and RSC generates less current and voltage THD at all operating points which is still lower than 5% limit for grid voltage and 12% limit for grid current required by IEEE 519 standard. Fig. 13 show the comparison of grid voltage THD at all wind speeds.

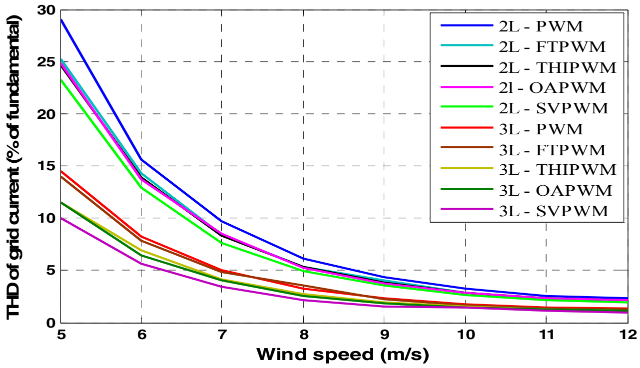


Fig. 12: Comparison of grid current THD at all wind speeds.

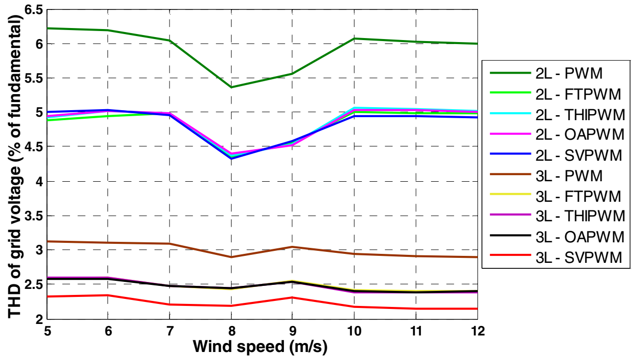


Fig. 13: Comparison of grid voltage THD at all wind speeds.

Figures 14 and 15 show comparison of THD for AC GSC current and voltage respectively between two-level and three-level topologies of converter connected to DFIG wind system with various switching techniques at all wind speeds. As it is clear that, for example, at wind speed 8 m/sec, the THD of AC GSC current decreases from 139.52% for two-level PWM to 45.27% for three-level SVPWM, while the THD of AC GSC voltage decreases from 71.29% for two-level PWM to 29.14% for three-level SVPWM. This is roughly a 67% decrease in AC GSC current harmonics and 59% decrease in AC GSC voltage harmonics.

Figure 16 shows comparison of THD for stator current between two-level and three-level topologies of converter connected to DFIG wind system with various switching techniques at all wind speeds. It is noted that the harmonic content of stator current decreases by changing switching techniques and converter topologies. For example, at sub-synchronous speed 0.7061 p.u corresponding to wind speed 5 m/sec, the THD of stator current decreases from 8.28% for two-level PWM to 2.84% for three-level SVPWM. This is roughly a 65% decrease in stator current harmonics. While at super-synchronous speed 1.21 p.u corresponding to wind speed 12 m/sec, the THD of stator current decreases from 1.29% for two-level PWM to 0.52% for three-level SVPWM, This is roughly a 59% decrease in stator current harmonics.

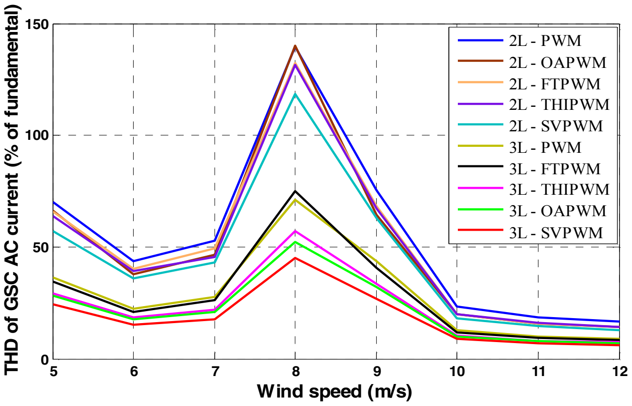


Fig. 14: Comparison of GSC AC current THD at all wind speeds.

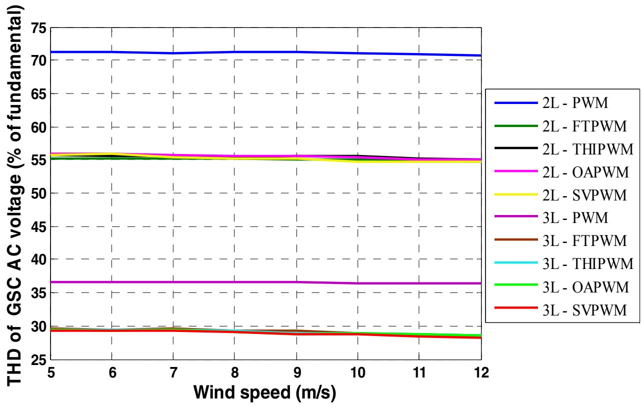


Fig. 15: Comparison of GSC AC voltage THD at all wind speeds.

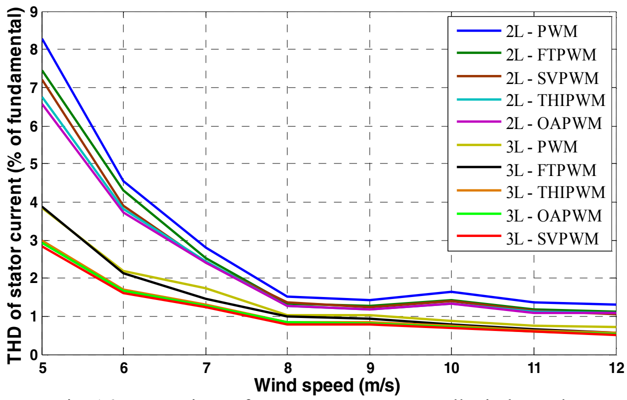


Fig. 16: comparison of stator current THD at all wind speeds.

VI. Conclusion

In this paper, an integrated system of wind farm based on DFIGs has been carried out and simulated in Matlab/Simulink environment. Two-level PWM for GSC and RSC produces the highest THD of grid current and voltage while three-level SVM for GSC and RSC produces the lowest THD of grid current and voltage at all operating points. The harmonic content decreases by changing switching techniques and converter topologies. Also, at super-synchronous speed 1.21 p.u corresponding to wind speed 12 m/sec, the THD of grid current decreases from 2.37% for two-level PWM to 0.94% for three-level SVM, while the THD of grid voltage decreases from 6% for two-level PWM to 2.15% for three-level SVM. This is roughly a 60% decrease in grid current harmonics and 64% decrease in grid voltage harmonics. The generation of grid current harmonics decreases with increasing rotor speed (i.e., increasing wind speed), where by increasing rotor speed, and the magnitude of grid current increases. Using either OAPWM or THIPWM or SVM with three level topology for GSC and RSC generates less current and voltage THD at all operating points which is still lower than 5% limit for grid voltage and 12% limit for grid current required by IEEE 519 standard.

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