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Research Article

Grid Connected Wind Energy Conversions System Performance is Improved by Switching of Shunt Active Filter

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Abstract: This study presents a Grid connected Wind Energy Conversions System (WECS) where performance is improved by switching of Shunt Active Filter. Shunt active filter for non linear loads is designed to minimize the harmonics present in the wind power system. Due to large penetration of power electronic controllers in the wind power applications, switching of these power electronic circuits induces harmonics in the source which causes undesirable effects on the wind energy conversion systems and the electrical components which is in the power system network. Shunt active filter is a harmonic mitigating device comprising of voltage source inverter fed through a DC capacitor. The control strategy is based on extraction of harmonics using synchronous reference frame theory. The major contributions of this study is to extract harmonics from the grid connected Wind Energy Conversion Systems (WECS) by generating the PWM signals using the Space Vector Pulse Width Modulation (SVPWM) to control the Voltage Source Inverter (VSI) which has reduced the losses. The proposed method has been simulated and validated using MATLAB/SIMULINK. The end result of the proposed system shows that the Total Harmonic Distortion (THD) of the grid connected wind generator has been reduced at the Point of Common Coupling (PCC).

Keywords: Harmonic extraction, Point of Common Coupling (PCC), Wind Energy Conversion Systems (WECS)

INTRODUCTION

Wind power is one kind of inexhaustible and harmless energy source in the world. The wind power has increasingly caught worldwide attention because of economic and environmental protection. Power quality and supply reliability are fast becoming recognized as important factors for successful modern wind power business. New requirement is that the Wind Energy Conversion System (WECS) has to provide increased penetration level of wind farms highlighting grid integration, the grid integration concerns including power systems stability, Power Quality (PQ), protection and dynamic interactions of the wind power units in a wind farm (De Araujo Ribeiro *et al*., 2012; Strachan and Jovcic, 2002; Abreu and Shahidehpour, 2006). With the increase in non linear loads in the power system, the quality of power delivered to the load is getting distorted because of the use of large number of power electronic switches which are used to control these non linear loads. The quality of power delivered by Wind Energy Conversion System directly affects the electrical utilities and the losses in these systems are increased due to the distorted power. The various power quality issues in the grid connected systems are voltage sag, swell, spike, flicker and harmonics. Many solutions have provided to improve the quality of power delivered to the load (De Araujo Ribeiro *et al*., 2012).

Harmonics present in the system can be reduced by adding active filters or passive filters. Passive filters are designed by using inductors and capacitors which can be connected in series, shunt or hybrid. Passive filters always eliminate the harmonics in a particular order for which it is tuned and the other harmonics remain the system. The Passive filters make the system bulky and cause resonance with other circuit elements in the same network. To overcome these resonances drawbacks active filters have been introduced in the power system (Koochaki *et al*., 2007; Wang *et al*., 2004).

The active filters can be developed to eliminate harmonics of any order and compensates both voltage harmonics and current harmonics present in the system. The series active filter and shunt active filter are the two types of active filters used for the system. The series active filter is used to compensate the voltage related harmonics and the shunt active filter is used for the elimination of current related harmonics present in the system (Hirofumi, 1996; Wang *et al*., 1993). Harmonics of any order are compensated using shunt active filter which comprises of a Voltage Source Inverter (VSI) fed by a DC source. The shunt active filter comprises of two main stages, the first stage is the harmonics detection by

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means of a suitable technique and the second stage is the generation of Pulse Width Modulation (PWM) signals to control the VSI circuit. The harmonics present in the source are extracted from the fundamental component by means of different techniques (Yunus and Bass, 1996; Hayashi *et al*., 1991). In this study the synchronous reference frame theory technique is used for harmonic detection from the fundamental component of the sinusoidal signal of the source. The extracted harmonics are separated from the fundamental component of the sinusoidal signal of the source by means of a high pass filter. With reference to harmonics, compensation signals are generated by the voltage source inverter. For the control of compensation signals in the VSI, the PWM signals have to be generated accordingly.

There are different techniques that are used for the generation of PWM signals (Viswanath and Kapoor, 2010). In this study, the PWM signals are generated using SVPWM technique and thus by increasing the modulation index and reduced harmonics by better switching of the VSI. The proposed method is used for the compensation of harmonics instantaneously within the wind farm by developing a shunt active filter which has been controlled by VSI with SVPWM technique.

SHUNT ACTIVE FILTER

Shunt Active Power filter is used to inject a compensation current in opposite direction to the harmonics and to cancel the harmonics at the Point of Common Coupling (PCC). Shunt active filters act as a current controlled voltage source which is normally designed using PWM voltage source inverters. It is used in the compensation of high power non linear loads. The efficiency of shunt active filter depends on the error that is computed and the time delay needed to compensate the I_{ABC_S} represents the source current and $V_{ABC'S}$ represents the source voltage of three phases. The active filter is connected to the lines through coupling reactors (Routimo *et al*., 2007; Vodyakho and Mi, 2009; Ahmet *et al*., 2011). The coupling inductor is used to reduce the current harmonics generated by the inverter and the capacitor keeps the dc voltage ripple factor low.

METHOD OF HARMONIC DETECTION

The shunt active filter must calculate the reference current for each phase of the non linear load, the DC bus voltage must be maintained constantly and appropriate gating signals has to be generated by the control circuit according to the error signal that is being generated. The compensation of the harmonics can be done in time domain or frequency domain. There are many methods proposed for the detection of harmonics present in the system in time domain, such as the instantaneous reactive power theory as proposed by Akagi, the synchronous detection method, the synchronous reference frame theory which is used for harmonic detection in this study. In Synchronous reference frame there are less current measurement devices (Kesler and Ozdemir, 2011; Ozdemir *et al*., 2007). This method is distorted load current. The shunt active filter is designed using a six leg voltage source inverter built using IGBT. The capacitor acts as a DC source for the VSI. Figure 1 shows the shunt active filter in which I_{ABC_L} represents the load current in the three phases; I_{ABC_AF} represents the active filter compensation current injected by the VSI:

$$IL_{\alpha} = 0.816 * (I_a - 0.5\, I_b - 0.5\, I_c) \quad (1)$$

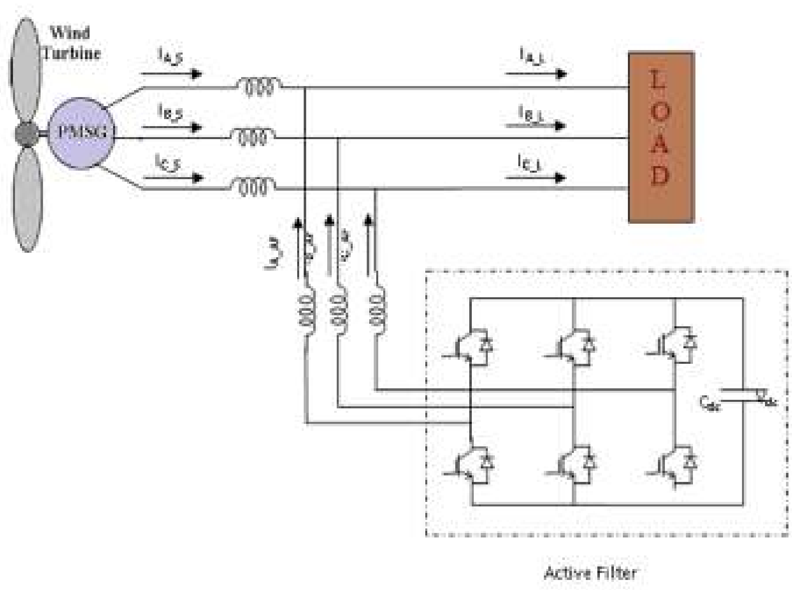

Fig. 1: Shunt active filter connected with PCC

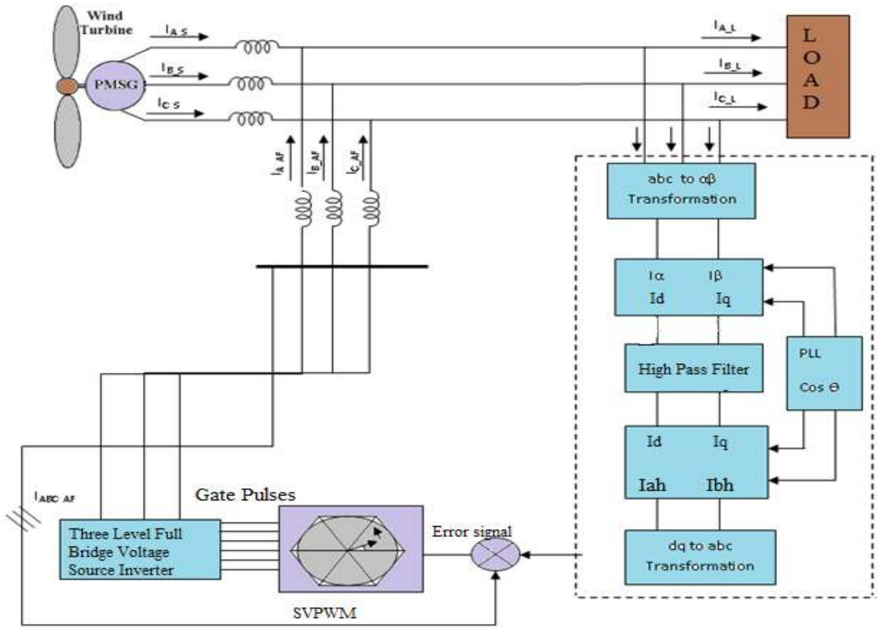

Fig. 2: Extraction of harmonics from PCC and SVPWM based switching of inverter

$$IL_{\beta} = 0.816 * (0.866\, I_b - 0.866\; I_c) \quad (2)$$

$$IL_0 = 0.816\; * (\, 0.707\, I_a + 0.707\, I_b + 0.707\, I_c) \quad (3)$$

The three phase distorted currents I_a, I_b, I_c are sensed and converted into stationary coordinates IL_{α}, IL_{β}, IL_0 components as shown in Eq. (1) to (3). The β, 0 represents the transformation to the stationary reference from the abc reference frame:

$$IL_d = \cos(\,2\,\pi f t * IL\alpha)\; + \sin\,\left(2\pi f t * IL_{\beta}\right) \quad (4)$$

$$IL_q = -\sin(\,2\pi f t *\; IL_{\alpha}) + \cos\,(2\pi f t *\; IL_{\beta}) \quad (5)$$

$$I_{ah} =\; Cos(2\pi f t *\; IL_d) -\; \sin\,(2\pi f t * ILq) \quad (6)$$

$$I_{bh} = \sin\;(2\pi f t * IL_d) +\; \cos\left(2\pi f t * IL_q\right) \quad (7)$$

The stationary reference frame quantities are transformed into synchronously rotating reference frame using cosine and sine function as shown in Eq. (4) and (5). The components IL_d and IL_q represent the direct and quadrature component of the distorted current. The d-q component rotates synchronously with the supply voltage. The 'd' coordinate corresponds to the positive sequence current and the 'q' component corresponds to the negative sequence and '0' represents the zero sequence components.

The harmonic component of the current which is in the synchronously rotating reference frame is transformed in to stationary reference frame as given in Eq. (6) and (7):

$$I_{ca} =\; 0.816\;\; (I_{ah} + 0.707\, IL_0\,) \quad (8)$$

$$I_{cb} =\;\; 0.816\;\; (-0.5\, I_{ah} + 0.866\;\, I_{bh} + 0.707\, IL0 \quad (9)$$

$$Icc =\; 0.816\;\; (-0.5\, I_{ah} -\; 0.866\, I_{bh} + 0.707\, IL0 \quad (10)$$

The currents IL_d and IL_q comprises of average component and the oscillating component of the currents. The oscillating components of the currents has to be separated by using a high pass filter which filters out the average sequence component of the current and passes the oscillating component of the current. The high pass filter passes only the harmonic components of the current.

The currents in two phase coordinates are transformed into three phase coordinates as given in the Eq. (8) and (10). The current in the three phase coordinates represents the extracted harmonic content of the supply currents and the current to be injected depends upon the difference between the harmonic content of the signal and the injected current of the active filter. The Extraction of Harmonics from PCC and SVPWM Based Switching of Inverter is shown in Fig. 2.

SWITCHING OF THE INVERTER CIRCUIT

The output of the VSI can be controlled by adjusting the switching operation of the inverter circuit. In SVPWM technique the three phase reference currents has picked up by the synchronous reference frame method to extract the harmonics is fed as input to the SVPWM. The active filter has to produce the

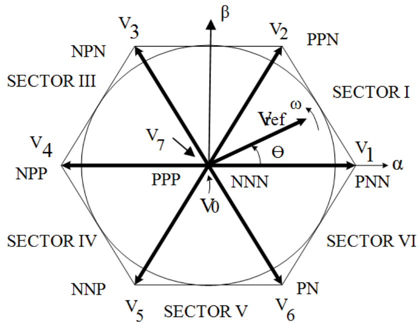

Fig. 3: Switching vectors of SVPWM

signals in opposite direction to the harmonic component of the load current. The output frequency and amplitude can be controlled with least harmonic distortion by this method. The modulation index can be increased by 16% without achieving over modulation. Using SVPWM technique the DC voltage applied to the inverter circuit can be minimized and the size of capacitor can be reduced considerably. In this study, the modulation index is set to unity. The output of SVPWM is connected to a discrete PWM signal generator to produce the required PWM signals for the VSI.

The reference currents available in three phases are converted into two phase coordinates which represents the vector sum of the three phase voltages:

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos 0 & \cos\frac{2\pi}{3} & \cos\frac{4\pi}{3} \\ \sin 0 & \sin\frac{2\pi}{3} & \sin\frac{4\pi}{3} \end{bmatrix}\begin{bmatrix} v_{AO} \\ v_{BO} \\ v_{CO} \end{bmatrix} \quad (11)$$

The conversion from three phases to two phase coordinates is given in Eq. (11). The inverter used is a Three Level Full Bridge (TLFB) inverter which has three arms and six switches. The SVPWM technique generates eight different voltage reference signals for the switching of the inverters. The space vector is divided in to six non zero vectors and it has separated from each other by an angle of 60°. Two zero vectors are placed at the origin. V_{ref} is obtained by the vector combination of two adjacent non zero vectors and the zero vectors.

Bidirectional switches are used for the inverter and can be switched ON or OFF. Each leg of the TLFB inverter has two switches one at the upper and other at the lower. If upper switch is ON, it is marked as P and if the lower switch is ON, it is marked as N. There are three legs so that eight combinations are possible. By using the eight states the PWM signal is generated in such a manner that average variation in one phase will be sinusoidal. If all the upper switches are ON or if all the lower switches are ON then these two states are called as zero state vectors. All active states can produce non zero output voltage. PWM operation has one out of eight states and the average voltage space vector will trace a circle. The hexagonal shape of the Fig. 3 shows the Switching Vectors of SVPWM, the radii of the hexagon is equal to voltage space structure for two level inverter, in this all the six active voltage vectors lie along the radii of the hexagon. The amplitude of the average variation for rotating voltage space vector is:

$$Vdc * Cos\, 30 = 0.686\, Vdc \quad (12)$$

V_{ref} has obtained by a combination of the switching patterns V_0 to V_7. In SVPWM the fundamental component moving at constant frequency is taken as a sinusoidal signal. The three phase vector in phase variable form is transformed in to two axes and the rotating reference voltage space vector V_s is at high sampling frequencies. The magnitude of V_s can be computed by computing the component of V_s along α and β axis as shown in Eq. (13) to (15), multiplied by the sampling period (Ts) and this should be equal to the volt second of the sectors NNN, PNN, PPN and PPP. T_0 is the total switching time for a sector; T_1 and T_2 are the ON time for the vectors V_1 and V_2:

$$T_0 = Ts - (T_1 + T_2) \quad (13)$$

Volt-Second along α axis is:

$$V_1T_1 + (V_2 \cos 60°)\ T2 = Vs\ Ts \cos\alpha \quad (14)$$

Volt second along β axis is:

$$0 + (V_2 \sin 60°)\, T_2 = Vs\ Ts\ Sin\ \alpha \quad (15)$$

In this algorithm, the switching sequence and the switching of various sub intervals are done such that the change in phase for any state occurs only once, thus losses occurring due to the switching of inverter are greatly minimized. The various sectors are selected based on the position of α which makes the angle from the start of sector. In SVPWM technique the voltage space vector amplitude measurement is not needed. Depending on the sector selected the firing of the inverter legs has done.

SIMULATION RESULTS

The Performance of shunt active filter with PMSG is simulated using MATLAB/SIMULINK. The simulation was done for a 400V star connected AC source feeding to a non linear load having a Load resistance of 20 Ω and an inductance of 10 mH, filtering inductance 0.001H, DC link capacitor of 500 μ farad, frequency is 50 Hz and the switching frequency is 10 khz.

The plot shown in Fig. 4 gives the load current characteristics. Due to the non linear load the current is non sinusoidal. The non sinusoidal currents distort the supply currents and it injects harmonics into the system. The crest factor is 3 to 4 times for non linear loads, based on that the RMS value of the output differs.

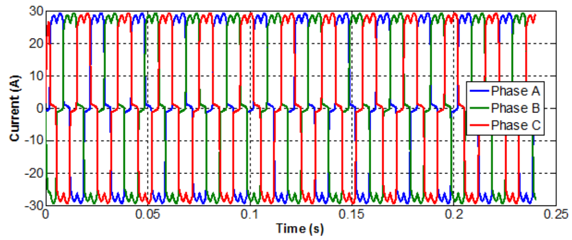

Fig. 4: Load current

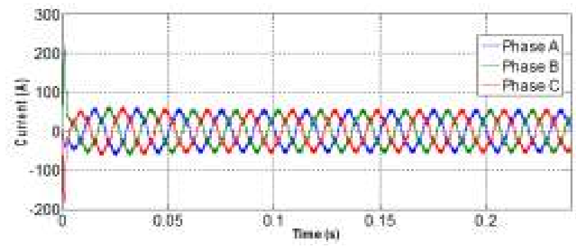

Fig. 5: Compensation current

The plot shown in Fig. 5 shows the compensation current that is generated by the shunt active filter to cancel the harmonics in the PCC which is produced by the non linear load.

The plot between load current and source current at the point of common coupling is as shown in Fig. 6. In this plot, the load current is distorted because of the non linear load and supply current remains purely sinusoidal due to the cancellation of harmonics by the shunt active filter.

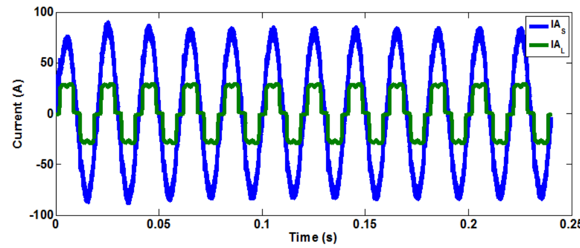

Fig. 6: Load current vs. source current

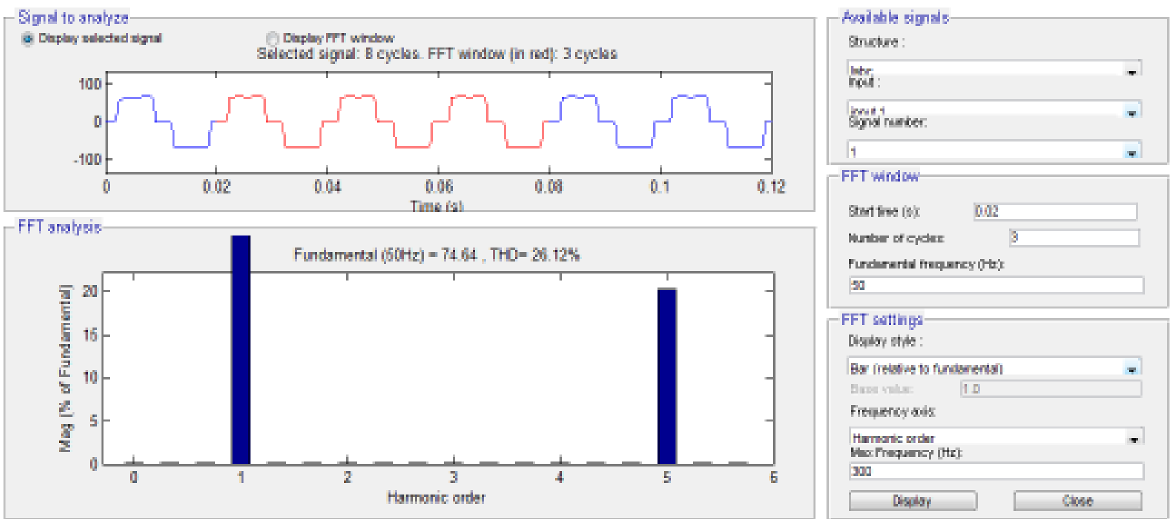

Fig. 7: THD measurement without shunt active power filter

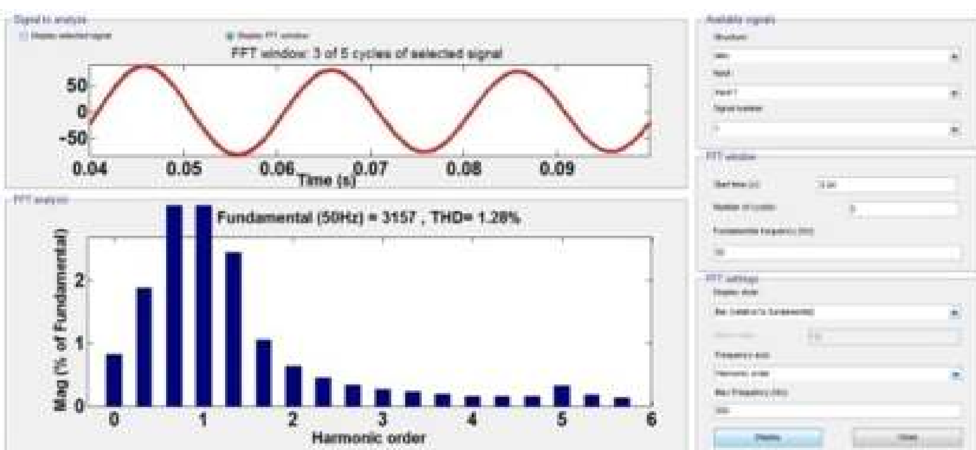

Fig. 8: THD measurement with shunt active power filter

The Total Harmonic Distortion is computed using FFT analysis and the analysis shows the THD value of 26.12% as shown in Fig. 7 without the shunt active filter in the system and with the addition of shunt active filter in the system the THD is reduced to 1.28% as shown in Fig. 8 which is very below the limits as specified by the IEEE 519 standard.

CONCLUSION

The study describes the Performance as improved by Switching of Shunt Active Filter by SRF based control for the detection of harmonics under non linear load conditions. The SVPWM is used for the switching technique of the inverter which has reduced losses and less harmonic distortions when compared to the previous methods. The performance of active power filters with this method in compensating harmonics instantaneously is examined and proved to be excellent. In the proposed method, current is measured and the harmonics are detected by SRF method, this method requires less number of sensors and there is no need for voltage sensors. SRF method is used in combination with SVPWM technique in which the PWM signals are generated based on the position angle of the reference vector but not based on the amplitude of the signal. The control algorithm shows that the harmonics generated due to the non linear load condition are eliminated and the source supply is made free from distortion. The THD present in the system has analyzed with and without the shunt active filter. The result shows due to the addition of shunt active power filter with the wind Energy Conversion system the THD value has been reduced from 26.12 to 1.28% which is very below the limits as specified by the IEEE 519 standards.

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