Reduction Techniques of Harmonics in Wind Energy System

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Abstract— *To meet the balance between supply and growing demand for power, the globe is focusing on renewable energy. In the renewable energy sector, wind is one of the frontrunners. The Doubly fed induction generator (DFIG) is one of the most popular wind energy conversion systems among the different processes available (WECS). The non-linear loads linked to the grid linked DFIG system draw harmonic currents, which distorts the grid injected currents. The rise in non-linear loads is attributed to breakthroughs in power electronics devices, which have resulted in switching mode and uninterrupted power supply. They inject harmonics into the electricity system, which is harmful to it. The harmonics add to the noise level by causing additional losses. They place additional strain on power factor correction devices, and they expose sensitive loads to harmonics. To compensate for the harmonic currents drawn by these non-linear loads, the thesis presents an active filtering methodology. The proposed method generates harmonic currents that cancel out the non-linear load's harmonic currents. For the grid side converter, a new vector control approach is proposed that produces additional harmonic currents in addition to the transmission of slip power. The grid converter current is warped as a result, but the grid current is unaffected, and total harmonic distortion (THD) is minimised. Self-tuning filters provide the harmonic isolation of the load currents required by the suggested vector control technique (STF). The DFIG model and control method are created in the MATLAB/Simulink environment, and the results show that the proposed control approach is effective.*

Keywords — *WECS ,DFIG, STF, THD ,MATLAB, Simulink.*

I. INTRODUCTION(SIZE 10 & BOLD)

With the depletion of non-renewable sources and with the global increase in the pollution levels, there is a need of renewable and clean energy source. With future demand increasing as per the current trend, renewable energy sources are the go to power generation methods [1]. The latest statistics on cost of power generation suggests that operating costs of old coal is higher than the new incoming all-in cost of renewable. According to these statistics the cost of new wind energy is $15 per MWh (Megawatt-hour) and the cost of solar is $28 per MWh. These prices are quite less than the combined operational, maintenance, and fuel costs of generating electricity from most existing coal-fired power plants. Therefore, cost superiority can also be achieved along with the added advantages.

The wind energy is fastest growing among the non-renewable resources [2]. It is undoubtedly the fastest growing as it has several advantages over the other non-renewable energy sources. Wind energy is inexhaustible in nature, it is a clean source of energy, it has lowest cost in terms of land based utility and it has many other advantages. The wind energy has been human's ally from a very old time.

II. LITERATURE REVIEW

The demand for electrical energy is increasing and with the future in sight the stress for bearing the demand has fell on the renewable energies. In the renewable sector wind energy is among the leading due its inexhaustible nature and other added advantages. In the wind energy, the preferred choice is Doubly fed induction generator (DFIG) as it offers versatility and is robust when compared to other WECS. As the wind farms are expanding and ratings are increasing in multifold, power quality is becoming more and more crucial. One important aspect of power quality is harmonics. Harmonics generate noise and losses. Due to the vibrations caused by harmonics, generators and transformers face early ageing. Harmonics in the system also put pressure on the reactive compensation devices. The DFIGs also faces the harmonics problem.

The DFIGs have back to back converter which itself is a source of harmonics. The variation in wind, bearing faults and fault in wind turbines are mechanical causes of harmonics. Core saturation, air gap flux non-linearity due to slots also take part in distorting power supply. But with the power electronics evolution, the uses of power electronics switches have become much high owing to fast switching. These fast switching is user friendly but it generates transients and harmonics. Most of the loads these days have inherent rectifier for its first stage be it switch mode power supply or interruptible power supply. These loads distort the grid currents and proper measures have to be taken to reduce this distortion.

III.DGIF AND ITS MODELLING

The DFIG based WECS comprises of wind turbine for capturing of wind power. It is pitch controlled that is it changes is aerodynamics to capture the optimum speed required for the generation. After the wind is captured the gear mechanisms help to attain the desired speed by the asynchronous generator. The Doubly fed nature makes the coupling of both rotor and stator to the grid. However, the rotor as its supplies or absorbs slip power which is varying in nature, it is coupled to grid via power electronics converter. The back to back converters help in optimizing the slip power i.e. 50 Hz frequency and required phase for the grid and slip frequency for the rotor. The converters produce voltages is step which can cause irregularities in rotor, so an inductive filter is introduced between rotor and the RSC. Also, for the grid side the currents should be sinusoidal with as minimum harmonics as possible. So, a grid side filter is also provided. The point where the coupling of stator and rotor happens is called point of common coupling (PCC).

The DFIG supports both Sub-synchronous mode and Super-synchronous mode.

A. *Wind Turbine Modelling*

The basic aim of wind turbine modelling is to provide the torque for the DFIG with the given wind speed. While doing this it also performs the following functions:

1. To make sure that maximum energy is extracted from the wind.
2. To keep the turbine speed, toque and power in tolerable limits.
3. To minimize the mechanical load.

The power in the wind (Pv) available for us to use is [11]

$$P_v = \left(\tfrac{1}{2}\right) \rho A\, v_\omega^3 \qquad (1)$$

where ρ, Vw and A are air density, wind velocity and blade swept area respectively.

This is a theoretical value and in practical a part of wind power is lost. For incorporating that loss we introduce a constant Cp. So, now power available to turbine (Pt) is given by:

$$P_t = \tfrac{1}{2}\rho\pi R^2 V_W^3 C_P \qquad (2)$$

Where R is the length of rotor blades.

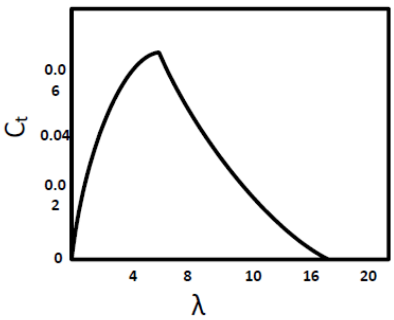

Fig. 1 Variation of Ct with λ

The whole control scheme of the wind turbine involves the mechanical, electrical as well as aerodynamics concepts. The block diagram is shown in the fig. 2.

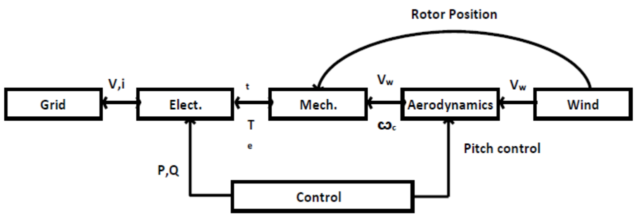

Fig. 2 Block diagram of turbine modeling

B. *Generator Modelling*

The generator consists of both rotor and stator having external slot and internal slot respectively. They both create same magnitude of magnetic field in the air-gap by having three phase windings. The rotor is also coupled to grid and it's also moving so the collection is done by the slip rings. The rotor is designed to work at 30% power or to its maximum allowable slip. This means that the maximum voltage of rotor can go to only 1/3 of the stator voltage.

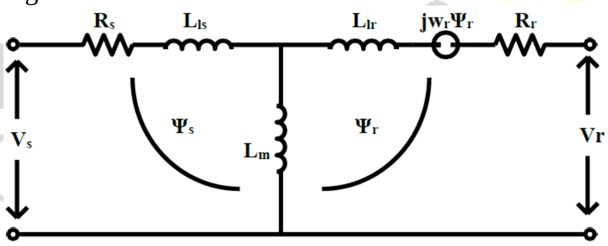

Fig. 3 Generator diagram of DFIG based WECS in stator reference frame

The voltage and flux equations of the stator and rotor circuit in stationary reference frame as per the fig. 3 are

$$V_s = R_s i_s + \frac{d\Upsilon_s}{dt} \qquad (3)$$

$$V_r = R_r + \frac{d\Upsilon_r}{dt} - JW_r\Upsilon_r \qquad (4)$$

$$\Upsilon_s = L_s i_s + L_m i_r \qquad (5)$$

$$\Upsilon_r = L_m i_s + L_m i_r \qquad (6)$$

Ψ is the flux linkage and ω is the frequency. Stator inductance L_s is the summation of L_{ls} and L_m. Rotor inductance is the summation of L_{lr} and L_m.

IV. Power Quality in DFIG

A. *Causes of Harmonics in DGIF*

There are many sources of harmonics in DFIGs which causes the reduction in power quality. One of the main causes of harmonics are the back to back converters which uses the PWM techniques. The converters are basically a semi-conductor device which itself is a source of harmonics [12].

Another source of harmonics is the unbalanced stator conditions. The negative sequence of this unbalanced stator condition leads to entering of high frequency components in rotor torque as well as rotor currents. It also causes over heating in the rotor.

Rotor slots and stator slots are also plays a major role in polluting the DFIGs. Each time the flux passes through the air gap, the slots causes the voltage in stator and rotor to increase in steps which is far from being sinusoidal.

B. *IEEE standards for harmonics*

The standards of IEEE are based on the total harmonic distortion (THD) which is given as

$$THD = \frac{\sqrt{f_2^2 + f_3^2 + f_4^2 \dots\dots\dots}}{f_1}$$

Where f can be voltage or current and the subscript denote the harmonic order. $f1$ denotes the fundamental component. Generally, it is given in percentages.

For a sinusoidal signal, if THD is 0% then it is free from harmonics or it is a pure sine wave. Higher the harmonics more is the other harmonic order components.

V. Proposed Control Strategy

A. *Simulink Model*

The developed control strategy is verified in MATLAB. A 1.5 MW wind turbine is taken as the model. The various parameters are listed in table I. For the non-linear load, a rectifier diode bridge is connected at the PCC with 0.2 MW rating. Fig. 4 shows the proposed simulation model. Fig. 5 is the proposed control for the GSC.

TABLE I
DFIF Simulink parameters

Rated power	1.5 MW
Nominal voltage	995.92 V
Nominal frequency	50 Hz
Stator and rotor resistances in p.u. respectively	0.023, 0.016
Stator and rotor leakage reactance's in p.u. respectively	2.9, 0.18
Magnetizing inductance in p.u.	0.16
Interfacing inductor	150e-6 H
DC-link voltage	1150 V
DC-link capacitance	10mF
Non-linear load	0.2 MW

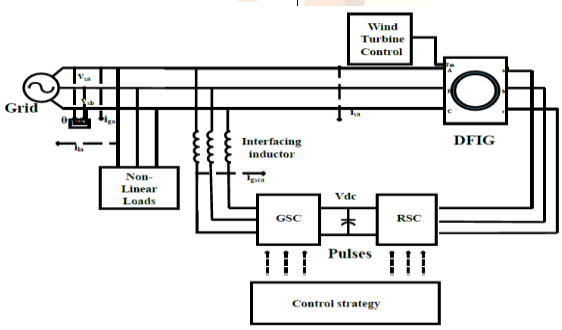

Fig. 4 Proposed simulation model

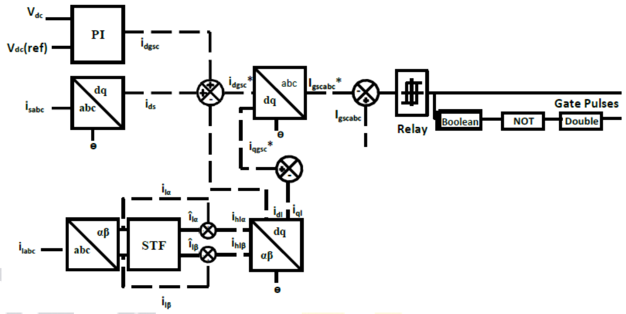

Fig. 5 GSC control

B. *Simulated Results*

The simulated performance is at wind speed of 11 m/s

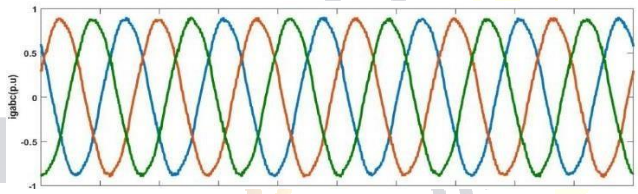

Fig.6 Grid current

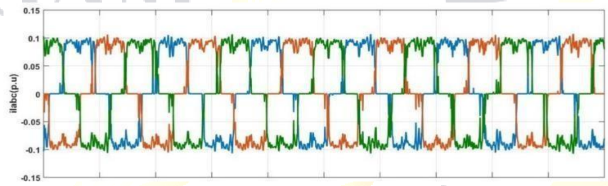

Fig.7 Load current

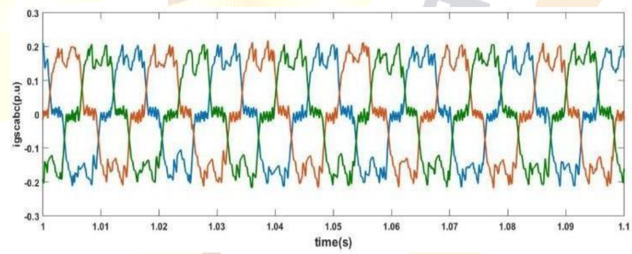

Fig.8 Load current

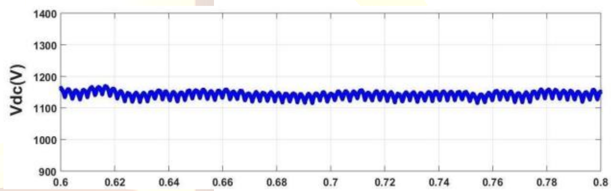

Fig.9 DC-link voltage

From the Fig. 6 we observe the grid current to be sinusoidal. Fig. 7 is the waveform of load current which is full of harmonics as expected. Fig.8. shows the nature of grid side converter current. As expected it contains both the sinusoidal component form its slip power and harmonic components which needs to be generated to compensate for the harmonics. The DC-link remains constant as in fig. 9 which validates the proper working of the GSC as well as the DFIG as the DC-link is very important for both the converters to work.

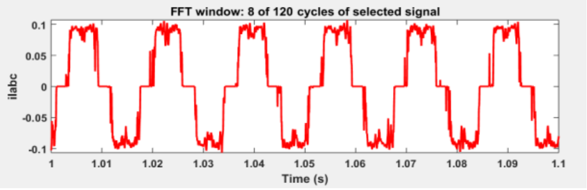

Fig.10 a phase of Load Current

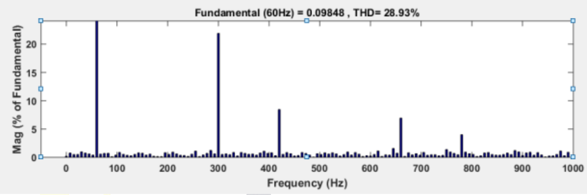

Fig.11 a phase of Load Current

The fig. 10 shows a phase sequence of the load current. In fig. 11 the Fast Fourier Transform of the a phase sequence of the load current is done. FFT analysis is done to find out the magnitudes of different frequency components. FFT analysis also gives us the THD measurement. As the load is non-linear, the THD comes out to be 28.93 %. This amount of harmonic pollution is enough to force the distortion limit of grid current beyond IEEE standard limit of 5%.

VI. CONCLUSIONS

The non-linearity in the load is increasing thanks to the increased use of power electronics devices. These non-linear loads will keep increasing as the devices are becoming energy efficient along with added speed. However, it causes harmonics and distorts the power in the system. To counter this problem, active filtering is employed in DFIG for reducing the. THD in the grid current thus is improving the power quality. The existing RSC control carries out the function of decoupled control of both active and reactive power. As mentioned earlier, both power factor and mitigation of harmonics cannot be done from the same converter, so RSC controls the power factor too. The GSC control is modified and it is shown that the GSC produces the compensating current required by the non-linear loads. The harmonics in the load is fed by the GSC and the sinusoidal supply from the stator goes undistorted to the grid. The Fast Fourier transform (FFT) analysis is performed on the grid current to obtain THD. The THD is found out to be 10.15% with the existing GSC control and 2.88% with the employed technique. 2.88% THD is well below the limits given in the IEEE-519 standards. The DC link voltage is also found to be stable. So, the work of GSC discussed earlier is fulfilled as both the harmonics mitigation and control of dc voltage is established.

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