

Doubly Fed Induction Generator for Wind Energy Conversion

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ABSTRACT: The doubly-fed induction generator (DFIG) is widely used in variable speed wind energy conversion systems (WECS). This paper presents a review on various topologies, configuration, power converters and control schemes used with the operation of the DFIG. The main contribution of this work lies in the control of GSC for supplying harmonics in addition to its slip power transfer. The rotor-side converter (RSC) is used for attaining maximum power extraction and to supply required reactive power to DFIG. Wind energy conversion system (WECS) works as a static compensator (STATCOM) for supplying harmonic even when the wind turbine is in shutdown condition. Control algorithms of both GSC and RSC are represented in detail. Implemented project DFIG-based WECS is simulated using MATLAB/Simulink. A prototype of the proposed DFIG based WECS is developed using a digital signal processor (DSP). The wind energy is the preferred for all renewable energy sources.

KEYWORDS- Variable speed DFIG, MPPT, wind energy, power quality, active filtering, GSC

I. INTRODUCTION

Now-a-days, the consumption of conventional energy sources has increased, So efforts have been made to generate electricity from renewable energy sources such as wind, solar etc., Wind energy has become one of the most important and promising sources of renewable energy. This demands additional transmission capacity and better means of maintaining system reliability. Today the wind power capacity of the world is approximately 50GW and it is expected to reach 160GW by 2012. In modern Wind Turbine Generation System (WTGS), the wind turbines are subjected to variation of load and impact of sudden wind speed variations. With increased penetration of wind power into electrical grids, Doubly-Fed Induction Generator (DFIG) wind turbines are largely

deployed due to their variable speed feature and hence influencing system dynamics. This has created an interest in developing suitable models for DFIG to be integrated into power system studies. The continuous trend of having high penetration of wind power, in recent years, has made it necessary to introduce new practices. Additionally, in order to model power electronic converters, in the simplest scenario, it is assumed that the converters are ideal and the DC-link voltage between the converters is constant. Consequently, depending on the converter control, a controllable voltage (current) source can be implemented to represent the operation of the rotor-side of the converter in the model.

In the literature, Manasi Pattnaik, "Study of Doubly-Fed Induction Generator for variable Speed Wind Energy Conversion Systems", gives brief idea about the operation and working of DFIG.[1]. F. Poitiers, M. Machmoum, R. Le Doeuff and M.E. Zaim, "Control Of A Doubly-Fed Induction Generator For Wind Energy Conversion System", gives information about the modeling of the DFIG and the control operation used.[2]. R. Pena, J.C. Clare and G.M. Asher (1996), "Doubly Fed Induction Generator using back-to-back PWM converter and its application to variable-speed wind-energy generation", describes the rotor side converter control of DFIG which provides the reference waveform for rotor side converter and the pulses for RSC have been obtained with this the real and reactive power can be controlled.[3].

T. Thiringer, A. Petersson, and T. Petru (2003), "Grid Disturbance Response Of Wind Turbine Equipped With Induction Generator and Doubly-Fed Induction Generator", gives brief idea about the grid disturbance response to fixed speed wind turbines

and wind turbines with DFIG are presented. [4]. A. Petersson, L. Harnfors, and T. Thiringer (2005), "Evaluation OF Current Control Methods For Wind Turbines Using Doubly-Fed Induction Machine," gives brief idea about the analysis of the stator-flux oriented current control of the DFIG. [5]. Carles Batlle, Arnau D'oria-Cerezo, Romeo Ortega (2006), "A Robustly Stable PI Controller for The Doubly-Fed Induction Machine", this paper gives the brief idea about the closed loop of the system using the PI controller.

II. CONTROL STRATEGY FOR UPFC

These DFIGs also provide good damping performance for the weak grid. Independent control of active and reactive power is achieved by the decoupled vector control algorithm. This vector control of such systems is usually realized in synchronously rotating reference frame oriented in either voltage axis or flux axis. In this work, the control of rotor-side converter (RSC) is implemented in voltage-oriented reference frame. Response of DFIG-based wind energy conversion system (WECS) to grid disturbance is compared to the fixed speed WECS. Generated power smoothing is achieved by implementing super magnetic energy storage systems.

The other auxiliary services such as reactive power requirement and transient stability limit are achieved by including static compensator (STATCOM). A distribution STATCOM (DSTATCOM) coupled with fly-wheel energy storage system is used at the wind farm for mitigating harmonics and frequency disturbances. A super capacitor energy storage system at the dc link of unified power quality conditioner (UPQC) improving power quality and reliability. The harmonics compensation and reactive power control are achieved with the help of existing RSC. An indirect current control technique is simple and shows better performance for eliminating harmonics as compared to direct current control.

Working principle: In this work, a new control algorithm for GSC is proposed for compensating harmonics produced by nonlinear loads using an indirect current control. RSC is used for controlling

the reactive power of DFIG. The other main advantage of proposed DFIG is that it works as an active filter even when the wind turbine is in shutdown condition. Therefore, it compensates load reactive power and harmonics at wind turbine stalling case. Both simulation and experimental performances of the proposed integrated active filter-based DFIG are presented in this work. The dynamic performance of the proposed DFIG is also demonstrated for varying wind speeds and changes in unbalanced nonlinear loads at point of common coupling (PCC).

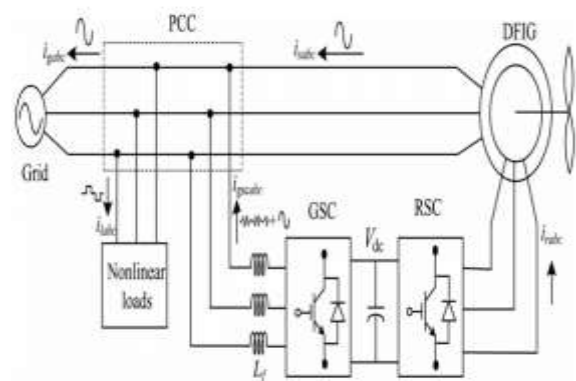


Fig. 1. Proposed system configuration

Above figure shows a schematic diagram of the proposed DFIG-based WECS with integrated active filter capabilities. DFIG, the stator is directly connected to the grid as shown in Fig. 1. Two back-to-back connected voltage source converters (VSCs) are placed between the rotor and the grid. Nonlinear loads are connected at PCC as shown in Fig. 1. The proposed DFIG works as an active filter in addition to the active power generation similar to normal DFIG. Harmonics generated by the nonlinear load connected at the PCC distort the PCC voltage.

RSC is controlled for achieving maximum power point tracking (MPPT) and also for making unity power factor at the stator side using voltage-oriented reference frame. Synchronous reference frame (SRF)

control method is used for extracting the fundamental component of load currents for the GSC control.

DESIGN OF DFIG-BASED WECS:

Selection of ratings of VSCs and dc-link voltage is very much important for the successful operation of WECS.

Selection of DC-Link Voltage: The dc-link voltage of VSC must be greater than twice the peak of maximum phase voltage. While considering from the rotor side, the rotor voltage is slip times the stator voltage. So, the design criteria for the selection of dc-link voltage can be achieved by considering only PCC voltage. While considering from the GSC side, the PCC line voltage (V_{ab}) is 230 V, as the machine is connected in delta mode. Therefore, the dc-link voltage is estimated as

$$V_{dc} \geq \frac{\sqrt{2}}{\sqrt{3} * m} V_{ab}$$

where

V_{ab} is the line voltage at the PCC.

Maximum modulation index is selected as 1 for linear range.

The value of dc-link voltage (V_{dc}) by (1) is estimated as 375 V.

Hence, it is selected as 375 V

Selection of VSC Rating: The DFIG draws a lagging volt-ampere reactive (VAR) for its excitation to build the rated air gap voltage. , the rating of the VSC used as RSC S_{rated} is given as

$$S_{rated} = \sqrt{P_{rmax}^2 + Q_{rmax}^2}$$

Design of Interfacing Inductor: The design of interfacing inductors between GSC and PCC depends upon allowable GSC current limit (I_{gscpp}), dc-link voltage, and switching frequency of GSC. Maximum possible GSC line currents are used for the calculation. Maximum line current depends upon the maximum power and the line voltage at GSC. The maximum possible power in the GSC is the

slippower. Interfacing inductor between PCC and GSC is selected as 4 mH.

$$L_i = \frac{\sqrt{3} m v_{dc}}{12 a f_m \Delta i_{gsc}}$$

$$= \frac{\sqrt{3} \times 1 \times 375}{12 \times 1.5 \times 10\ 000 \times 0.25 \times 3.76} = 3.8\text{mH}$$

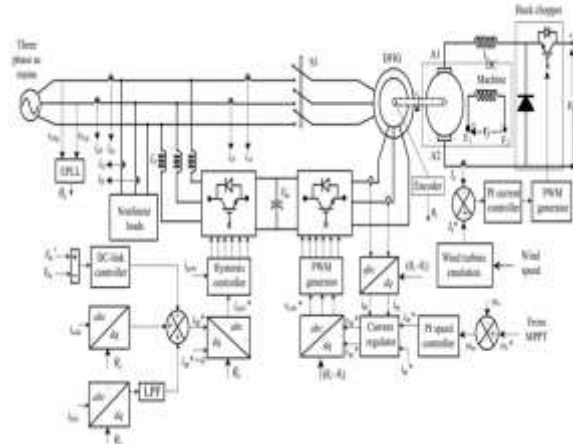


Fig. 2. Control algorithm of the proposed WECS.

CONTROL STRATEGY:

Control algorithms for both GSC and RSC are presented in this section. The control algorithm for emulating wind turbine characteristics using dc machine and Type A chopper is also shown in Fig. 2.

Control of RSC: The main purpose of RSC is to extract maximum power with independent control of active and reactive powers. Here, the RSC is controlled in α lge oriented reference frame., the active and reactive powers are controlled by controlling direct and quadrature axis rotor currents (i_{dr} and i_{qr}).

$$\hat{i}_{dr}^*(k) = \hat{i}_{dr}^*(k-1) + k_{pid} \{ \omega_{er}(k) - \omega_{er}(k-1) \} + k_{id} \omega_{er}(k)$$

Where:

The speed error (ω_{er}) is obtained by subtracting sensed speed (ω_r) from the reference speed (ω^*r).

k_{pd} and k_{id} are the proportional and integral constants of the speed controller.

$\omega_{er}(k)$ and $\omega_{er}(k - 1)$ are the speed errors at k th and $(k-1)$ th instants.

$i^*_{dr}(k)$ and $i^*_{dr}(k - 1)$ are the direct axis rotor reference current at k th and $(k-1)$ th instants.

Reference rotor speed (ω^*_{r}).

In general, the quadrature axis reference rotor current (i^*_{qr}) is selected such that the stator reactive power (Q_s) is made zero. In this DFIG, quadrature axis reference rotor current (i^*_{qr}) is selected for injecting

the required reactive power. Inner current control loops are taken for control of actual direct and quadrature axis rotor currents (i_{dr} and i_{qr}) close to the direct and quadrature axis reference rotor currents (i^*_{dr} and i^*_{qr}). The rotor currents i_{dr} and i_{qr} are calculated from the sensed rotor currents (i_{ra} , i_{rb} , and i_{rc}).

Control of GSC:

The novelty of this work lies in the control of this GSC for mitigating the harmonics produced by the nonlinear loads. The control block diagram of GSC is shown in Fig. 2. Here, an indirect current control is applied on the grid currents for making them sinusoidal and balanced. Therefore, this GSC supplies the harmonics for making grid currents sinusoidal and balanced. These grid currents are calculated by subtracting the load currents from the summation of stator currents and GSC currents. Active power component of GSC current is obtained by processing the dc-link voltage error (v_{dce}) between reference and estimated dc-link voltage (V^*_{dc} and V_{dc}) through PI controller as

$$i^*_{gsc}(k) = i^*_{gsc}(k - 1) + k_{pdc} \{v_{dce}(k) - v_{dce}(k - 1)\} + k_{idc} v_{dce}(k)$$

Where k_{pdc} and k_{idc} are proportional and integral gains of dc-link voltage controller. $v_{dce}(k)$ and $v_{dce}(k - 1)$ are dc-link voltage errors at k th and $(k-1)$ th instants. $i^*_{gsc}(k)$ and $i^*_{gsc}(k - 1)$ are active

power component of GSC current at k th and $(k-1)$ th instants.

III. SIMULATION RESULTS

The DFIG machine modes of operation namely sub-synchronous generating, super-synchronous generating are simulated and the waveforms for speed and stator, rotor power and torque in each of the above modes of operation are presented. The rotor speed is controlled by using v/f control and grid-side reactive power & V_{dc} are controlled by using voltage oriented control techniques. The grid-side current is controlled by using reference current control techniques under p-q theory.

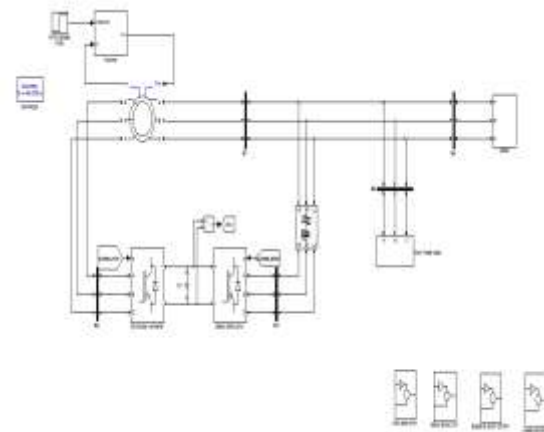
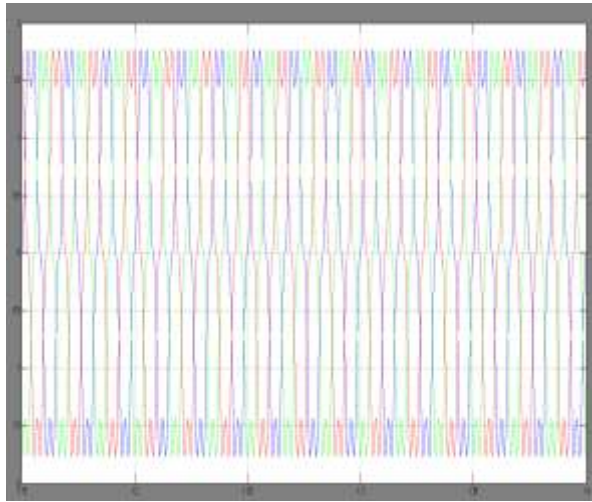


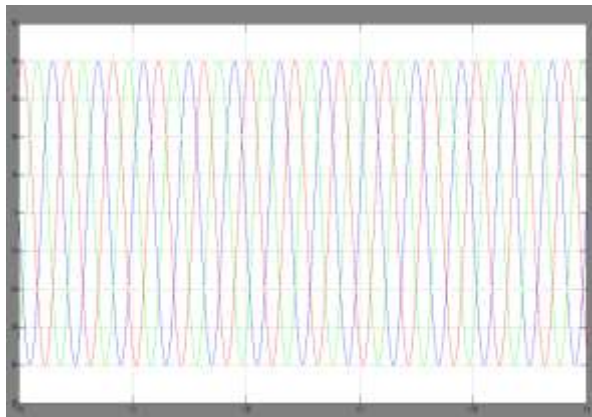
Fig 3 Matlab/simulink diagram of DFIG connected to WECS



Fig 4 Wind speed (m/s)

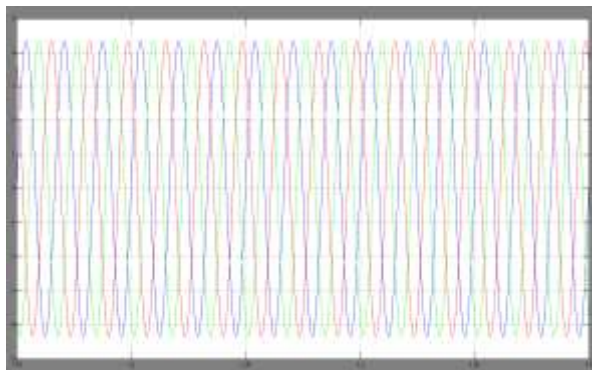


(a)

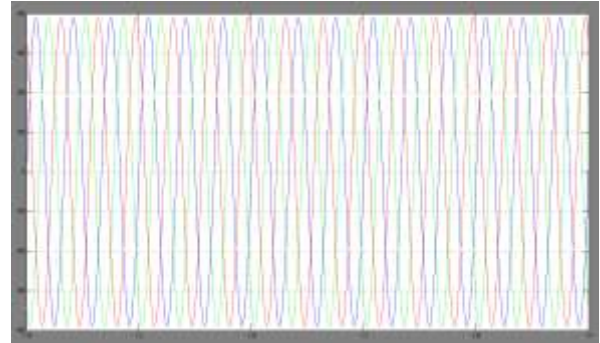


(b)

Fig 5 (a) Load current (Iabc1) (b) Load voltage (Vabc1)



(a)



(b)

Fig 6 (a) grid current (Iabc) (b) grid voltage (Vabc)

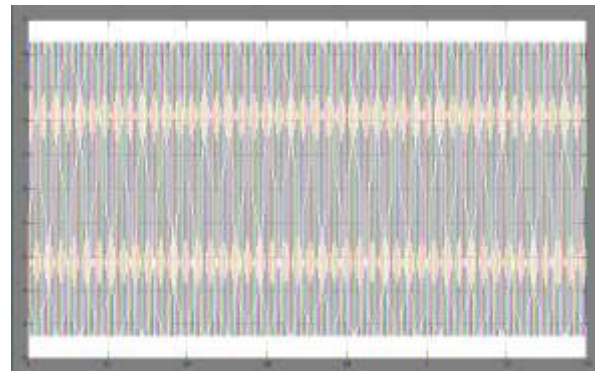


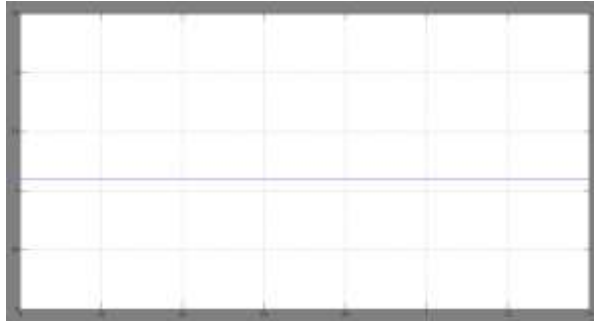
Fig 7 stator current (Iabc stator)



(a)

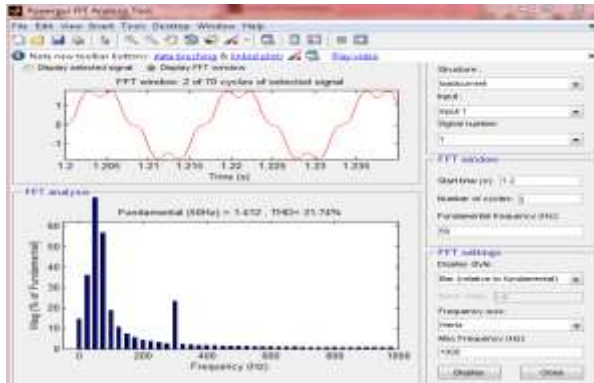


(b)

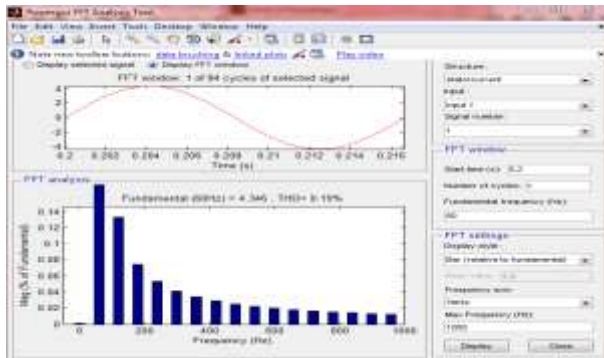


(c)

Fig 8 (a) stator active power (b) grid active power
 (c) load active in kw



(a)



(b)

Fig 9 FFT Analysis tool

IV. CONCLUSION

Proposed DFIG, the reactive power for the induction machine has been supplied from the RSC and the load reactive power has been supplied from the GSC. Decoupled control of both active and reactive powers has achieved by RSC control. DFIG has also been verified at wind turbine stall condition for

compensating harmonics and reactive power of local loads. Proposed DFIG-based WECS with an integrated active filter has been simulated using MATLAB/Simulink environment, and the simulated results are verified with test results of the developed prototype of this WECS.

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