



Enhanced Performance of Grid Connected Doubly Fed Induction Generator Using Vector Control

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Abstract: This paper presents a novel methodology for compensating harmonics in the grid connected doubly fed induction generator (DFIG). A vector control (VC) scheme has been proposed in order to maintain minimal harmonic content in the line and to enhance the power quality of the line. A Simulink model of grid connected DFIG with and without VC scheme has been presented. Introducing different types of faults in the line and DFIG, the harmonic compensation is analysed with the incorporation of VC and the obtained results are compared with pulse width modulation (PWM) controlled DFIG. Simulations are performed in MATLAB by connecting different types of loads and the variations in the performance of controllers are examined. Simulation results illustrate the effectiveness of the proposed controller and its impact on the load variations as well as grid faults. Results obtained enlighten that VC is the best method.

Keywords: DFIG, rotor side converter (RSC), grid side converter (GSC), total harmonic distortion (THD).

I. INTRODUCTION

Due to decrement in non-renewable energy sources like coal and oil etc. power generation is mainly concentrated on renewable energy sources. In renewable energy sources wind power conversion system is fastest growing technology due to some of advantages like eco-friendly and low cost per unit. Synchronous speed generators are not so economical and technically beneficial for the high power applications of wind energy conversion system (WECS) due to variable wind speed. So in order to have better performance of generator, induction (asynchronous) generators are used. DFIG is the most popularly used generator in the WECS. A grid connected wind power generation using DFIG has been presented along with modelling and simulation of DFIG operating in two quadrants (torque-speed) employs a stator flux VC [1]. Stator flux oriented VC is applied to decouple the control of active and reactive power generated by the DFIG based WT [2]. The vector scheme is embedded in control loops which enable optimal speed tracking for maximum energy capture from the wind [3]. An experimental work has been presented along with simulation, the VC of rotor current is carried out using a commercial PWM inverter equipped with VC as standard [4]. A switch-by-switch representation of the PWM converters with a carrier-based Sinusoidal PWM modulation for both rotor- and stator-side converter has been proposed. Stator-Flux Oriented vector control approach is deployed for both stator- and rotor-side converters to provide independent control of active and reactive power and keep the DC-link voltage constant [5]. In this paper rotor flux oriented VC scheme is presented for both GSC and RSC by different conditions rotor currents and its effect on grid are measured. Results obtained enlighten the effectiveness of controller.

II. SYSTEM DESCRIPTION

The general diagram of grid connected WECS with DFIG is illustrated in fig: 1 basic working of GSC and RSC with speed variation is described here.

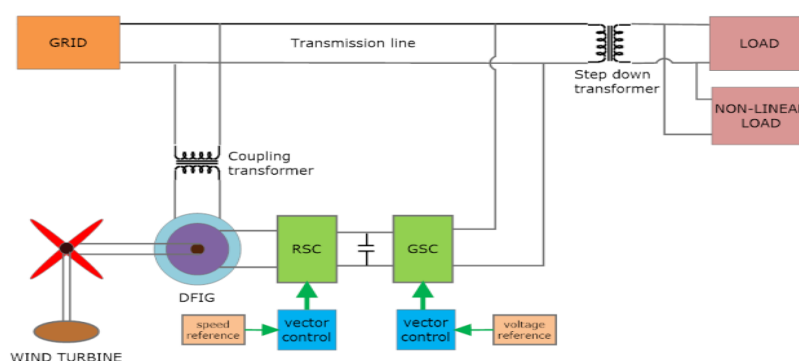


Fig. 1: Block diagram of WECS

As the wind blows turbines will be rotated which will rotate the shaft of the generator. Turbine and shaft are connected via gear box. This mechanical energy received from the shaft is converted to electrical energy and it is collected from the stator which is connected to the grid.

As the wind speed is not constant the shaft of the generator is variable and generates a variable voltage at the stator terminals. This voltage fluctuations introduces power quality problems in to the line which leads to distortions in line voltages and currents. As long as the distortions are in the specified limits there will be no affect to DFIG and grid. If these distortions are out of limits then it will cause hazardous damage to the grid and DFIG. So in order to achieve lower harmonics, rotor field oriented VC is proposed in this paper, control techniques are illustrated as follows.

III. VECTOR CONTROL APPROACH

Power electronic switches used in the converters are basically insulated bi-polar transistors (IGBTs). They are consists of three terminals namely gate, emitter and collector these switches are turned ON and turned OFF by single gate pulse. There are plenty of power electronic switches like bi-polar junction transistors (BJTs), metal oxide semiconductor field effect transistors (MOSFETs) and thyristors etc. due to some advantages over other switches, IGBTs are employed in power converters in this report. Some advantages are its lesser conduction losses, lesser on-state losses and most importantly no additional commutation circuit is needed to switch it OFF. A power electronic converter can be controlled by many control approaches like single pulse width modulation (PWM), multi PWM, sinusoidal PWM and hysteresis control. Controllers proposed have some disadvantages like more harmonic content at its output, some of them causes more switching losses etc. but coming to VC it has advantage of having lower harmonics at the output and have moderate switching losses.

A. Vector control for RSC

As discussed earlier RSC is responsible for constant rotor speed and to provide harmonic less voltages at stator. Controlling the stator mmf both in amplitude and phase angle this control is named as VC. This is the way to control three phase induction motor as separately excited DC motor. Advantage of this method is, in DC motor torque is a function of both armature current and field current. By knowing components of field current and armature current independently, we can directly control the armature current component because with field current component delay will be associated so we control the armature current component. By the same principle 3-phase induction motor is controlled as separately excited DC motor. To achieve this type of control we have moved to space vector control.

By Park's transformation a 3-phase induction motor can be modelled as a steady state two winding motor. Later this two phase motor is assumed as DC motor and the control has been initiated.

ϕ_{dr}^e, ϕ_{qr}^e are rotor flux of d and q axis respectively and are given by following equation.

$$\phi_{dr}^e = \phi_r \quad (1)$$

$$\phi_{qr}^e = 0 \quad (2)$$

Here DFIG is designed under one condition that the wind turbine is rotating under sub-synchronous speed. It is assumed in such a way because in practical oriented applications speed of the wind will be always lesser than the synchronous speed sometimes it exceeds the synchronous speed. So for sub-synchronous speed DFIG acts as induction motor.

In motoring action rotor voltages are short circuited and d-axis rotor voltage is expressed as

$$V_{dr}^e = 0 = r_r i_{dr}^e + p \phi_{dr}^e - \omega_{sl} \phi_{qr}^e$$

$$0 = r_r i_{dr}^e + p \phi_{dr}^e \text{ from equation (2)}$$

$$0 = r_r i_{dr}^e$$

since we kept flux constant $p \phi_{dr}^e = 0$

$$\text{Or } i_{dr}^e = 0 \quad (3)$$

Therefore d-axis current has no effect on machine performance.

q-axis rotor voltage given as

$$V_{qr}^e = 0 = r_r i_{qr}^e + p \phi_{qr}^e + \omega_{sl} \phi_{dr}^e$$

$$0 = r_r i_{qr}^e + \omega_{sl} \phi_{dr}^e$$

$$\omega_{sl} = -r_r i_{qr}^e / \phi_{dr}^e$$

$$\phi_{qr}^e = 0 = L_r i_{qr}^e + L_m i_{qs}^e$$

$$\text{Or } i_{qr}^e = -(L_m / L_r) i_{qs}^e$$

Where L_r and L_m are rotor inductance and mutual inductance respectively, i_{dr}^e and i_{qr}^e are d and q axis rotor currents rotating in synchronous reference frame.

Suffix s in place of r in above equations represent stator components

$$\omega_{sl} = \text{slip speed} = (r_r / L_r) L_m (i_{qs}^e / \phi_{dr}^e)$$

$$= (L_m / T_r) (i_{qs}^e / \phi_{dr}^e)$$

$$\phi_{dr}^e = L_r i_{dr}^e + L_m i_{ds}^e$$

From equation (3), $L_r i_{dr}^e = 0$

$$\phi_{dr}^e = L_m i_{ds}^e$$

$$\omega_{sl} = (1/T_r) (i_{qs}^e / i_{ds}^e)$$

Torque for induction motor:

$$\begin{aligned} T_e &= (3/2) (P/2) L_m [i_{qs}^e i_{dr}^e - i_{ds}^e i_{qr}^e] \\ &= (3/2) (P/2) L_m [-i_{ds}^e (- (L_m/L_r) i_{qs}^e)] \\ T_e &= (3/2) (P/2) L_m^2 i_{ds}^e i_{qs}^e \end{aligned}$$

Where P is number of poles of the machine

$$\begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \cos\theta_1 & -\sin\theta_1 \\ \cos\theta_2 & -\sin\theta_2 \end{pmatrix} \begin{pmatrix} i_{ds} \\ i_{qs} \end{pmatrix}$$

$$\text{Where } \theta_1 = \theta - 2\pi/3$$

$$\theta_2 = \theta + 2\pi/3$$

Evaluation of flux vector angle θ

$$\theta = \int w_e dt = \int (w_r + \omega_{sl}) dt$$

$$\omega_{sl} = \frac{1}{T_r} \frac{i_{qs}}{i_{ds}}$$

$$\text{where } T_r = L_r/r_r$$

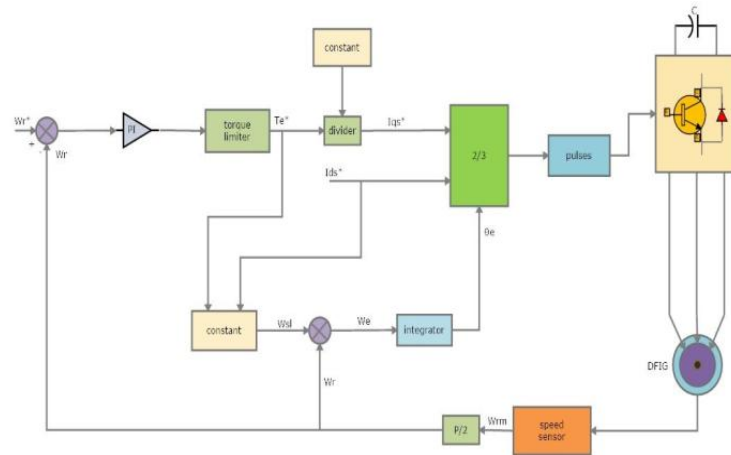


Fig. 2: Vector control for RSC

B. Vector control for GSC

As discussed earlier GSC is responsible for maintaining constant coupling capacitor voltage. For super synchronous and sub synchronous speed of the shaft, capacitor voltage varies so as to maintain a constant value VC approach is used. A VC approach is used with reference frame oriented along the grid side voltage vector position, with d-axis current used to regulate DC link voltage while q-axis current used to regulate reactive power.

Fig: 3 illustrates schematic arrangement of grid side VC voltage source converter, where u_{gabc} are grid side three phase voltages, u_{gcabc} are grid side converter voltages, i_{gabc} are three phase grid side converter currents, R_g , L_g are the inductor resistance and inductance, i_{dcr} , i_{dcr} are grid side and rotor side currents, C is DC link capacitor.

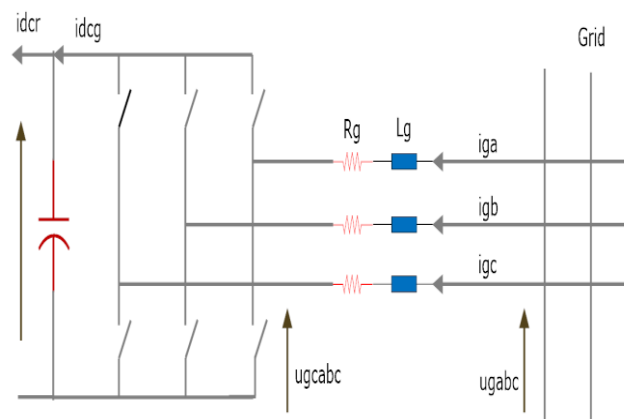


Fig. 3: Grid side VC voltage source converter to grid

IV. SIMULATION RESULTS

The system described above is simulated using MATLAB, Simulink obtained results are illustrated as follows.

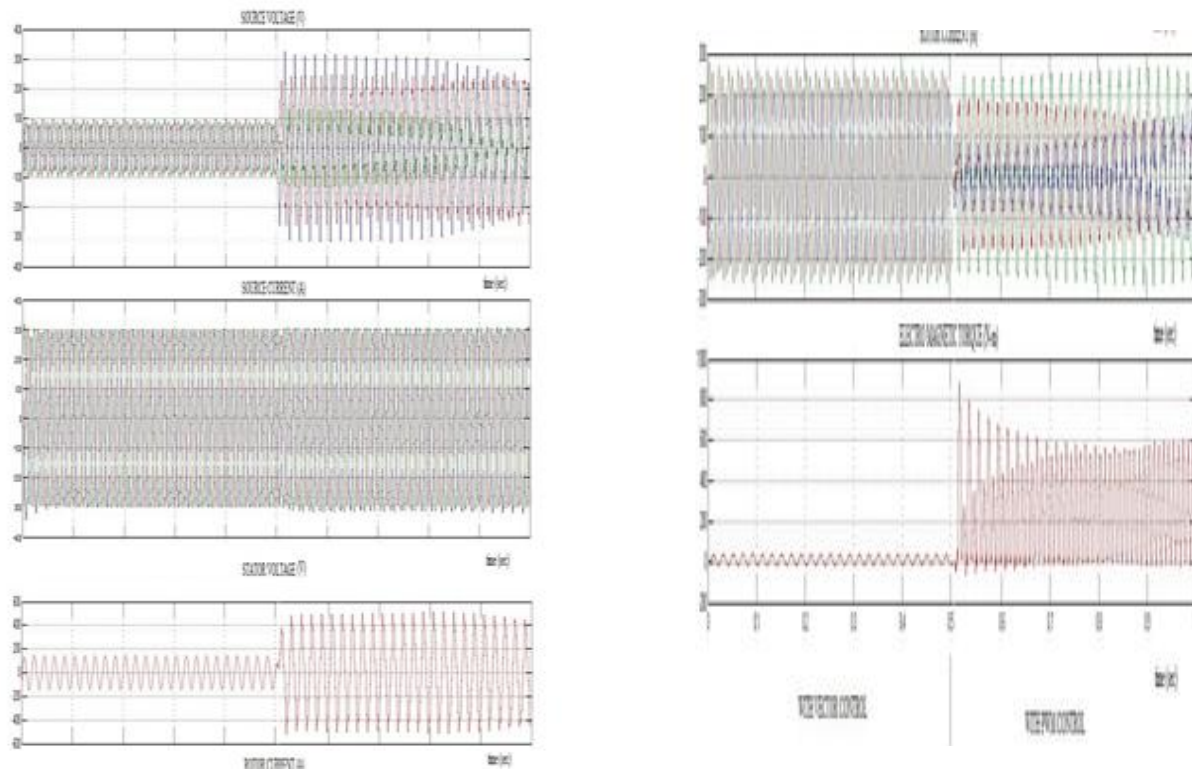


Fig. 5: VC & PWM for different voltages and currents

Grid connected DFIG has been loaded with different types of loads and the variation in THD when controlled by PWM and VC are illustrated as follows.

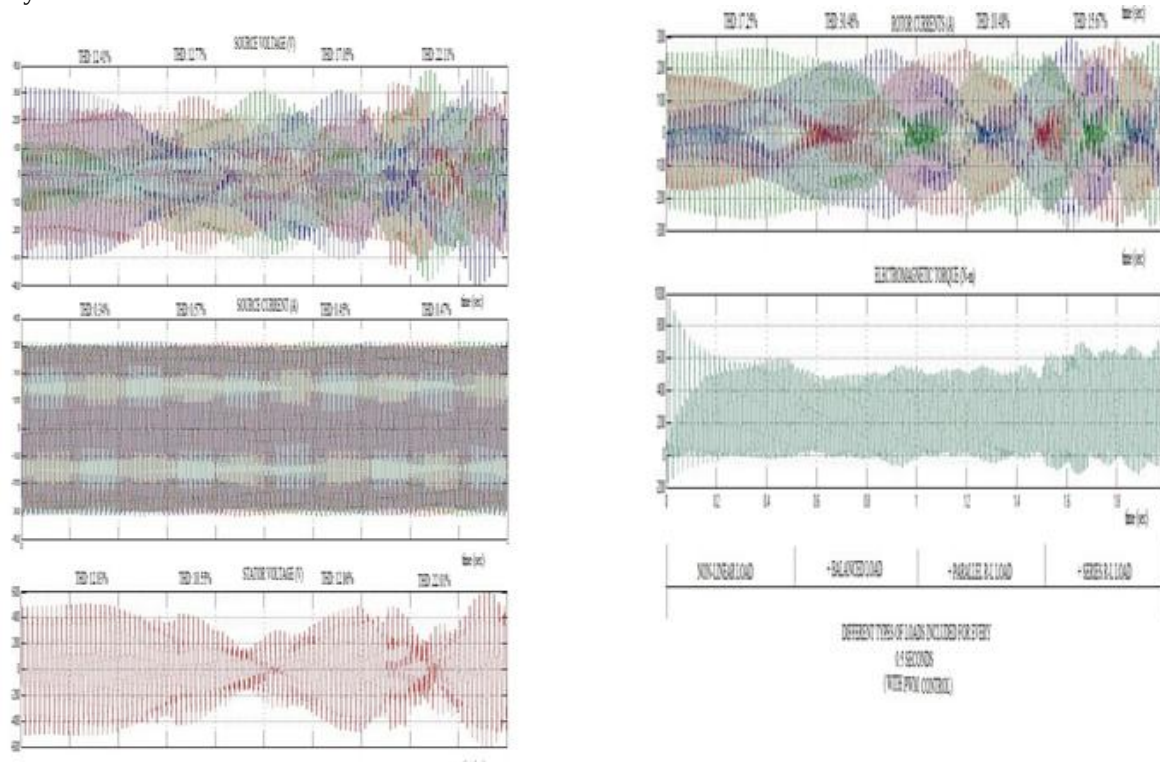


Fig. 6: Behaviour of DFIG for PWM control with different types of loads adding for every 0.5sec

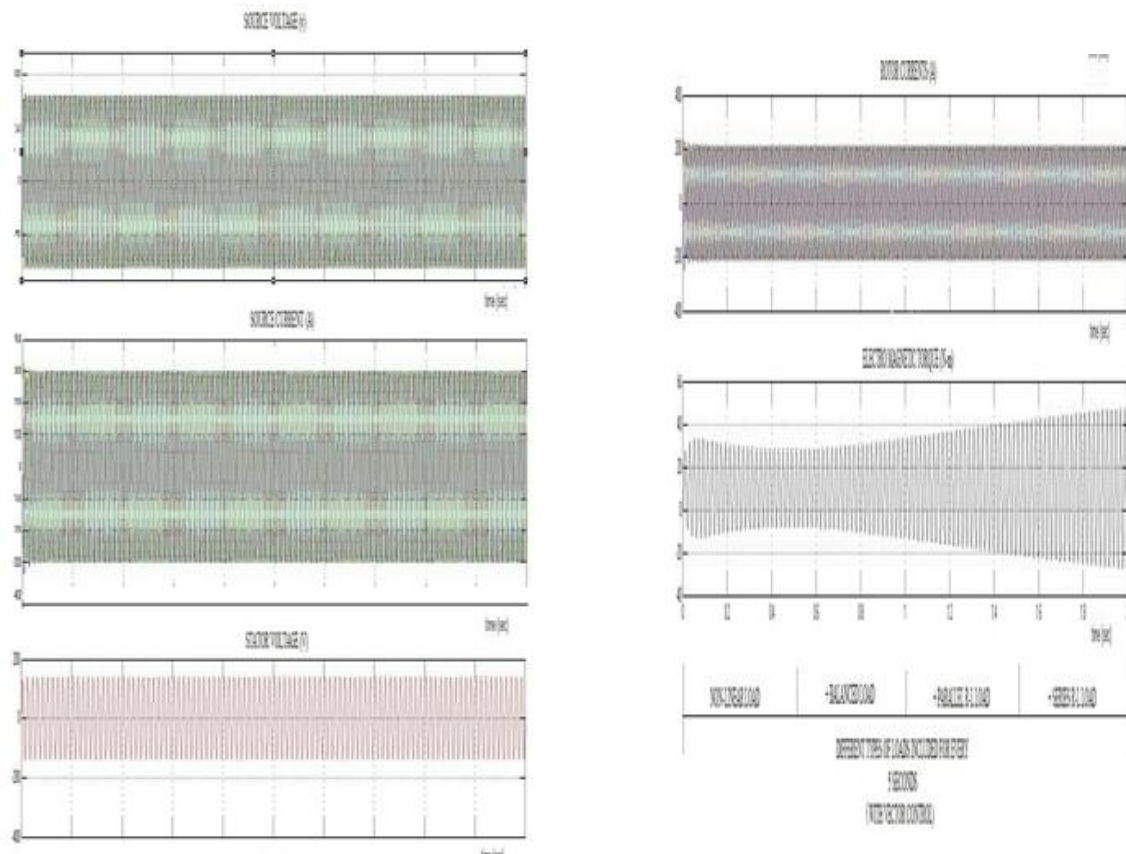


Fig. 7: Behaviour of DFIG for vector control with different types of loads adding for every 0.5sec

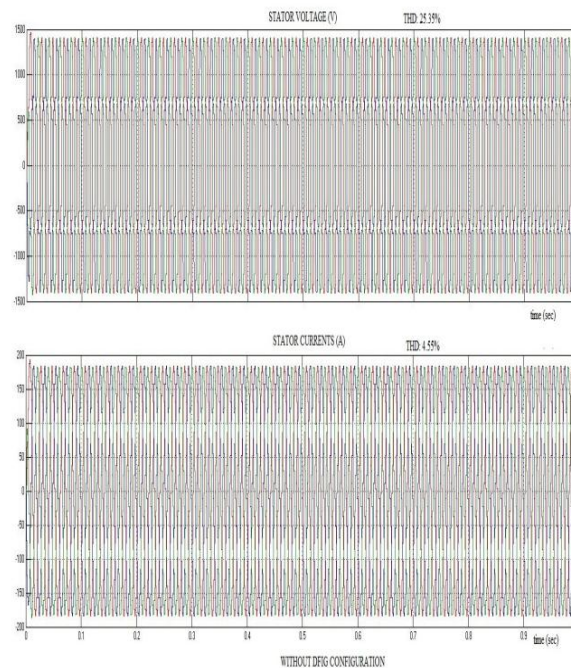


Fig. 8: Grid directly connected to non-linear load without any DFIG configuration in middle of the transmission line

The fig: 8 illustrate results of the source voltage and currents with no DFIG configuration in the middle of the transmission line. Here grid is directly connected to the non-linear load and the effect on grid has been measured. The results obtained have voltage THD of 25.35% and current THD of 4.55%.

V. Conclusion

A grid connected DFIG controlled by vector control scheme supplying a non-linear load is presented in this paper. The variations in THD levels when controlled by PWM and VC is illustrated in results. By the results it can be conclude that when converters are controlled by PWM technique, source voltage, current, and stator voltage and rotor currents contains higher harmonics, than those converters controlled by VC. And also when grid connected DFIG is controlled by the proposed control scheme, then there no need of any FACTS controllers for maintaining voltage stability in the line. Hence vector control is the best control for grid connected DFIG.

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