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Vector Control Technique using GSC and RSC converter for DFIG Based Wind Energy Conversion System

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ABSTRACT: - Integrating alternative renewable energy sources into the electric grid presents various challenges in terms of power quality issues, voltage regulation and stability. Power quality relates to those factors which affect the variation of voltage level and distortion of the voltage and current waveforms, which can cause severe adverse effects on the electric grid. The paper focuses on designing and evaluating a field-oriented vector control strategy for improving the quality of energy of a standalone grid-connected variable speed Doubly Fed Induction Generator (DFIG) wind energy conversion system. A field-oriented control method for back-to-back PWM converters in the DFIG is used in this paper. The control scheme is implemented in the synchronously rotating reference frame and provides precise current control for both the GSC and RSC. The primary objective of the control scheme is to maintain constant voltage and frequency under variable operating conditions of load. The effectiveness of the coordinated control strategy is verified by the MATLAB simulation results on a 3.7-KW DFIG wind power generation system under harmonically distorted standalone voltage conditions.

Keywords: - Doubly fed induction generator, Field oriented control, Sensor less, Standalone Grid, Total Harmonic Distortion.

1. Introduction

Both fixed-speed squirrel cage induction and variable-speed double-fed induction generators are extensively used for Wind Energy conversion systems. In modern times DFIG has discovered increasing applications in wind-turbine generation. DFIG can control the active and reactive power and sustain constant frequency operation. With wind speed deviation or under power system disturbance, the injected rotor voltage, current or the frequency of the injected rotor voltage can be forced to achieve constant frequency and stable operation at the stator or grid side. Considering the prime mover characteristics, the wound rotor induction machine with field-oriented control is very attractive for high-performance variable speed generation applications. In this electric generator organization, the speed of the prime mover is allowed to vary within a certain range (sub-synchronous and super synchronous mode), and the output of electrical power is always maintained at a constant voltage and constant frequency by controlling the slip power from the rotor terminals. An additional fundamental feature of this configuration is that the power converters have to handle the slip power. Thus, their rating is only a fraction of the total system power. Figure 1 shows a standalone generating system with a rotor-side control block diagram. The bidirectional power flow capability is potential by using two back-to-back voltage source inverters through a common dc link. The converters are rotor-side converters and grid-side converters. The grid-side converter is also known as the front-end converter. Much work has been reported on the grid-connected operation of such generators the grid-connected generator. The grid-connected generator technology [1-7] is quite mature and widely used today. However, very little attention has been paid to the issues of standalone generators. While more variable-speed generators are installed in wind farms, several new problems are introduced in power systems.

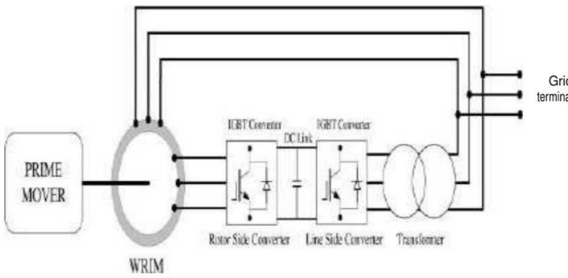

Figure 1 Basic block diagram of DFIG generator with back-to-back converter.

Most of the authors have explained the field-oriented control scheme for regulating stator voltage and frequency. The stator voltage is regulated indirectly by controlling the magnetizing current of the machine, while the stator frequency is kept constant by impressing proper slip frequency currents from rotor terminals. All the schemes have used either speed or position sensors for the control. Recently, work has been reported that attempted sensorless control of a standalone doubly fed generator [9] based on the model reference adaptive system observer scheme. This paper presents a control scheme which addresses nearly all the features of the standalone generation system mentioned above [10]. The control scheme has dedicated voltage and frequency controllers to regulate stator voltage and frequency. The control scheme is novel and sensorless. It acts as a part of the frequency loop. The whole control scheme has been simulated with MATLAB Simulink. Detailed simulation results are presented to demonstrate and validate the control scheme. The control of the rotor side converter for a DFIG machine using a current-controlled PWM voltage source converter has been reported widely [1-7]. With a controlled converter at rotor terminals, rotor currents are controlled in amplitude and frequency by applying suitable rotor voltages from the rotor side converter. The stator flux-oriented frame of reference is used for decoupling the active and reactive current control loops. The q-axis is aligned along the stator voltage vector leading the d-axis by 90◦ while the d-axis is aligned along the grid flux axis (Figure 2). The d-axis controls the machine's flux by controlling the reactive power flow, while the q-axis current loop controls the machine's torque by controlling the active power flow.

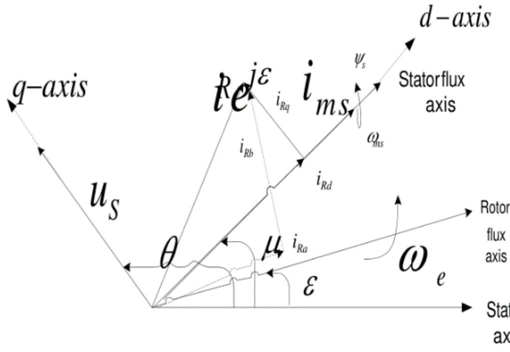

Figure2 Vector diagram of field-oriented control

The dynamic equations governing the rotor currents in the stator flux coordinates [1], [4] are as follows:

2.1. Reference generation for q-axis rotor current loop

$$\sigma T_R \frac{di_{Rd}}{dt} + i_{Rd} - \frac{u_{Rd}}{R_R} = (\omega_{mS} - \omega_e)\sigma T_R i_{Rq} - (1-\sigma) T_R \frac{di_{mS}}{dt} \quad (4)$$

$$\sigma T_R \frac{di_{Rq}}{dt} + i_{Rq} - \frac{u_{Rq}}{R_R} = -(\omega_{mS} - \omega_e)\sigma T_R i_{Rd} - (\omega_{mS} - \omega_e)(1-\sigma) T_R i_{mS} \quad (5)$$

Where

$$\sigma = 1 - \left(L_m^2 / L_s L_r \right)$$

The active component is q of the stator current is measured, the reference for the q component of the rotor current is set using TR (= LR/RR) is the electrical time constant of the rotor circuit and σ (= 1 − (1/ (1 + σS) (1 + σR) is the total leakage factor of the machine. If the stator resistance drop is ignored, these can also be taken as valid for grid flux [1]. These equations are used to design the current control loops. The cross-coupling terms between the d-axis and q-axis (ωmS − ωe) σLRiRq and (ωmS − ωe) σLRiRd and disturbance input (ωmS − ωe) (1 − σ) LRimS are cancelled by feed-forward compensation and thereby independent control of d- axis and q-axis current loops are achieved by adding PI controllers in the loop. For the application of standalone generators, the broad objectives of the rotor side iRa flux e axis Stator axis converter are: 1) establishment of a local grid, 2) changes of voltage and frequency, 3) reference generation for active (q) component of rotor current, 4) Sensor less control. A control strategy is implemented in the rotor side converter through MATLAB Simulink to achieve the objectives.

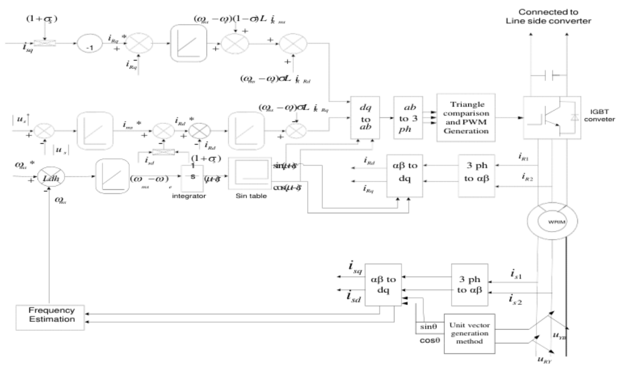

Figure 3 Control Block Diagram of Rotor side Converter

$$i_{Rq} = -(1+\sigma_S)\, i_{Sq} \quad (1)$$

2.2. Design of voltage loop

The stator voltage is regulated by controlling the magnitude of the stator flux. The magnetizing current vector (imS) responsible for producing the stator flux is regulated to control the stator voltage magnitude. The equations governing the dynamics and steady state of the magnetizing current are given in equations 2 and 3.

$$T_S \frac{di_{mS}}{dt} + i_{mS} = (1+\sigma s)\frac{u_{Sd}}{R_S} + i_{Rd} \quad (2)$$

$$i_{mS} = (1+\sigma s) i_{Sd} + i_{Rd} \quad (3)$$

The machine's total magnetizing current, imS, is supplied from the rotor side converter by d-axis rotor current iRd.

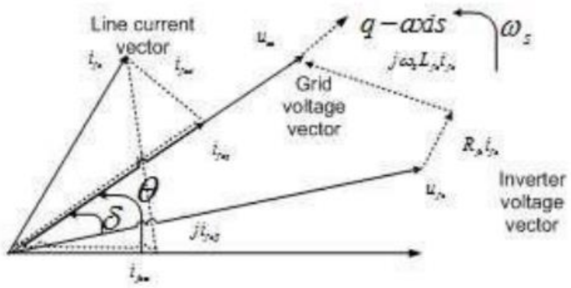

Figure 7 Vector Diagram of Stator side Converter

This is required as there is no initial grid. An external voltage loop is added such that the stator voltage is regulated by controlling the magnitude of imS through the d-axis current control loop. The magnetizing current imS controls the magnitude of the uSq component of stator voltage, leading it by 90 degrees.

2.3. Estimation of grid frequency and design of frequency loop

A dedicated frequency loop is used to regulate the grid frequency. The frequency reference command is nominal grid frequency. Actual stator frequency is estimated using the feedback of the stator line-to-line voltages. Initially, unit vectors are generated using a unit vector generation scheme. With the information of unit vectors, the actual grid frequency is estimated using equation 4.

$$\omega_{ras} = \cos(\theta)\frac{d}{dt}\sin(\theta) - \sin(\theta)\frac{d}{dt}\cos(\theta) \quad (4)$$

The controller's output is the slip frequency command, the frequency at which the rotor voltage needs to be applied from the rotor side converter to maintain constant stator frequency. The prime mover speed variation is sensed indirectly in this scheme. Variation in prime mover speed will reflect in variation in grid frequency for a constant rotor frequency. The difference in frequency is sensed, and the controller takes corrective action to return the stator frequency to the nominal set value.

3. Control of stator side converter

The line side converter control objectives in the standalone generator application are: (1) Regulation of dc link voltage; (2) clean unit vector generation; The line side converter is a current-controlled voltage source converter. The principle of field-oriented control is used to achieve a fast dynamic response. The line currents are controlled in the rotating frame of reference attached to the stator voltage vector. The q-axis is aligned along the stator voltage vector, while the d-axis lags it by 90◦ to maintain compatibility with the rotor side converter control.

3.1. Voltage and current loop

The equations governing the dynamics of line currents in the q-axis and d-axis [1], [4] are given in equations 5, 6.

$$T_{fe}\frac{di_{feq}}{dt} + i_{feq} = -\frac{u^{feq}}{R_{fe}} + \frac{u^{acq}}{R_{fe}} - \omega_s T_{fe} i_{fed} \quad (5)$$

$$T_{fe}\frac{di_{fed}}{dt} + i_{fed} = -\frac{u^{fed}}{R_{fe}} + \omega_s T_{fe} i_{feq} \quad (6)$$

Where, $T_{fe} = \frac{L_{fe}}{R_{fe}}$ is the time constant of line filter impedance.

These equations are used to design inner current control loops. The d-axis and q-axis current loop responses are independent by cancelling the cross-coupling terms (ωSLfeifed and ωSLfeifeq) and disturbance input (uacq) by introducing feed-forward compensation in the loops. The control is achieved by adding a PI controller in the loops. Equation 7 gives the equation governing the dynamics of the dc link:

$$c\frac{du_{dc}}{dt} = (2/3)\left(\frac{u_{acq}}{u_{dc}}\right) i_{feq} - i_L \quad (7)$$

In the above equation, the load current iL acts as a disturbance input and is compensated using feed-forward cancellation. The PI voltage controller is added externally to q-axis current loop to regulate the dc link voltage.

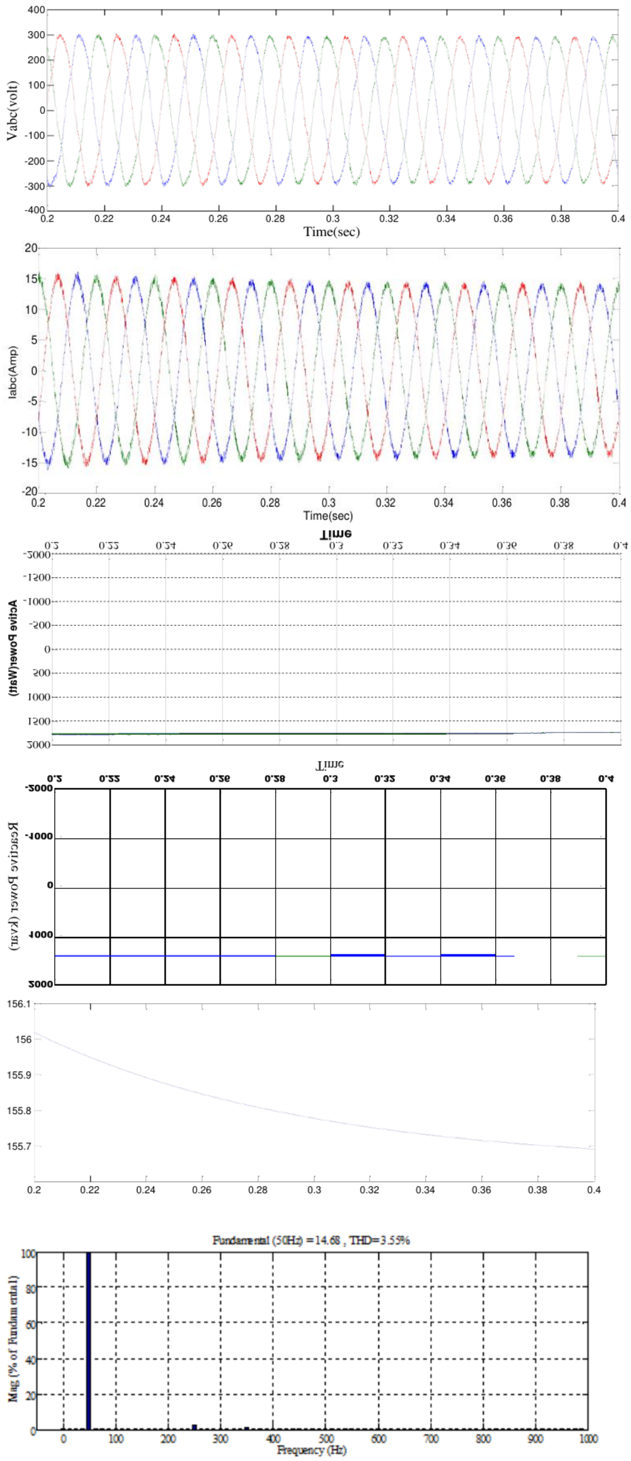

Figure 9 Simulated performance of(a) stator voltage (b) stator current (c) active power (d) reactive power (e) rotor speed (f) Total Harmonics Distortion of VFC for DFIG based under variable wind speed 10m/s with PI controller (at full load) in

4. Simulation results

The simulation results are carried out using MATLAB–Simulink package under a wind speed profile of (8 m/s) mean value, as depicted in Figure 9. The stator voltages, current currents, and frequency are constant under these dynamic changes and are observed in Figure 9(a) and (b). Figures 9 (c) and (d) display the active and reactive powers at the stator side of the DFIG. These quantities under the Simulation results demonstrate the performance of output voltage and current under variable load operation.

5. Conclusion

This paper has presented a device intended to fit in a windmill based on a Doubly Fed Induction Generator connected to the grid. After describing this device and its connection procedure, we have established a two-phase mathematical model of the DFIG. A vector-control strategy has been presented to control stator active and reactive power exchanged between the DFIG and the grid. A vector control scheme for grid-connected generators based on a wound rotor induction machine with rotor side control has been developed. The grid-connected generator's objectives, such as establishing a local grid and regulating its voltage and frequency, are achieved using a novel and simple sensorless scheme using unit vector generation for the DFIG system.

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