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Modeling and Designing a Deadbeat Power Control for Doubly-Fed Induction Generator

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1. Introduction

Renewable energy systems, especially wind energy have attracted interest as a result of the increasing concern about CO₂ emissions. Wind energy systems using a doubly fed induction generator (DFIG) have some advantages due to variable speed operation and four quadrants active and reactive power capabilities compared with fixed speed squirrel cage induction generators (Simões & Farret, 2004).

The stator of DFIG is directly connected to the grid and the rotor is connected to the grid by a bi-directional converter as shown in Figure 1. The converter connected to the rotor controls the active and the reactive power between the stator of the DFIG and ac supply or a stand-alone grid (Jain & Ranganathan, 2008).

The control of the wind turbine systems is traditionally based on either stator-flux-oriented (Chowdhury & Chellapilla, 2006) or stator-voltage-oriented (Hopfensperger et al, 2000) vector control. The scheme decouples the rotor current into active and reactive power components. The control of the active and reactive power is achieved with a rotor current controller. Some investigations using PI controllers and stator-flux-oriented have been reported by Peña et al (2008). The problem with the use of a PI controller is the tuning of gains and the cross-coupling on DFIG terms in the whole operating range.

Some investigations using predictive functional controller (Morren et al, 2005) and internal mode controller (Guo et al, 2008) have presented a satisfactory power response when compared with the power response of PI, but it is hard to implement one of them due to the predictive functional controller and internal mode controller formulation. Another way to achieve the DFIG power control is using fuzzy logic (Yao et al, 2007). The controllers calculate at each sample interval the voltage rotor to be supplied to the DFIG to guarantee that the active and the reactive power reach their desired reference values. These strategies have satisfactory power response, although the errors in parameters estimation and the fuzzy rules can degrade the system response.

The aim of this chapter is to provide the designing and the modeling of a deadbeat power control scheme for DFIG in accordance with the present state of the art. In this way, the deadbeat power control aims the stator active and reactive power control using the discretized DFIG equations in synchronous coordinate system and stator flux orientation. The deadbeat controller calculates the rotor voltages required to guarantee that the stator active and reactive power reach their desired references values at each sample period using a rotor current space vector loop. Experimental results using a TMS320F2812 platform are presented to validate the proposed controller.

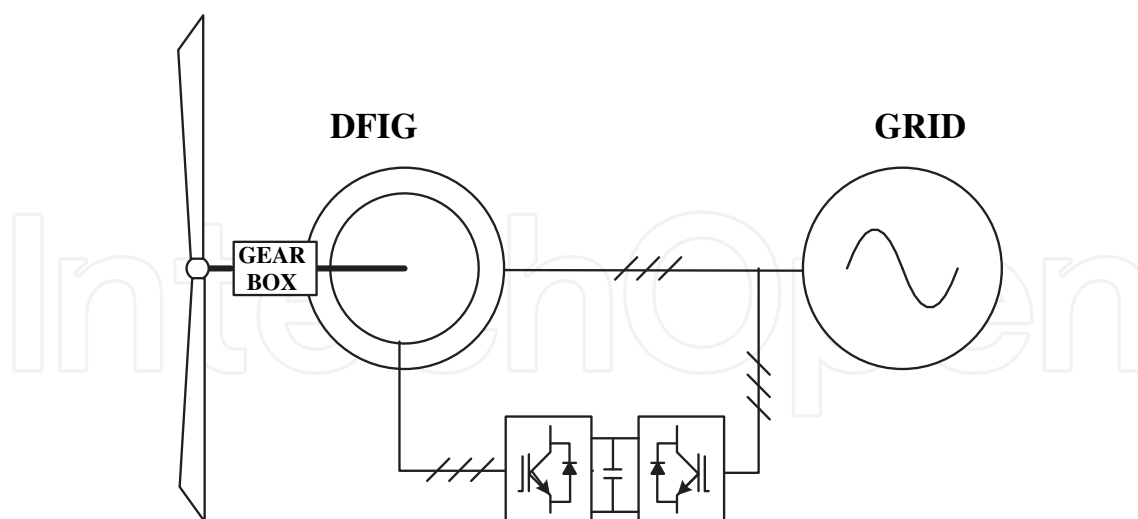


Fig. 1. Configuration of the DFIG directly connected to the grid.

2. Doubly-fed induction machine model

The doubly-fed induction machine model in synchronous reference frame is given by (Leonhard, 1985).

$$\vec{v}_{1dq} = R_1 \vec{i}_{1dq} + \frac{d\vec{\lambda}_{1dq}}{dt} + j\omega_1 \vec{\lambda}_{1dq} \quad (1)$$

$$\vec{v}_{2dq} = R_2 \vec{i}_{2dq} + \frac{d\vec{\lambda}_{2dq}}{dt} + j(\omega_1 - NP\omega_{mec}) \vec{\lambda}_{2dq} \quad (2)$$

The relationship between fluxes and currents is done by

$$\vec{\lambda}_{1dq} = L_1 \vec{i}_{1dq} + L_m \vec{i}_{2dq} \quad (3)$$

and

$$\vec{\lambda}_{2dq} = L_m \vec{i}_{1dq} + L_2 \vec{i}_{2dq} \quad (4)$$

Where $\vec{v}$, $\vec{i}$, $\vec{\lambda}$ are voltage, currents and flux space vectors respectively, R is resistance of the winding, L is inductance of the winding, the subscripts 1, 2, m denotes stator, rotor and mutual, NP is the pole pairs and ω_{mec} is the mechanical rotor speed.

The electromagnetic torque is given by

$$T_e = \frac{3}{2} NP \cdot \text{Im} \left\{ \vec{i}_1 \vec{\lambda}_1^* \right\} \quad (5)$$

The superscript $*$ represents the complex conjugate and Im represents the imaginary component of the result.

The mechanical dynamics of the machine is given by:

$$J \frac{d}{dt} \omega_{mec} = T_e - T_L \quad (6)$$

Where J is the load and rotor inertia moment and T_L is the load torque.
The induction machine active power P is

$$P = (v_{1d} i_{1d} + v_{1q} i_{1q}) \quad (7)$$

and the reactive power Q is

$$Q = (v_{1q} i_{1d} - v_{1d} i_{1q}) \quad (8)$$

2.1 Power control principles using stator field orientation

The DFIG power control aims independent stator active P and reactive Q power control by means a rotor current regulation. For this propose, the stator field orientation (Novotny & Lipo, 1996) technique is used. Thus, the P and Q are represented as functions of each individual rotor current using the stator flux space vector position. In the synchronous system reference frame dq , the synchronous speed ω_1 is the speed of the stator flux vector and it is given by

$$\frac{d\delta_s}{dt} = \omega_1 \quad (9)$$

The stator flux space vector transformation from stationary reference frame $\alpha\beta$ to the synchronous system reference frame dq is given by:

$$\begin{aligned} \vec{\lambda}_{1dq} &= \lambda_{1d} + j\lambda_{1q} = \\ &= \vec{\lambda}_{1\alpha\beta} e^{-j\delta_s} = (\lambda_{1\alpha} + j\lambda_{1\beta}) [\cos(\delta_s) - j\sin(\delta_s)] \end{aligned} \quad (10)$$

Therefore, the components of the direct and quadrature axis become:

$$\lambda_{1d} = [\lambda_{1\alpha} \cos(\delta_s) + \lambda_{1\beta} \sin(\delta_s)] \quad (11)$$

and

$$\lambda_{1q} = [\lambda_{1\beta} \cos(\delta_s) - \lambda_{1\alpha} \sin(\delta_s)] \quad (12)$$

Thus, by using the stator flux orientation, the flux space vector components become:

$$\lambda_1 = \lambda_{1d} = |\vec{\lambda}_{1dq}| = \sqrt{\lambda_{1d}^2 + \lambda_{1q}^2} \quad (13)$$

and

$$\lambda_{1q} = 0 \quad (14)$$

The relationship between the fluxes and currents of Equation (3) becomes, respectively:

$$\lambda_1 = L_1 i_{1d} + L_m i_{2d} \quad (15)$$

and

$$0 = L_1 i_{1q} + L_m i_{2q} \quad (16)$$

In the same way of the stator flux vector components, the stator voltage vector components become:

$$v_{1d} = 0 \quad (17)$$

and

$$v_1 = v_{1q} = |\vec{v}_{1dq}| = \sqrt{v_{1d}^2 + v_{1q}^2} \quad (18)$$

Now, the active power can be calculated substituting the expression of i_{1q} using Equation (16), the value of v_{1d} of Equation (17) and the value of v_{1q} using Equation (18) in the Equation (7). The new active power expression, using the rotor quadrature axis current i_{2q} , is given by

$$P = -\frac{3L_m}{2L_1} v_1 i_{2q} \quad (19)$$

In the same way of the active power, the reactive power can be calculated by substituting the expression of i_{1d} using Equation (15), the value of v_{1d} of Equation (17) and the value of v_{1q} using Equation (18) in the Equation (8). The new reactive power expression, using the rotor direct axis current i_{2d} , is given by:

$$Q = \frac{3}{2} v_1 \left(\frac{\lambda_1}{L_1} - \frac{L_m}{L_1} i_{2d} \right) \quad (20)$$

From Equations (19) and (20), the stator power can be calculated using the rotor current space vector components. As the stator of the doubly-fed induction generator is directly connected to the grid, the magnitude of the stator flux space vector and the stator voltage space vector is constant. Thus, the independent stator active and reactive power control is achieved through rotor current space vector control.

3. Deadbeat control theory

The deadbeat control is a digital control technique that allows to calculate the required input $\bar{u}(k)$ to guarantee that the output $\bar{x}(k)$ will reach their desired reference values in N samplings intervals using a discrete equation of the continuous linear system (Franklin et al, 1994).

A linear continuous system (Ogata, 2002) can be represented by

$$\begin{aligned} \dot{\bar{x}} &= A\bar{x} + B\bar{u} + G\bar{\omega} \\ \bar{y} &= C\bar{x} \end{aligned} \quad (21)$$

Where ω denotes the perturbation vector and A , C , B and G are $n \times n$ matrices. In this paper $C = I$, where I is the identity matrix.

The Equation (21) can be discretized considering T as the sampling period and k as the sampling time. Thus, using zero-order-hold (ZOH) with no delay Equation (21) becomes

$$\bar{x}(k+1) = A_d \bar{x}(k) + B_d \bar{u}(k) + G_d \bar{\omega}_d(k) \quad (22)$$

Where

$$\begin{aligned} A_d &= e^{AT} = I + AT \\ B_d &= \int_0^T e^{A(T-\tau)} B d\tau = BT \\ G_d &= \int_0^T e^{A(T-\tau)} G d\tau = GT \end{aligned} \quad (23)$$

The input calculation to guarantee a null steady state error (Franklin et al, 1994) is given by

$$\bar{u}(k) = F(\bar{x}_{ref} - \bar{x}) \quad (24)$$

Where $\bar{x}_{ref} = \bar{x}(k+1)$ and it is the reference vector and F is the gain matrix.

Substituting (24) in (22) and making $\bar{x}_{ref} = \bar{x}(k+1)$ the input that guarantees a null steady state error is given by

$$\bar{u}(k) = B_d^{-1} A_d [A_d^{-1} \bar{x}_{ref} - \bar{x}(k)] - A_d^{-1} G_d \bar{\omega}_d \quad (25)$$

The block diagram of the deadbeat control is presented in Figure 2.

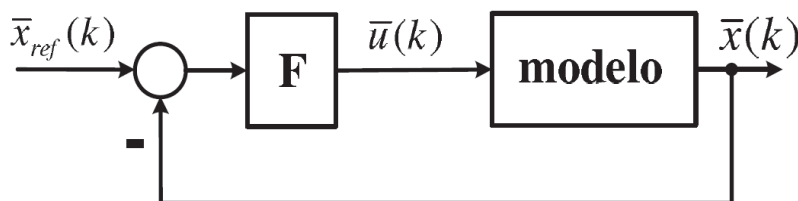


Fig. 2. Deadbeat control block diagram.

4. Deadbeat power control for doubly-fed induction generator

4.1 Rotor side equations

The stator power control of DFIG is made by the rotor current control using the stator field orientation. Thus, the rotor state space equation was necessary in the application of the deadbeat control theory in which the rotor current space vector in synchronous reference frame dq is the state variable. In this way, the rotor voltage space vector substituting Equation (4) in Equation (2) is given by

$$\vec{v}_{2dq} = R_2 \vec{i}_{2dq} + \frac{d(L_m \vec{i}_{1dq} + L_2 \vec{i}_{2dq})}{dt} + j(\omega_1 - NP\omega_{mec})(L_m \vec{i}_{1dq} + L_2 \vec{i}_{2dq}) \quad (26)$$

Which means

$$v_{2d} = R_2 i_{2d} + \frac{d(L_m i_{1d} + L_2 i_{2d})}{dt} - (\omega_1 - NP\omega_{mec})(L_m i_{1q} + L_2 i_{2q}) \quad (27)$$

and

$$v_{2q} = R_2 i_{2q} + \frac{d(L_m i_{1q} + L_2 i_{2q})}{dt} + (\omega_1 - NP\omega_{mec})(L_m i_{1d} + L_2 i_{2d}) \quad (28)$$

Thus, substituting the stator direct axis current i_{1d} of Equation (15) in the derivative of Equation (27) and substituting the stator quadrature axis current i_{1q} of Equation (16) in the derivative of Equation (28), the rotor voltage equations are done by

$$v_{2d} = R_2 i_{2d} + \frac{d}{dt} \left[L_m \left(\frac{\lambda_1}{L_1} - \frac{L_m}{L_1} i_{2d} \right) + L_2 i_{2d} \right] - (\omega_1 - NP\omega_{mec})(L_m i_{1q} + L_2 i_{2q}) \quad (29)$$

and

$$v_{2q} = R_2 i_{2q} + \frac{d}{dt} \left[L_m \left(-\frac{L_m}{L_1} i_{2q} \right) + L_2 i_{2q} \right] + (\omega_1 - NP\omega_{mec})(L_m i_{1d} + L_2 i_{2d}) \quad (30)$$

In this work, the stator of the DFIG is directly connected to the grid and the stator voltage has constant frequency and magnitude. Thus, the magnitude of the stator flux is also constant and in this case $\frac{d\lambda_1}{dt} = 0$. Therefore, the rotor voltage equations become

$$v_{2d} = R_2 i_{2d} - L_2 \omega_{sl} i_{2q} + \left(\frac{L_1 L_2 - L_m^2}{L_1} \right) \frac{di_{2d}}{dt} - L_m \omega_{sl} i_{1q} \quad (31)$$

and

$$v_{2q} = R_2 i_{2q} + L_2 \omega_{sl} i_{2d} + \left(\frac{L_1 L_2 - L_m^2}{L_1} \right) \frac{di_{2q}}{dt} + L_m \omega_{sl} i_{1d} \quad (32)$$

which means

$$\vec{v}_{2dq} = (R_2 + jL_2 \omega_{sl}) \vec{i}_{2dq} + \left(\frac{L_1 L_2 - L_m^2}{L_1} \right) \frac{d\vec{i}_{2dq}}{dt} + jL_m \omega_{sl} \vec{i}_{1dq} \quad (33)$$

Where $\omega_{sl} = \omega_1 - NP\omega_{mec}$.

In the state-space form, Equation (33) becomes:

$$\dot{\vec{i}}_2 = H \vec{i}_2 + K \vec{v}_2 + L \vec{i}_1 \quad (34)$$

which means

$$\begin{aligned} \begin{bmatrix} \frac{di_{2d}}{dt} \\ \frac{di_{2q}}{dt} \end{bmatrix} &= \begin{bmatrix} \frac{-R_2}{\sigma L_2} & \frac{\omega_{sl}}{\sigma} \\ \frac{-\omega_{sl}}{\sigma} & \frac{-R_2}{\sigma L_2} \end{bmatrix} \begin{bmatrix} i_{2d} \\ i_{2q} \end{bmatrix} + \\ &+ \begin{bmatrix} \frac{1}{\sigma L_2} & 0 \\ 0 & \frac{1}{\sigma L_2} \end{bmatrix} \begin{bmatrix} v_{2d} \\ v_{2q} \end{bmatrix} + \begin{bmatrix} 0 & \frac{\omega_{sl} L_m}{\sigma L_2} \\ \frac{-\omega_{sl} L_m}{\sigma L_2} & 0 \end{bmatrix} \begin{bmatrix} i_{1d} \\ i_{1q} \end{bmatrix} \end{aligned} \quad (35)$$

Where $\sigma = 1 - \frac{L_m^2}{L_1 L_2}$.

From now on, it will be assumed that the mechanical time constant is much greater than the electrical time constants. Thus, $\omega_{mec} = \text{constant}$ is a valid approximation for a sample time. Since the synchronous speed ω_1 is fixed by the grid and $\omega_{sl} = \omega_1 - NP \omega_{mec}$, $\omega_{sl} = \text{constant}$ is also a valid approximation for a sample time (Sguarezi Filho et al., 2011).

4.2 Deadbeat power control

The DFIG power control scheme uses a deadbeat controller to obtain rotor voltages which should be applied on induction generator in order to guarantee the active and reactive power reach their desired reference values in a few sample intervals. The sample time T interval is the same time of PWM modulator. The power control is made using the rotor current space vector control in the synchronous reference frame dq .

Equation (35) can be discretized, since the rotor applied voltage remains constant during a control period of the PWM voltage source inverter. Thus, Equation (35) can be discretized using Equations (22) and (23), considering the mentioned hypothesis above and making:

- $\bar{x} = \bar{i}_2$;
- $A = H$;
- $B = K$;
- $\bar{u} = \bar{v}_2$;
- $G = L$;
- $\bar{w} = \bar{i}_1$.

The discrete equation of the rotor voltage is shown in Equation (36).

$$\bar{i}_2(k+1) = A_d \bar{i}_2(k) + B_d \bar{v}_2(k) + G \bar{i}_1(k) \quad (36)$$

which means

$$\begin{bmatrix} i_{2d}(k+1) \\ i_{2q}(k+1) \end{bmatrix} = \begin{bmatrix} 1 - \frac{R_2 T}{\sigma L_2} & \frac{\omega_{sl} T}{\sigma} \\ \frac{-\omega_{sl} T}{\sigma} & 1 - \frac{R_2 T}{\sigma L_2} \end{bmatrix} \begin{bmatrix} i_{2d}(k) \\ i_{2q}(k) \end{bmatrix} + \begin{bmatrix} \frac{T}{\sigma L_2} & 0 \\ 0 & \frac{T}{\sigma L_2} \end{bmatrix} \begin{bmatrix} v_{2d}(k) \\ v_{2q}(k) \end{bmatrix} + \begin{bmatrix} 0 & \frac{\omega_{sl} L_m T}{\sigma L_2} \\ \frac{-\omega_{sl} L_m T}{\sigma L_2} & 0 \end{bmatrix} \begin{bmatrix} i_{1d}(k) \\ i_{1q}(k) \end{bmatrix} \quad (37)$$

Where

$$A_d = e^{AT} = I + AT = \begin{bmatrix} 1 - \frac{R_2 T}{\sigma L_2} & \frac{\omega_{sl} T}{\sigma} \\ \frac{-\omega_{sl} T}{\sigma} & 1 - \frac{R_2 T}{\sigma L_2} \end{bmatrix} \quad (38a)$$

$$B_d = \int_0^T e^{AT} B d\tau = BT = \begin{bmatrix} \frac{T}{\sigma L_2} & 0 \\ 0 & \frac{T}{\sigma L_2} \end{bmatrix} \quad (38b)$$

$$G_d = \int_0^T e^{AT} G d\tau = GT = \begin{bmatrix} 0 & \frac{\omega_{sl} L_m T}{\sigma L_2} \\ -\frac{\omega_{sl} L_m T}{\sigma L_2} & 0 \end{bmatrix}$$

The rotor voltage which is calculated to guarantee null steady state error using Equations (24) and (37) is given by

$$v_{2d}(k) = \sigma L_2 \frac{i_{2d_{ref}} - i_{2d}(k)}{T} + R_2 i_{2d}(k) - L_2 \omega_{sl} i_{2q}(k) - L_m \omega_{sl} i_{1q}(k) \quad (39)$$

and

$$v_{2q}(k) = \sigma L_2 \frac{i_{2q_{ref}} - i_{2q}(k)}{T} + R_2 i_{2q}(k) + L_2 \omega_{sl} i_{2d}(k) + L_m \omega_{sl} i_{1d}(k) \quad (40)$$

The rotor current space vector references are $i_{2d_{ref}} = i_{2d}(k+1)$ and $i_{2q_{ref}} = i_{2q}(k+1)$.

For the active power control, the rotor current quadrature axis reference using Equation (19) is given by

$$i_{2q_{ref}} = -\frac{2P_{ref}L_1}{3v_1L_m} \quad (41)$$

Using Equation (20) for the reactive power control, the rotor current direct axis reference is

$$i_{2d_{ref}} = -\frac{2Q_{ref}L_1}{3v_1L_m} + \frac{\lambda_1}{L_m} \quad (42)$$

Thus, if the d and q axis of the rotor voltage space vector components are calculated according to Equations (39)-(42) mentioned above and they are applied to the generator, then the active and reactive power convergence to their respective commanded values will occur in a few sampling intervals. The space vector modulation using the desired rotor voltage in the rotor stationary reference frame $\alpha\beta r$ generates switching signals for the rotor side inverter. The transformation from dq reference frame to the $\alpha\beta r$ reference frame is done by:

$$\begin{aligned} \vec{v}_{2\alpha\beta r}(k) &= \vec{v}_{2dq} e^{j(\delta_s - \delta_r)} = \left[v_{2d} \cos(\delta_s - \delta_r) - v_{2q} \sin(\delta_s - \delta_r) \right] + \\ &+ j \left[v_{2d} \sin(\delta_s - \delta_r) + v_{2q} \cos(\delta_s - \delta_r) \right] \end{aligned} \quad (43)$$

In this work the back to back converter is used in the power control strategy. The rotor voltage calculated using the deadbeat control theory will allow to drive the inverter connected to the rotor of DFIG. The converter that is connected to the grid controls the DC-

link voltage and this one can be controlled by a current control presented by Rodríguez et al. (2005). The Deadbeat power control block diagram is shown in Figure 3 and a detailed block diagram of the deadbeat power control implementation is shown in Figure 4.

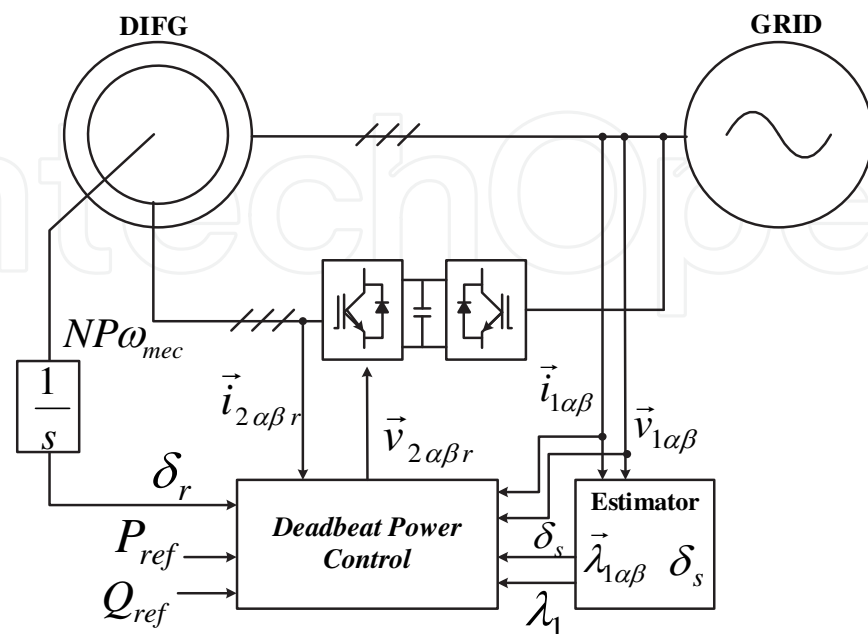


Fig. 3. Deadbeat power control diagram for DFIG.

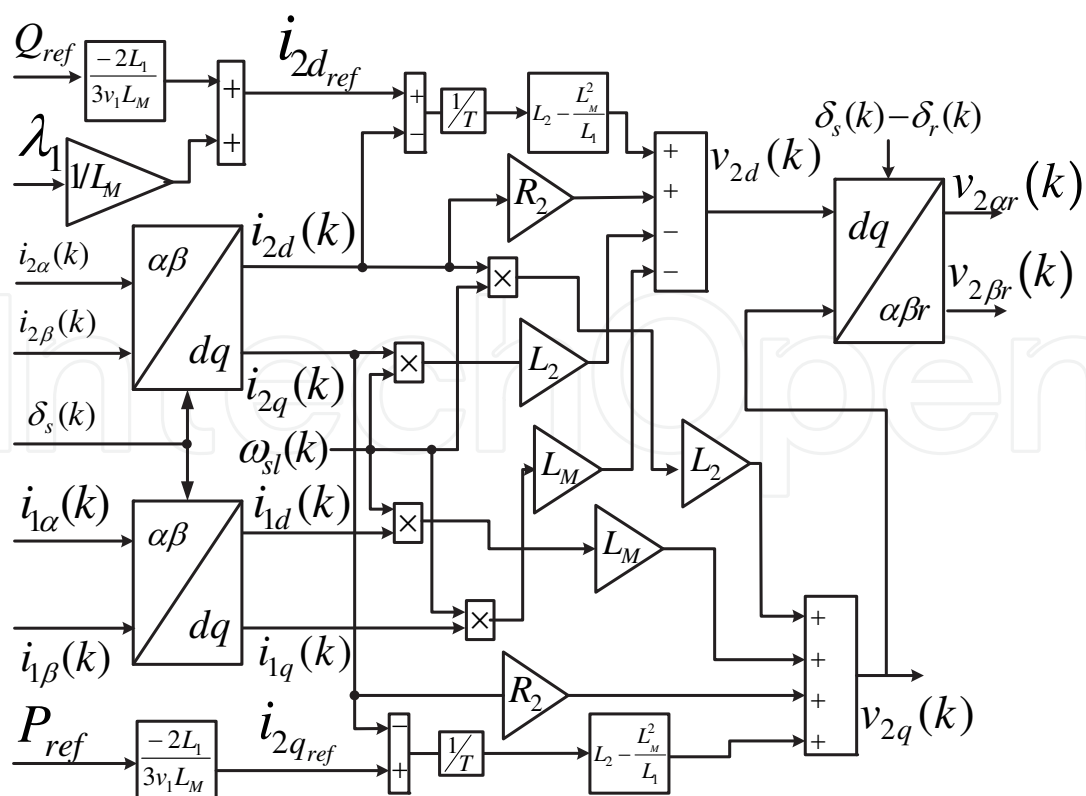


Fig. 4. Detailed deadbeat power control algorithm.

Stator currents and voltages, rotor speed and currents are measured to stator flux position and magnitude, synchronous frequency and slip frequency estimation.

4.3 Estimation

The stator flux estimation in stationary reference frame $\alpha\beta$ is given by

$$\vec{\lambda}_{1\alpha\beta} = \int f e m_{1\alpha\beta} dt = \int (\vec{v}_{1\alpha\beta} - R_1 \vec{i}_{1\alpha\beta}) dt \quad (44)$$

The position of stator flux is estimated by using the trigonometric function and it is given by

$$\delta_s = \tan^{-1} \left(\frac{\lambda_{1\beta}}{\lambda_{1\alpha}} \right) \quad (45)$$

The synchronous speed ω_1 estimation is given by

$$\omega_1 = \frac{d\delta_s}{dt} = \frac{(v_{1\beta} - R_1 i_{1\beta})\lambda_{1\alpha} - (v_{1\alpha} - R_1 i_{1\alpha})\lambda_{1\beta}}{(\lambda_{1\alpha})^2 + (\lambda_{1\beta})^2} \quad (46)$$

and the slip speed estimation using the rotor speed and the synchronous speed is

$$\omega_{sl} = \omega_1 - NP\omega_{mec} \quad (47)$$

The angle in rotor reference frame is

$$\delta_s - \delta_r = \int \omega_{sl} dt \quad (48)$$

5. Experimental results

The deadbeat power control strategy was implemented with a Texas Instruments DSP TMS320F2812 platform which also has a $T = 400\mu s$. The system consists of a three-phase voltage source inverter with insulated-gate bipolar transistors (IGBTs) and the three-phase doubly-fed induction generator and its parameters are shown in the appendix. The rotor voltage commands are modulated by using symmetrical space vector PWM, with switching frequency equal to 2.5 kHz. The DC bus voltage of the inverter is 36 V. The stator voltages and currents are sampled in the frequency of 2.5 kHz. The encoder resolution is 3800 pulses per revolution.

The algorithm of the deadbeat control was programmed on the Event Manager 1 of the Texas Instruments DSP TMS320F2812 platform and its flowchart is presented in Figure 5. The schematic of the implementation of the experimental setup is presented in Figure 6 and the experimental setup is shown in Figure 7.

Six tests were made, five in the subsynchronous operation and one in several speed operations from supersynchronous to subsynchronous operation. The first one was the response of i_{2d} step from 0.5A to 5 A which is shown in Figure 8 (a) and the satisfactory performance of the controller can be seen due to the fact that the reference was followed. In this test the i_{2q} is 0.5A.

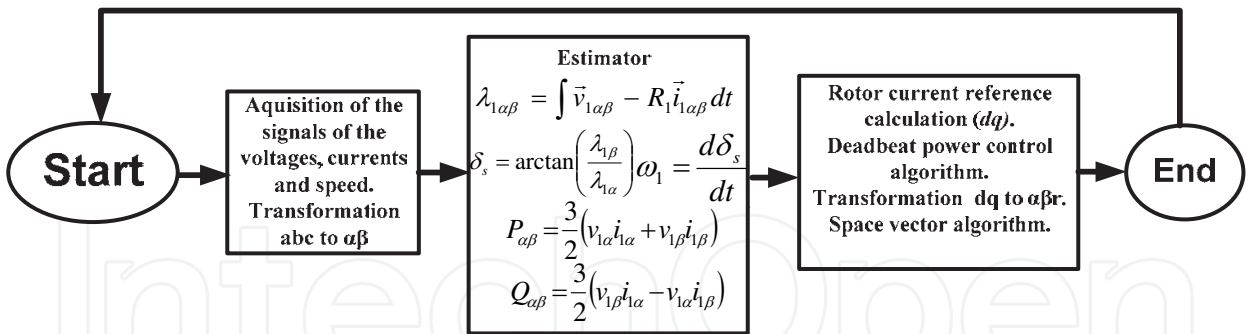


Fig. 5. The flowchart of the DSP program.

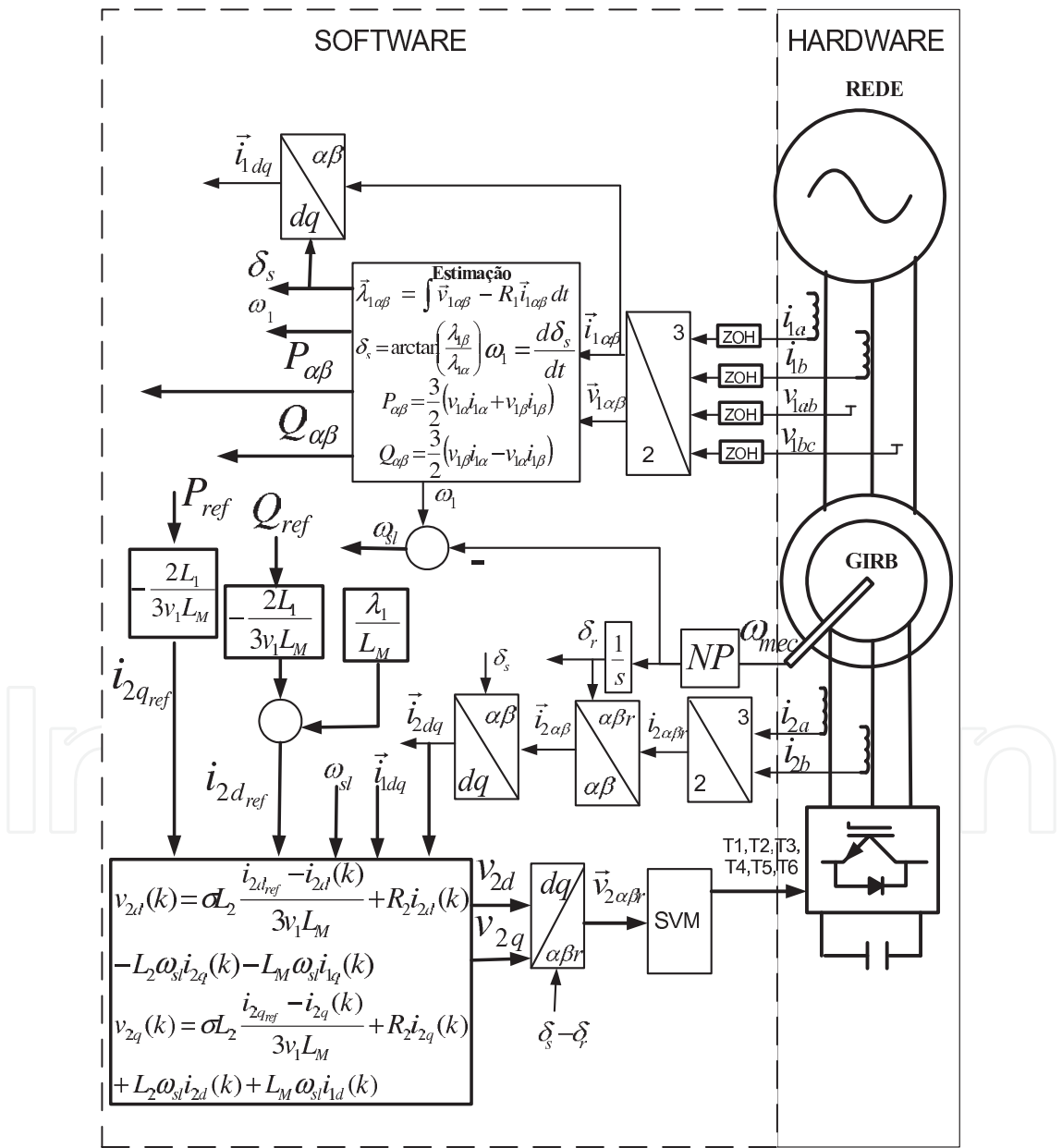


Fig. 6. The schematic of the implementation of the deadbeat power control setup.

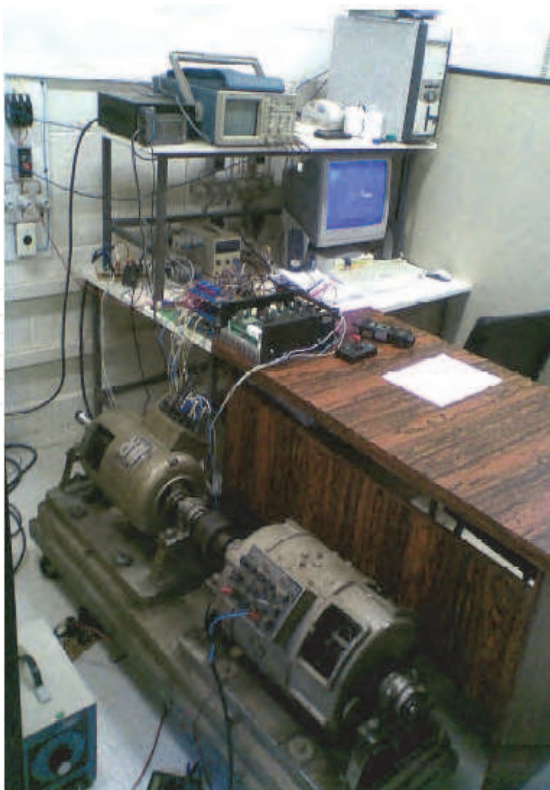
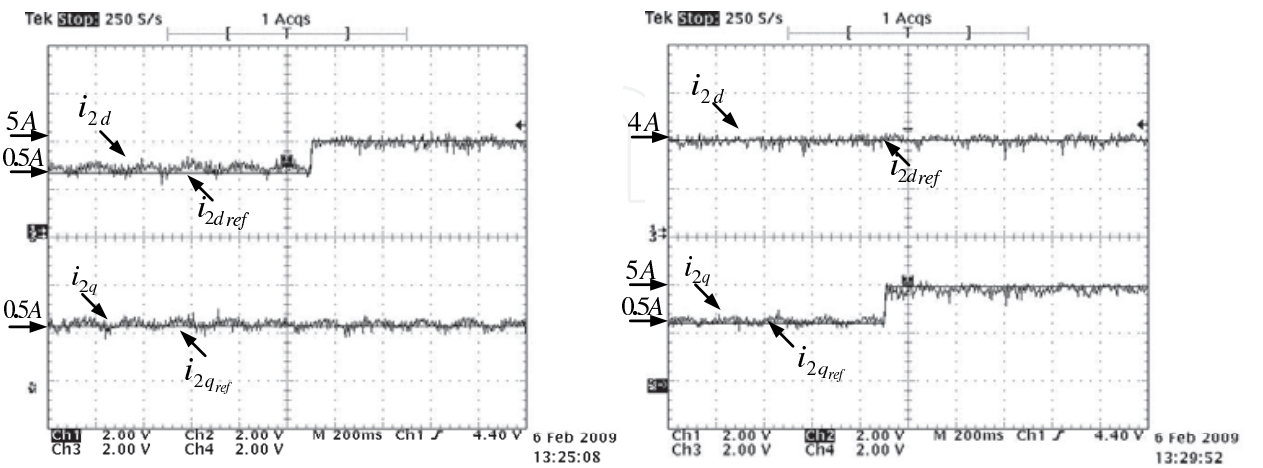


Fig. 7. Experimental Setup.

The second one was the response of i_{2q} step from 0.5A to 5 A. The satisfactory performance of the controller in this test can be seen in Figure 8 (b), due to the fact that the reference was followed. In this test i_{2d} is 4A.

The same test of the i_{2q} step from 0A to 5A, as mentioned above, with rotor currents in rotor reference frame is presented in Figure 9. In this test the i_{2d} is 5A. The satisfactory response of the controller can be seen due to the fact that the reference was followed and the amplitude of the rotor *ac* currents increased.



(a) Response of step test of the i_{2d} . (b) Response of step test of the i_{2q} .
Fig. 8. Response of step test of the rotor current (1.33A/div.).

The fourth test was the response of the reactive power Q_{ref} of -300VA, 300VA and 0VA which means lag, lead and unitary power factor. The active power reference is -300W. The rotor current references were calculated using Equations (41) and (42). The satisfactory performance of the controller can be seen in Figure 10(a), due to the fact that the reference was followed. The rotor current is shown in Figure 10(b).

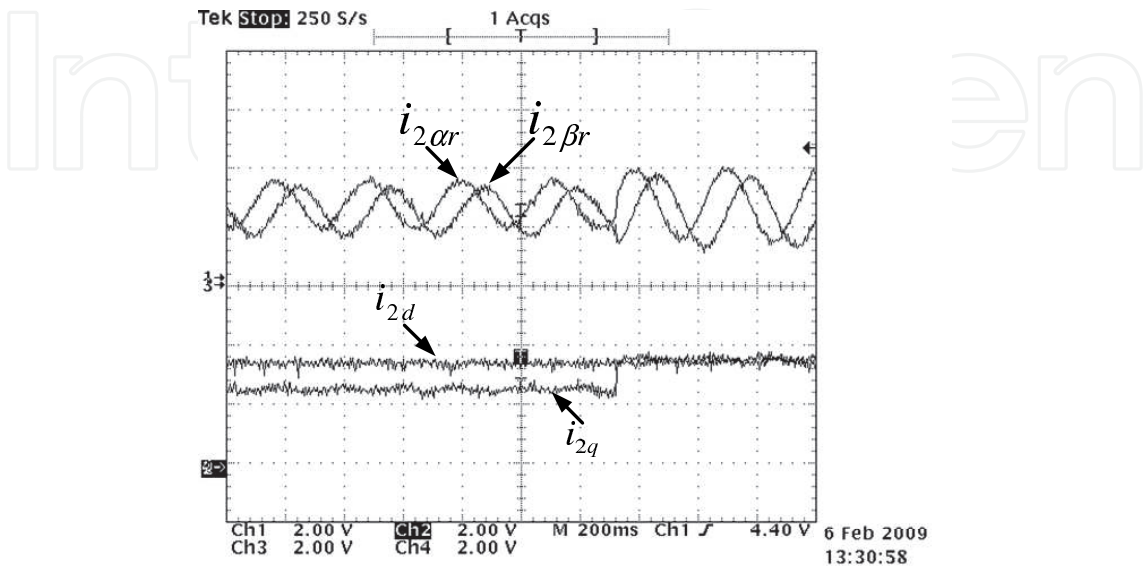
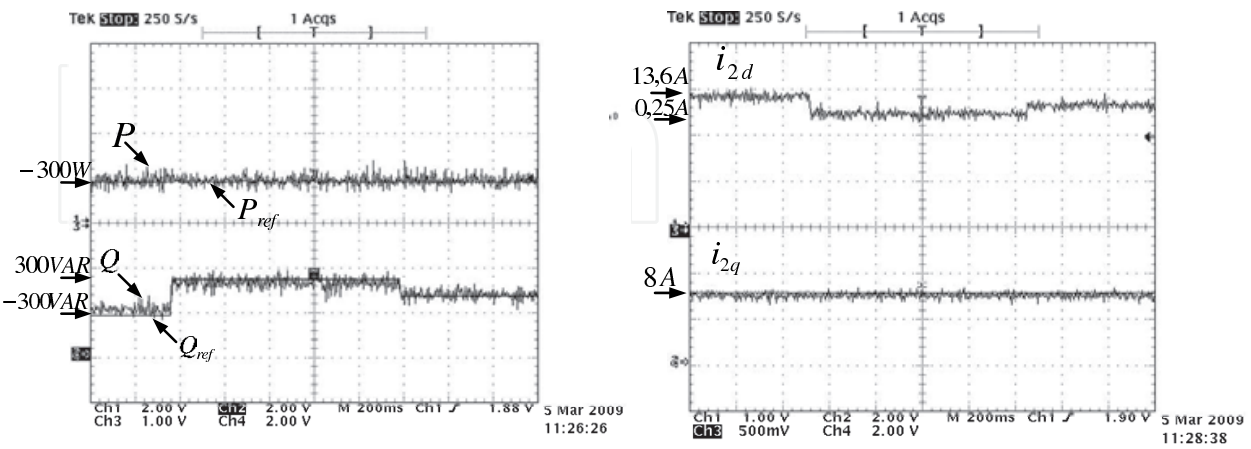


Fig. 9. Response of step test for i_{2q} (1.66 A/div.).

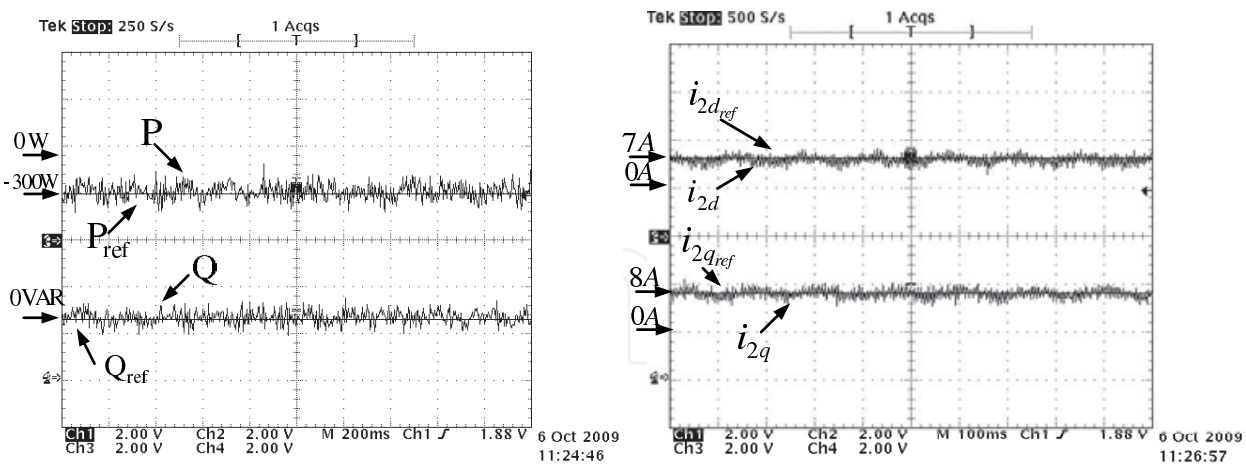
The fifth test was the steady state of unitary power factor and the active power was -300W. Again, the rotor current references were calculated using Equations (41) and (42). The response of stator power and rotor current are presented in Figures 11(a) and 11(b), respectively. The stator voltage (127Vrms) and the stator current (0.8Arms) are shown in Figure 12. The satisfactory performance of the controller can be seen because the angle between the stator voltage and the stator current is 180°.



(a) Response of step test of the reactive power (800VA/div.).

(b) Response of step test of the i_{2d} (28A/div.).

Fig. 10. Response of step of reactive power and rotor direct axis current.



(a) Response of test of the active and the reactive power (300VA/div.).

(b) Response of test of the rotor current (8A/div.).

Fig. 11. Response of steady state test of unitary power factor and the rotor current.

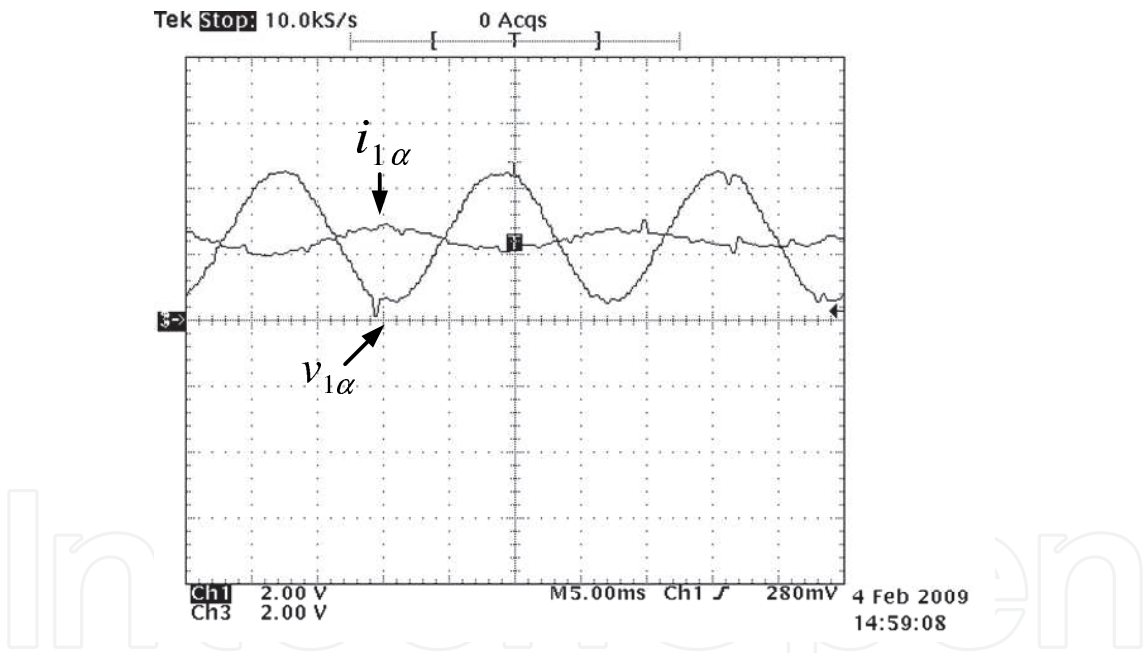
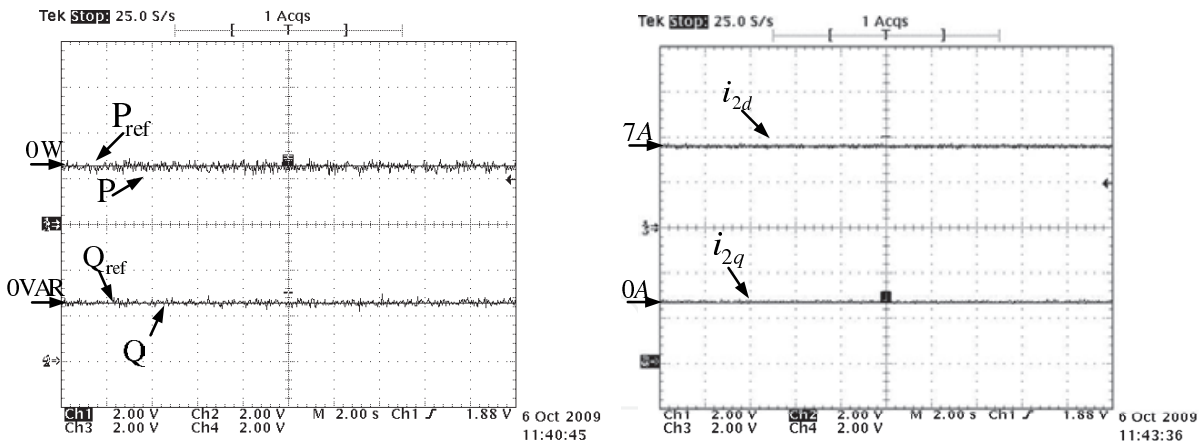


Fig. 12. The stator voltage(18V/div.) and current (0.38A/div.).

In the last test, the generator operates with several speed from 1850 rpm to 1750 rpm and a constant active and reactive power reference of 0W and 0VA, respectively. The rotor current references were also calculated using Equations (41) and (42). So, $i_{2dref}=7A$ and $i_{2qref}=0A$. In this case, this test just maintains the magnetization of the generator. The response of the active and reactive power is shown in Figure 13(a) and the rotor current is presented in Figure 13(b). The rotor speed in several operations and the rotor current of phase α are shown in Figure 14. The satisfactory performance of the controller can be seen during several speed operations, since the reference was followed.



(a) Response of constant active and reactive power. (b) Response of constant rotor current.

Fig. 13. Response of the active and reactive power and rotor current.

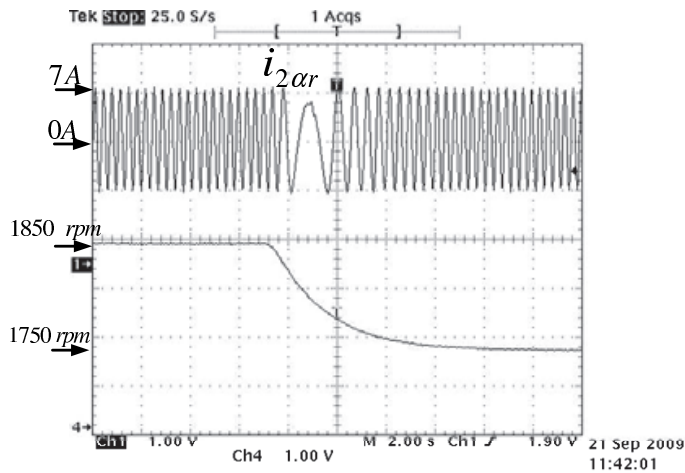


Fig. 14. Rotor speed and current of phase α (7A/div.).

6. Conclusion

This book chapter has presented a model and design of a deadbeat power control scheme for a doubly-fed induction generator using a deadbeat control theory and rotor current space vector loop. The stator field orientation technique allows the independent control of the rotor current components in synchronous reference frame dq , in this case, the direct and quadrature axis of the rotor current space vector. Thus, the control of the rotor current components allows controlling the active and reactive power of the generator. The deadbeat controller uses the DFIG discretized equations to calculate at each sample period the required rotor voltages, so that the active and reactive power values reach the desired reference values. Thus, the deadbeat controller does not need to tune gains as the PI controllers. This strategy constant switching frequency overcomes the drawbacks of conventional direct power control (Xu & Cartwright, 2006). The experimental results confirm the effectiveness of the power controller during several operating conditions of generator speed. Thus, the deadbeat power control strategy is an interesting tool for doubly-fed power control in wind turbines.

7. Acknowledgment

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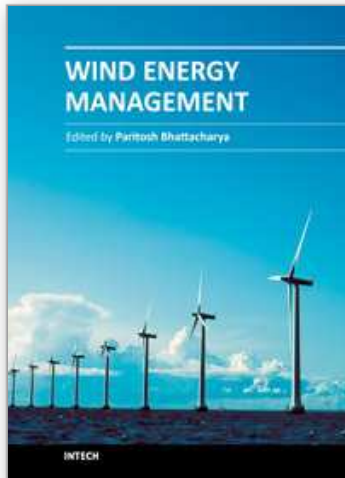
8. Appendix

Doubly-fed induction generator parameters:

$R_1 = 2.2 \, \Omega$; $R_2 = 1.764 \, \Omega$; $L_m = 0.0829 \, \text{H}$; $L_{l1} = 0.0074 \, \text{H}$; $L_{l2} = 0.0074 \, \text{H}$; $J = 0.05 \, \text{Kg.m}^2$; $NP = 2$; $PN = 2.25 \, \text{kW}$; $V_N = 220 \, \text{V}$.

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