Predictive-Integral Current Controller for Active- and Reactive-Power Control of Wind Generators

Pedro Roncero-Sánchez[1], Vicente Feliu[1] and Aurelio García-Cerrada[2]

[1]Department of Electrical, Electronics, Control Engineering and Communications
E.T.S.I. Industriales, Universidad de Castilla-La Mancha. Avda. Camilo José Cela S/N, 13071, Ciudad Real, (Spain)
Phone:+34 926 29 53 00. e-mail: **Pedro.Roncero@uclm.es**, **Vicente.Feliu@uclm.es**

[2]Department of Electronics and Control Engineering
E.T.S. de Ingeniería ICAI, Universidad Pontificia Comillas. C/ Alberto Aguilera 23, 28015, Madrid, (Spain)
Phone:+34 91 542 28 00. e-mail: **aurelio@iit.upcomillas.es**

Abstract

This paper deals with the design of a predictive-integral current controller for wind generators connected to the grid. The goal is to achieve a decoupled control of d- and q-axes current components at the connection point and a deadbeat closed-loop system. The robustness of the closed-loop dynamic response and the active and reactive-power coupling are studied.

Key words

Wind generator, voltage-source converter, deadbeat system, predictive control, robust control

1 Introduction

Electricity generation making use of wind energy has experienced a great growth in the last few years [1]. A wind generator must transfer the energy efficiently to the grid or to the load while supplying the necessary reactive power and, for this purpose, current-controlled voltage-source electronic converters are normally used.

Current controllers can be classified into two main groups [2], namely, (a) linear controllers with conventional pulse-width modulators and, (b) non-linear controllers. A type of linear current control scheme is the predictive current controller, where the output voltage is calculated to make the measured current to track the reference based on a predictive model [3]. The implementation of these controllers is not ideal due to factors such as modelling errors, which may substantially affect the dynamic performance. Research work has been reported on predictive current controllers applied to power-electronic converters [4–6].

This work deals with the design of a predictive-integral current controller to implement active- and reactive-power control in a wind generator, obtaining a decoupled deadbeat closed-loop system. An integral action is added to guarantee zero tracking error in steady state for step changes in the reference, even when there are parameter errors. The dynamic performance is also studied.

2 Model of the grid-connection system

Fig. 1 shows the configuration of a wind generator. The main elements are an induction machine driven by a wind turbine, the generator converter, the grid converter and an inductive filter plus a transformer at the grid side.

The generator converter controls the wind generator, resulting in a real power p_g flowing into the d.c.-link capacitor, and the grid converter controls the active power flowing into the grid (p) and the reactive power required (q).

By using a power-invariant Park's transformation and by choosing a rotating reference frame so that the v_q component is always zero, the instantaneous real power, p, and the instantaneous reactive power, q injected into the grid by the converter are:

$$p = v_d i_d,\; q = -v_d i_q \tag{1}$$

Hence p and q can be controlled by i_d and i_q, respectively. A decoupled equivalent discrete-time state-variable model can be obtained after some transformations:

$$\begin{bmatrix} x_n \\ u_n^{'} \end{bmatrix}_{k+1} = \begin{bmatrix} a_n & b_n \\ 0 & 0 \end{bmatrix} \begin{bmatrix} x_n \\ u_n^{'} \end{bmatrix}_k + \begin{bmatrix} 0 & -b_n \\ 1 & 0 \end{bmatrix} \begin{bmatrix} u_n^{'*} \\ v_n^{'} \end{bmatrix}_k \tag{2}$$

where subscript n stands for d and q axes without distinction, x_n and $u_n^{'}$ are the state variables to be controlled, $u_n^{'*}$ is the control input, and $v_n^{'}$ is a measured input. The coefficients a_n and b_n are related with the resistance and the inductance of the filter plus the transformer.

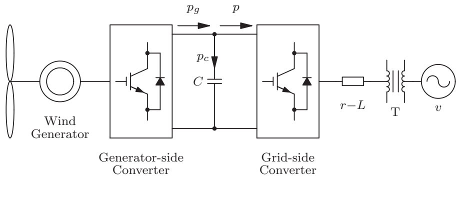

Fig. 1: Wind generator system

3 Design of the control system

The predictive-current controller designed here includes an integral action to guarantee zero tracking error in steady state for step changes in the reference.

Taking (2) into account, the proposed control law is:

$$u_n^{'*}(k) = \frac{1}{\hat{b}_n} x_n^*(k) - \frac{\hat{a}_n}{\hat{b}_n} \hat{x}_n(k+1) + \hat{v}_n^{'}(k+1) + g_n(k) \quad (3)$$

$$g_n(k+1) = g_n(k) + c_n t_s \left[x_n^*(k-2) - x_n(k)\right] \quad (4)$$

where $\hat{x}_n(k+1)$ and $\hat{v}_n(k+1)$ are the predicted values for x_n and v_n, at $k+1$, respectively, g_n is the integral of the error between the reference x_n^* and the system output, and c_n weights that integral action. In addition, $\hat{a}_n$ and $\hat{b}_n$ are the estimated values of the model parameters. The value $\hat{x}_n(k+1)$ is obtained by using (2) as prediction model, while the assumption that $\hat{v}_n^{'}(k+1) = v_n^{'}(k)$ is considered. By applying the Z transform, the new closed-loop system is:

$$\frac{X_n(z)}{X_n^*(z)} = \frac{1}{z^2}\left[\frac{\frac{b_n}{\hat{b}_n} z^2(z-1) + b_n c_n t_s}{D_f(z)}\right] \quad (5)$$

with

$$D_f(z) = (z+\hat{a}_n)(z-a_n)(z-1) + \frac{b_n}{\hat{b}_n}\hat{a}_n^2(z-1) + b_n c_n t_s \quad (6)$$

Note that if (5) is closed-loop asymptotically stable, the static gain is always $F_n(1) = 1$. Furthermore, if there are no modelling errors the closed-loop system is a second order deadbeat system $F_n(z) = 1/z^2$.

4 Performance with parameter errors

The dynamic performance of the closed-loop system can be affected by several factors such as modelling errors in the parameters of the filter and the transformer, among others. For that reason, the robustness of the control scheme to modelling errors in the resistance r and the inductance L has been investigated.

5 Experimental results

A small wind-generation prototype such as that depicted in Fig. 1, where only the grid converter has been used, has built to test the performance of the controller.

The current references change as follows: i_d^* changes from 0 to 2 A at $t = 0.5$ s and i_q^* changes from 0 to -1 A at $t = 0.6$ s. Coefficient c_n was set to $10 \cdot 10^3$. Fig. 2(a) plots the responses of i_d and i_q obtained without modelling errors: the currents are fully decoupled; there is no overshoot and no steady-state error. Fig. 2(b) shows the active ($p = 800$ W) and reactive ($q = 400$ VAr) powers injected into the grid. The powers p and q are proportional to the currents i_d and i_q, respectively (see Figs. 2(a) and 2(b)). A detail of the current i_d is shown in Fig. 2(c), where the dead-beat response can be seen. Finally Fig. 2(d) shows a detail of the line current.

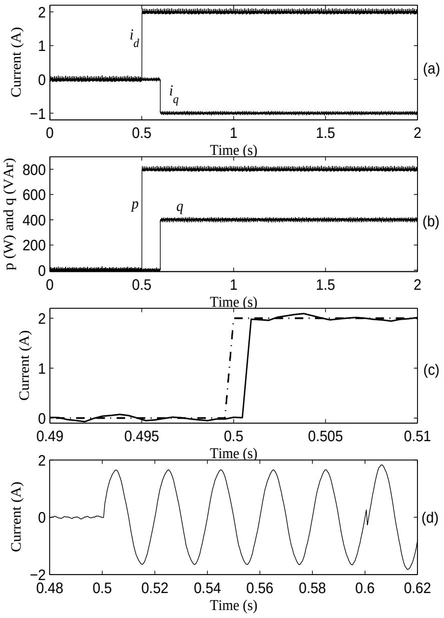

Fig. 2: Time response of (a) the current components and (b) active and reactive powers injected into the grid. (c) Detail of the current i_d: (—·) reference, and (–) measured current. (d) Detail of the measured line current i_R

6 Conclusions

This work studies a predictive-integral current controller for PWM voltage-source converters connected to the grid. The closed-loop system is a second-order deadbeat system which provides zero tracking error when the system parameters are known exactly. The paper also investigates how the closed-loop performance is affected by modelling errors in the parameters. The closed-loop system is robust for a wide range of parameter errors.

References

[1] T. Burton, D. Sharpe, N. Jenkins, and E. Bossanyi, *Wind Energy Handbook*. Chichester: John Wiley & Sons, Ltd, 2001.

[2] M. P. Kazmierkowski and L. Malesani, “Current control techniques for three-phase voltage-source PWM converters: a survey,” *IEEE Transactions on Industrial Electronics*, vol. 45, no. 5, pp. 691–703, October 1998.

[3] S. J. Henriksen, R. E. Betz, and B. J. Cook, “Digital hardware implementation of a current controller for IM variable-speed drives,” *IEEE Transactions on Industry Applications*, vol. 35, no. 5, pp. 1021–1029, September/October 1999.

[4] H. Abu-Rub, J. Guziński, Z. Krzeminski, and H. A. Toliyat, “Predictive current control of voltage source inverters,” *IEEE Transactions on Industrial Electronics*, vol. 51, no. 3, pp. 585–593, June 2004.

[5] G. H. Bode, P. C. Loh, M. J. Newman, and D. G. Holmes, “An improved robust predictive current regulation algorithm,” *IEEE Transactions on Industry Applications*, vol. 41, no. 6, pp. 1720–1733, Nov./Dec. 2005.

[6] H. M. Kojabadi, B. Yu, I. A. Gadoura, L. Chang, and M. Ghribi, “A novel DSP-based current-controlled PWM strategy for single phase grid connected inverters,” *IEEE Transactions on Power Electronics*, vol. 21, no. 4, pp. 985–993, July 2006.