Appendix A

Electrical power definitions

In this Appendix we provide expressions for active and reactive electrical power, both for three-phase and reduced dq systems.

A.1 Three–phase electrical power

Let us consider three-phase electrical (voltages and currents)

$$V^T(t) = [v_a, v_b, v_c], \quad I^T(t) = [i_a, i_b, i_c].$$

Assumption 1 *All the signals are periodic with the same fundamental period T.*

From the basic power definition, the *instantaneous power* of a system is

$$p(t) = V^T(t)I(t).$$

For periodical signals it is more useful to define the power as an averaged value.

Definition A.1. *The inner product of two periodic signals f, g is defined as*

$$\langle f, g\rangle = \bar{f}g = \frac{1}{T}\int_0^T f(t)^T g(t)\, dt$$

Definition A.2. *The active power, P, is defined as the electrical power (consumed or delivered) by a system,*

$$P := \langle V, I\rangle$$

or

$$P = \frac{1}{T}\int_0^T V^T I\, dt. \tag{A.1}$$

Definition A.3. *The* rms value *of a signal f, $\|f\|$, is defined as*

$$\|f\|^2 := \frac{1}{T}\int_0^T |f(\tau)|^2\, d\tau \tag{A.2}$$

where $|\cdot|$ is the Euclidian norm.

Definition A.4. *The apparent power, S, is defined as the* potentially maximum *active power by a system,*

$$S := \|V\|\|I\| \tag{A.3}$$

where $\|\cdot\|$ is the rms value.

From the Cauchy-Schwartz inequality

$$P = \langle V, I\rangle \leq \|V\|\|I\| = S$$

So S is indeed the highest average power delivered or consumed by the electrical system.

Definition A.5. *The power factor PF can be defined as the ratio*

$$PF := \frac{P}{S},$$

which, from the above inequality, satisfy $|FP| \leq 1$.

The reactive power Q definition is not so straightforward. The most popular definition is, for a three-phase system,

$$Q = v_a i_a \sin(\phi_a) + v_b i_b \sin(\phi_b) + v_c i_c \sin(\phi_c)$$

where ϕ is the phase angle, and the following equality

$$S^2 = P^2 + Q^2.$$

However, for a non-sinusoidal systems one has

$$S^2 \geq P^2 + Q^2.$$

Because of this the so-called *distortion power* D is introduced as

$$D^2 = S^2 - P^2 - Q^2.$$

This last result does not assure the additivity property and complicates power balancing studies (see [38] for extended discussion).

Definition A.6. *The sinusoidal and balanced three phase system reactive power Q can be defined as*

$$Q = S \sin\phi \tag{A.4}$$

where ϕ is the phase angle.

A.2 Power definitions in the dq-framework

In this Section, from the previous definitions and using the dq-transformation, the active and apparent power are recalculated. Let us to recall the dq-transformation described in subsection 1.2.3.

A sinusoidal and balanced three-phase signal

$$f(t) = F\left[\cos(\alpha(t)), \cos\left(\alpha(t) - \frac{2}{3}\pi\right), \cos\left(\alpha(t) + \frac{2}{3}\pi\right)\right]^T,$$

can be transformed into a three-phase constant vector f_{dq0} (with the third component equal to zero) by means of

$$f_{dq0} = Te^{J_2\alpha(t)} f(t), \tag{A.5}$$

with

$$T = \begin{bmatrix} \frac{\sqrt{2}}{\sqrt{3}} & -\frac{1}{\sqrt{6}} & -\frac{1}{\sqrt{6}} \\ 0 & \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} \end{bmatrix}$$

and

$$e^{J_2\alpha(t)} = \begin{bmatrix} \cos(\alpha(t)) & -\sin(\alpha(t)) \\ \sin(\alpha(t)) & \cos(\alpha(t)) \end{bmatrix}.$$

Notice that $T^{-1} = T^T$. In order to simplify the computation we neglect the third component, and to redefine T as

$$T = \begin{bmatrix} \frac{\sqrt{2}}{\sqrt{3}} & -\frac{1}{\sqrt{6}} & -\frac{1}{\sqrt{6}} \\ 0 & \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \end{bmatrix}.$$

Proposition A.7. *The active power of a sinusoidal and balanced three-phase system in a dq-coordinates is*

$$P_{dq} = i_{dq}^T v_{dq}. \tag{A.6}$$

Proof. From the definition of active power for a three-phase system (A.1),

$$P = \frac{1}{T}\int_0^T V^T I \mathrm{d}t,$$

with the inverse of the dq-transformation (A.5), $f = T^T e^{-J_2\alpha(t)} f_{dq}$, we can write

$$P = \frac{1}{T}\int_0^T \left(i_{dq}^T e^{J_2\alpha(t)} T T^T e^{-J_2\alpha(t)} v_{dq}\right) \mathrm{d}t.$$

Since, $TT^T = I_2$ and $e^{-J_2\alpha(t)} e^{J_2\alpha(t)} = I_2$, the active power yields

$$P = \frac{1}{T}\int_0^T \left(i_{dq}^T v_{dq}\right) \mathrm{d}t,$$

which, integrating, we recover (A.6). □

Proposition A.8. *The apparent power of a sinusoidal and balanced three-phase system in dq-coordinates is*

$$S_{dq} = |i_{dq}||v_{dq}|. \tag{A.7}$$

Proof. From the definition of the rms value of a three-phase variable (A.2),

$$\begin{aligned}\|I\|^2 &= \frac{1}{T}\int_0^T |I|^2 \mathrm{d}\tau \\ &= \frac{1}{T}\int_0^T I^T I \mathrm{d}\tau.\end{aligned}$$

With the dq-transformation,

$$\begin{aligned}\|I\|^2 &= \frac{1}{T}\int_0^T i_{dq}^T e^{J_2\alpha(t)} T T^T e^{-J_2\alpha(t)} i_{dq} \mathrm{d}\tau \\ &= \frac{1}{T}\int_0^T i_{dq}^T i_{dq} \mathrm{d}\tau\end{aligned}$$

Since i_{dq} is a constant vector

$$\|I\|^2 = i_{dq}^T i_{dq} = |i_{dq}|^2. \tag{A.8}$$

Similarly, for V,

$$\|V\|^2 = v_{dq}^T v_{dq} = |v_{dq}|^2. \tag{A.9}$$

Then, from the definition of apparent power for a three-phase system (A.3),

$$S = \|I\|\|V\|,$$

with (A.8) and (A.9) we recover (A.7). □

Proposition A.9. *The reactive power of a sinusoidal and balanced three-phase system in a dq-coordinates is*

$$Q_{dq} = i_{dq}^T J_2 v_{dq}. \tag{A.10}$$

Proof. From the definition of reactive power, (A.4), and tacking into account that the angle β between two vectors, a and b, can be written as

$$\sin\beta = \frac{1}{|a||b|} a^T J_2 b,$$

it follows that

$$Q_{dq} = S_{dq} \sin\phi,$$

and from (A.7)

$$Q_{dq} = |i_{dq}||v_{dq}| \frac{1}{|i_{dq}||v_{dq}|} i_{dq}^T J_2 v_{dq} = i_{dq}^T J_2 v_{dq}.$$

□

Appendix B

Optimal speed for a doubly-fed induction machine

In this Appendix we compute the stator and rotor powers (active and reactive), in function of the two variables of control in motor mode (mechanical speed ω and reactive stator power Q_s), of the doubly-fed induction machine, in order to find the optimal mechanical speed.

These computations are based on the equations of the equilibrium points of the DFIM, presented in subsection 1.2.3,

$$\omega_s L_s J_2 i_s + \omega_s L_{sr} J_2 i_r + R_s I_2 i_s - v_s = 0 \quad (B.1)$$

$$(\omega_s - \omega)[L_{sr} J_2 i_s + L_r J_2 i_r] + R_r I_2 i_r - v_r = 0 \quad (B.2)$$

$$L_{sr} i_s^T J_2 i_r - B_r \omega - \tau_L = 0. \quad (B.3)$$

Besides, some basic properties of the skew-symmetric matrix J_2 are used, namely

$$J_2^{-1} = -J_2 \quad (B.4)$$

$$J_2^{-T} = -J_2 \quad (B.5)$$

$$J_2 J_2 = -I_2 \quad (B.6)$$

$$a^T J_2 a = 0 \quad (B.7)$$

where $a \in \mathbb{R}^{2\times 1}$.

B.1 Previous calculus

To compute the rotor active and reactive powers we will use some nontrivial expressions which we calculate before.

Stator currents: $|i_s|^2$

For the stator currents, i_s, we want to compute $|i_s|^2$. Using the active and reactive power definitions, (A.6) and (A.10),

$$P_s = i_{sd} v_{sd} + i_{sq} v_{sq}$$

$$Q_s = i_{sq} v_{sd} - i_{sd} v_{sq},$$

we can obtain the following equations

$$\begin{aligned} v_{sq}P_s + v_{sd}Q_s &= i_{sq}(v_{sd}^2 + v_{sq}^2) \\ v_{sd}P_s - v_{sq}Q_s &= i_{sd}(v_{sd}^2 + v_{sq}^2) \end{aligned}$$

or, in compact form

$$i_s = \frac{1}{|v_s|^2}(v_{sd}I_2 + v_{sq}J_2)\begin{bmatrix} P_s \\ Q_s \end{bmatrix}.$$

From then,

$$|i_s|^2 = i_s^T i_s = \frac{1}{|v_s|^2}(P_s^2 + Q_s^2). \tag{B.8}$$

Rotor currents: $|i_r|^2$

Similarly, from the rotor currents, i_r, we need $|i_r|^2$. From (B.1), using (B.4) and (B.6),

$$i_r = -\frac{1}{\omega_s L_{sr}}\left(J_2(v_s - R_s i_s) + \omega_s L_s I_2 i_s\right). \tag{B.9}$$

Now, from (B.9), and tacking into account (B.5)

$$|i_r|^2 = i_r^T i_r = \frac{1}{\omega_s^2 L_{sr}^2}\left(|v_s|^2 + (R_s^2 + \omega_s^2 L_{sr}^2)|i_s|^2 + 2R_s v_s^T i_s\right)$$

and, with (A.6), (A.10) and (B.8),

$$|i_r|^2 = \frac{1}{\omega_s^2 L_{sr}^2}\left(|v_s|^2 + \frac{R_s^2 + \omega_s^2 L_{sr}^2}{|v_s|^2}(P_s^2 + Q_s^2) + 2R_s P_s\right). \tag{B.10}$$

Computation of $i_r^T i_s$

To compute Q_r we will need $i_r^T i_s$. From (B.9)

$$i_r^T i_s = -\frac{1}{\omega_s L_{sr}}\left(-(v_s^T - R_s i_s^T)J_2 + \omega_s L_s i_s^T\right) i_s$$

and simplifying with (B.7), we obtain,

$$i_r^T i_s = -\frac{1}{\omega_s L_{sr}}\left(-v_s^T J_2 i_s + \omega_s L_s |i_s|^2\right).$$

Notice that $Q_s = -v_s^T J_2 i_s$, and finally and from (B.8),

$$i_r^T i_s = -\frac{1}{\omega_s L_{sr}} Q_s - \frac{L_s}{|v_s|^2 L_{sr}}(P_s^2 + Q_s^2). \tag{B.11}$$

Stator active power: P_s

Finally, we will compute the stator active power, P_s. From (A.6)

$$P_s = i_s^T v_s.$$

and replacing v_s from (B.1),

$$P_s = \omega_s L_{sr} i_s^T J_2 i_r + R_s |i_s|^2,$$

with (B.8) and (B.3)

$$P_s = \omega_s(B_r\omega + \tau_L) + \frac{1}{|v_s|^2}(P_s^2 + Q_s^2). \tag{B.12}$$

This is a quadratic equation for P_s with two solutions

$$P_s = \frac{|v_s|^2 \pm \sqrt{|v_s|^4 - 4|v_s|^2\omega_s(B_r\omega + \tau_L) + Q_s^2}}{2}.$$

Since we are interested in the minimum power case we select

$$P_s = \frac{|v_s|^2 - \sqrt{|v_s|^4 - 4|v_s|^2\omega_s(B_r\omega + \tau_L) + Q_s^2}}{2}. \tag{B.13}$$

B.2 Rotor active power: P_r

From the definition of active power in dq-coordinates, (A.6),

$$P_r = i_r^T v_r.$$

Replacing v_r from (B.2), and using (B.7)

$$P_r = (\omega_s - \omega)(B_r\omega + \tau_L) + R_r|i_r|^2.$$

Finally, from (B.10)

$$P_r = (\omega_s - \omega)(B_r\omega + \tau_L) + \frac{R_r}{\omega_s^2 L_{sr}^2}\left(|v_s|^2 + \frac{R_s^2 + \omega_s^2 L_{sr}^2}{|v_s|^2}(P_s^2 + Q_s^2) + 2R_s P_s\right), \tag{B.14}$$

where P_s is computed as in (B.13). This is a complicated expression. However, the second term is small for usual parameter and variable values. So, P_r is small near $\omega = \omega_s$.

Figure B.1 plots function (B.14) with the DFIM parameters of the experimental machine (see Chapter 5, where $\omega_s = 314\text{rad}\cdot\text{s}^{-1}$). Notice that this function is smooth near $\omega = \omega_s$. Figure B.2 is for $Q_s = 0$, it is also clear that for $\omega = \omega_s$ the rotor active power is small.

B.3 Rotor reactive power, Q_r

From the dq-definition of reactive power (A.10),

$$Q_r = i_r^T J_2 v_r$$

replacing v_r from (B.2),

$$Q_r = i_r^T J_2((\omega_s - \omega)L_{sr} J_2 i_s + (\omega_s - \omega)L_r J_2 i_r + R_r I_2 i_r),$$

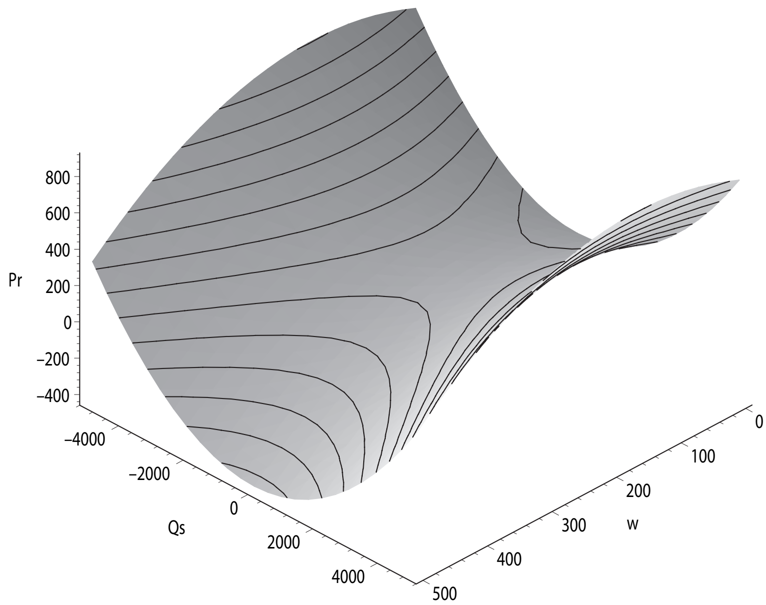

Figure B.1: Rotor active power, P_r, depending on Q_s and ω.

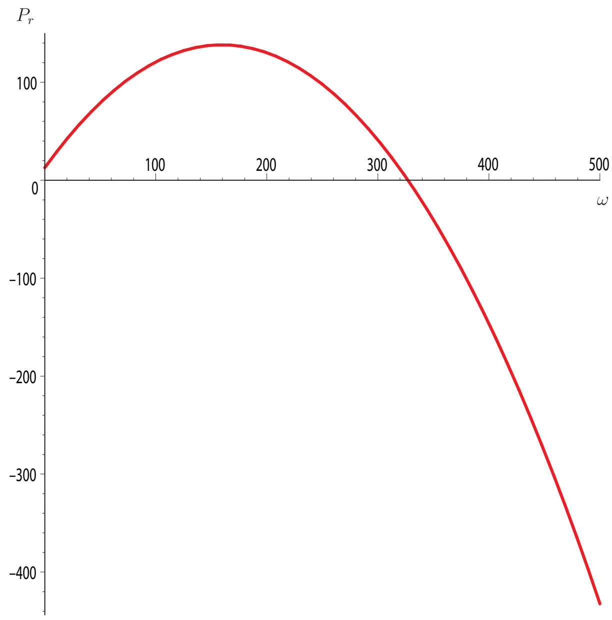

Figure B.2: Rotor active power, P_r, with $Q_s = 0$.

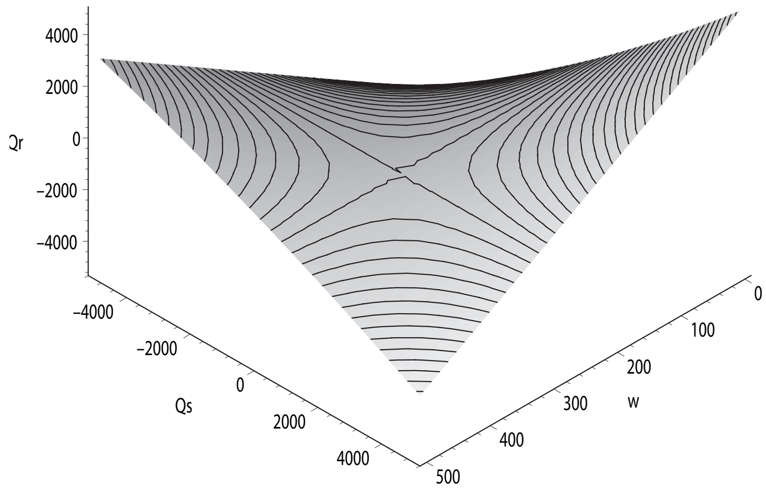

Figure B.3: Rotor reactive power, Q_r, depending on Q_s and ω.

with (B.6) and (B.7)

$$Q_r = -(\omega_s - \omega)(L_{sr} i_r^T i_s + L_r |i_r|^2).$$

Finally from (B.10) and (B.11)

$$\begin{aligned} Q_r &= -(\omega_s - \omega)\left(-\frac{1}{\omega_s} Q_s - \frac{L_s}{|v_s|^2}(P_s^2 + Q_s^2)\right. \\ &+ \left.\frac{L_r}{\omega_s^2 L_{sr}^2}\left(|v_s|^2 + \frac{R_s^2 + \omega_s^2 L_{sr}^2}{|v_s|^2}(P_s^2 + Q_s^2) + 2R_s P_s\right)\right), \end{aligned}$$

which can be simplified to

$$Q_r = (\omega_s - \omega)\left(\frac{1}{\omega_s} Q_s - \frac{L_r}{\omega_s^2 L_{sr}^2}|v_s|^2 - \frac{1}{|v_s|^2}\left(L_r - L_s + \frac{L_r R_s^2}{\omega_s^2 L_{sr}^2}\right)(P_s^2 + Q_s^2) - \frac{2L_r R_s}{\omega_s^2 L_{sr}^2} P_s\right), \tag{B.15}$$

where P_s is (B.13). It is clear that for $\omega = \omega_s$ the reactive power consumed (or delivered) by the rotor is zero.

Function (B.15) is depicted in Figure B.3 for the DFIM parameters of Chapter 5. As expected $Q_r = 0$ for $\omega = \omega_s$. To better understand its dependence on ω, the same function is plotted for $Q_s = 0$ in Figure B.4. Notice that there is a large value of ω for which $Q_r = 0$. Nevertheless, as is depicted in Figure B.5, near $\omega = \omega_s$ both active and reactive rotor powers are close to zero.

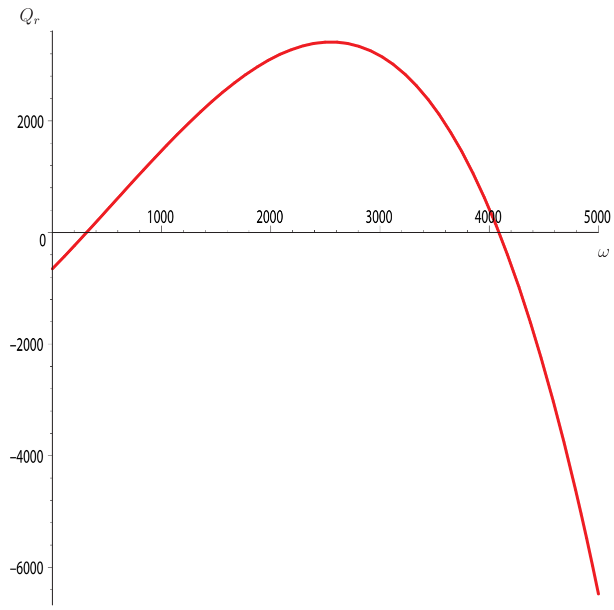

Figure B.4: Rotor reactive power, Q_r, with $Q_s = 0$.

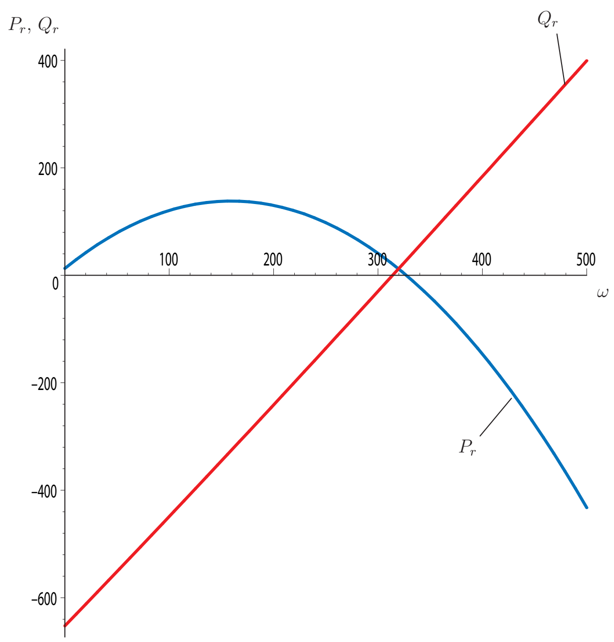

Figure B.5: Rotor active and reactive powers, P_r and Q_r, with $Q_s = 0$.

List of Notations

This is a partial list of symbols. We have tried to make it as completed as possible, and we think that it defines a map from left to right (but it is certainly not one-to-one...).

B_r	mechanical damping
C	capacitance
H	energy or Hamiltonian function
I	current electrical variable, (single-phase or three-phase)
I_2	identity matrix 2×2
I_3	identity matrix 3×3
J	interconnection matrix
J_2	skew-symmetric matrix 2×2
J_m	rotor inertia
L	inductance, inductance matrix
O_2	zero matrix 2×2
P	active electrical power
Q	reactive electrical power
R	dissipation matrix
$R_{(\cdot)}$	resistance
V	voltage electrical variable, (single-phase or three-phase)
Z	impedance
Λ	three-phase inductor fluxes
$\cos\phi$	power factor for a three-phase sinusoidal and balanced system
δ	dq-transformation arbitrary angle
η	arbitrary angle
λ	inductor flux, (single-phase or two-phase)
$\mathcal{L}$	inductance matrix in dq coordinates
τ_L	external torque
τ_e	electrical torque
θ	rotor angular position
e	effort
f	flow
g	port interconnection matrix
i	electrical current
v	electrical voltage
ω	mechanical speed

Subscripts

$(\cdot)^*$ .... fixed point
$(\cdot)^d$ .... desired fixed point
$(\cdot)_{DC}$ .... direct current electrical variable
$(\cdot)_d$ .... desired matrices or functions
$(\cdot)_e$ .... electrical
$(\cdot)_l$ .... local load
$(\cdot)_m$ .... mechanical
$(\cdot)_n$ .... power network
$(\cdot)_r$ .... rotor side of the DFIM
$(\cdot)_s$ .... stator side of the DFIM
$\hat{(\cdot)}$ .... estimated

Bibliography

[1] *Webster's Encyclopedic Unabridged Dictionary of the English Language*. Gramercy Books, New York, 1996.

[2] J.A. Acosta, R. Ortega, and A. Astolfi. Interconnection and damping assignment passivity-based control of mechanical systems with underactuation degree one. In *American Control Conference*, 2004.

[3] H. Akagi and H. Sato. Control and performance of a doubly-fed induction machine intended for a flywheel energy storage system. *IEEE Trans. on Power Electronics*, 17(1):109–116, 2002.

[4] C. Batlle and A. Dòria-Cerezo. Energy-based modelling and simulation of the interconnection of a back-to-back converter and a doubly-fed induction machine. In *Accepted to the 2006 American Control Conference*, 2006.

[5] C. Batlle, A. Dòria-Cerezo, G. Espinosa, and R. Ortega. Simultaneous Interconnection and Damping Assignment Passivity-Based Control: Two Practical Examples. In *Accepted to 3rd IFAC Workshop on Lagrangian and Hamiltonian Methods for Nonlinear Control*, 2006.

[6] C. Batlle, A. Dòria-Cerezo, and E. Fossas. IDA-PBC controller for a bidirectional power flow full-bridge rectifier. In *IEEE Proc. Conference on Decision and Control*, 2005.

[7] C. Batlle, A. Dòria-Cerezo, and E. Fossas. Improving the robustness of hamiltonian passive control. Technical report, IOC, Technical University of Catalonia, 2005.

[8] C. Batlle, A. Dòria-Cerezo, and E. Fossas. Bidirectional power flow control of a power converter using passive techniques. *Submitted to IEEE Trans. on Power Electronics*, 2006.

[9] C. Batlle, A. Dòria-Cerezo, and E. Fossas. Energy-based modelling and control of a multi-domain energy storage and management system. In *Proc. 5th Mathmod Conference*, 2006.

[10] C. Batlle, A. Dòria-Cerezo, and E. Fossas. Robust Hamiltonian passive control for higher relative degree outputs. In *Submitted to IEEE Conference on Decision and Control*, 2006.

[11] C. Batlle, A. Dòria-Cerezo, and R. Ortega. Power Flow Control of a Doubly–Fed Induction Machine Coupled to a Flywheel. In *IEEE Proc. Conference on Control Applications*, pages 1645–1651, 2004.

[12] C. Batlle, A. Dòria-Cerezo, and R. Ortega. Power Flow Control of a Doubly–Fed Induction Machine Coupled to a Flywheel. *European Journal of Control*, 11(3):209–221, 2005.

[13] C. Batlle, A. Dòria-Cerezo, and R. Ortega. A Robustly Stable PI Controller for the Doubly-fed Induction Machine. In *Submitted to Conference of the IEEE Industrial Electronics Society (IECON)*, 2006.

[14] C. Batlle, A. Dòria-Cerezo, and R. Ortega. A robust adaptive pi controller for the doubly-fed induction machine. *Submitted to IEEE Trans. on Industrial Electronics*, 2006.

[15] C. Batlle and A. Dòria-Cerezo. Modelling and control of electromechanical systems. Technical report, Lectures Notes of II EURON/GeoPlex Summer School on Modelling and control of complex dynamical systems, 2005.

[16] C. Batlle, E. Fossas, R. Griñó, and S. Martínez. Generalized state space averaging for port controlled hamiltonian systems. In *Proc. 16th IFAC World Congress*, 2005.

[17] M. Becherif, R. Ortega, E. Mendes, and S. Lee. Passivity-based control of a doubly-fed induction generator interconnected with an induction motor. In *IEEE Proc. Conference on Decision and Control*, 2003.

[18] E. Bogalecka and Z. Krzeminski. Control systems of doubly-fed induction machine supplied by current controlled voltage source inverter. In *IEEE Proc. Conference on Electrical Machines and Drives*, pages 168–172, 1996.

[19] P.C. Breedveld. *Physical systems theory in terms of Bond Graphs*. PhD thesis, University of Twente, 1984.

[20] P.C. Breedveld. MultiBond-graph elements in physical systems theory. *Journal of the Franklin Institute*, 319:1–36, 1985.

[21] V.A. Caliscan, G.C. Verghese, and A.M. Stankovic. Multi-frequency averaging of dc/dc converters. *IEEE Trans. on Power Electronics*, 14(1):124–133, January 1999.

[22] P. Caratozzolo. *Nonlinear control strategies of an isolated motion system with a double-fed induction generator*. PhD thesis, Universitat Politècnica de Catalunya, 2003.

[23] J. Chiasson. *Modeling and High Performance Control of Electric Machines*. John Wiley & Sons Inc., 2005.

[24] T.J. Courant. Dirac manifolds. *Trans. American Math. Soc.*, 319:631–661, 1990.

[25] M. Dalsmo and A. van der Schaft. On representations and integrability of mathematical structures in energy-conserving physical systems. *SIAM J. Control Optim.*, 37:54–91, 1998.

[26] C.A. Desoer and M. Vydiasagar, editors. *Feedback Systems: Input-Output Properties*. Academic Press, New York, 1975.

[27] I. Dorfman, editor. *Dirac structures and integrability of nonlinear evolution equations*. Wiley Interscience, New York, 1993.

[28] J.C. Doyle, B.A. Francis, and A.R. Tannenbaum, editors. *Feedback Control Theory*. Macmillan Publishing Company, New York, 1992.

[29] A. Dòria-Cerezo, E. Panteley, and R. Ortega. Switch analysis of the flywheel energy storage system. Technical report, Universitat Politècnica de Catalunya - Supelec, 2006.

[30] V. Duindam, S. Stramigioli, and J.M.A Scherpen. Passive compensation of nonlinear robot dynamics. *IEEE Trans. on Robotics and Automation*, 207(3):480–488, 2004.

[31] D. Eberard, B. Maschke, and A. van der Schaft. Conservative systems with ports on contact manifolds. In *Proc. of the 16th IFAC World Congress*, 2005.

[32] R. Erickson. *Fundamentals of Power Electronics*. Kluwer, 1997.

[33] G. Escobar, D. Chevreau, R. Ortega, and E. Mendes. An adaptive passivity-based controller for a unity power factor rectifier. *IEEE Trans. Control Systems Technology*, 9(4):637–644, 2001.

[34] G. Escobar, A.J. van der Schaft, and R. Ortega. A hamiltonian viewpoint in the modeling of switching power converters. *Automatica*, 35:445–452, 1999.

[35] E. Fossas and J.M. Olm. Asymptotic tracking in dc-to-dc nonlinear power converters. *Discrete and Continuous Dynamical Systems*, 2:295–307, 2002.

[36] K. Fujimoto, K. Sakurama, and T. Sugie. Trajectory tracking control of port-controlled Hamiltonian systems via generalized canonical transformations. *Automatica*, 39:2059–2069, 2003.

[37] K. Fujimoto and T. Sugie. Canonical transformations and stabilization of generalized Hamiltonian systems. *Systems & Control Letters*, 42(3):217–227, 2001.

[38] E. Garcia-Canseco, R. Griñó, R. Ortega, M. Salichs, and A. Stankovic. Power factor compensation of electrical circuits: a control theory viewpoint. *Submitted to IEEE Control Systems Magazine*, 2005.

[39] C. Gaviria, E. Fossas, and R. Griñó. Robust controller for a full-bridge rectifier using the IDA approach and GSSA modelling. *IEEE Trans. Circuits and Systems I*, 52(3):609–616, 2005.

[40] L. Gentili and A.J. van der Schaft. Regulation and input distrubance suppression for port-controlled hamiltonian systems. In *Proc. 2nd IFAC Workshop on Lagrangian and Hamiltonian Methods for Nonlinear Control*, 2003.

[41] G. Golo, V. Talasila, A.J. van des Schaft, and B. Maschke. Hamiltonian discretitzation of boundary control systems. *Automatica*, 40:757–771, 2004.

[42] G. Golo, A.J. van der Schaft, P.C. Breedveld, and B. Maschke. Hamiltonian formulation of Bond Graphs. In *Workshop NACO II*, pages 2642–2647, 2001.

[43] R. Griñó, E. Fossas, and D. Biel. Sliding mode control of a full-bridge unity power factor rectifier. *Lecture Notes in Control and Information Sciences*, 281:139–148, 2002.

[44] B. Hopfensperger, D.J. Atkinson, and R.A. Lakin. Stator-flux-oriented control of a doubly-fed induction machine with and without position encoder. In *IEE Proc. Electric Power Applications*, volume 147-4, pages 241–250, 2000.

[45] S.Y.R. Hui, H.S.H. Chung, and S.C. Yip. A bidirectional ac-dc power converter with power factor correction. *IEEE Trans. on Power Electronics*, 15(5):942–949, September 2000.

[46] A. Isidori. *Nonlinear Control Systems*. Springer Verlag, 3 edition, 1995.

[47] T. Kailath. *Linear Systems*. Prentice-Hall, 1980.

[48] D.C. Karnopp, D.L. Margolis, and R.C. Rosenberg. *System dynamics modeling and simulation of mechatronic systems*. J. Wiley, New York, 3th edition, 2000.

[49] H. K. Khalil. *Nonlinear Systems*. Prentice Hall, 2 edition, 1996.

[50] P. C. Krause. *Analysis of electric machinery*. McGraw-Hill, 1986.

[51] A. Kugi. *Non-linear control based on physical models*. Springer, 2001.

[52] Y. Le Gorrec, H. Zwart, and B. Maschke. Dirac structures and boundary control systems associated with skew-symmetric differential operators. *SIAM J. Control Optim.*, 44:1864–1892, 2005.

[53] D.C. Lee, G.M. Lee, and K.D. Lee. Dc-bus voltage control of three-phase ac/dc pwm converters using feedback linearization. *IEEE Trans. on Industry Applications*, 36(3):826–833, 2000.

[54] W. Leonard. *Control of electric drives*. Springer, 1995.

[55] J. Mahdavi, A. Emaadi, M. D. Bellar, and M. Ehsani. Analysis of power electronic converters using the generalized state-space averaging approach. *IEEE Trans. on Circuits and Systems I*, 44(8):767–770, August 1997.

[56] B. Maschke and A. van der Schaft. Port-controlled Hamiltonian Systems: Modelling origins and system-theoretic properties. In *2nd. IFAC NOLCOS*, pages 282–288, 1992.

[57] B. Maschke and A. van der Schaft. *Systems and networks: Mathematical theory and applications*, volume II, pages 349–352. Academic-Verlag, 1994.

[58] B. Maschke, A. van der Schaft, and P. C. Breedveld. An intrinsic hamiltonian formulation of the dynmics of *lc*-circuits. *IEEE Trans. on Circuits and Systems*, 42:73–82, 1995.

[59] R. Morici, C. Rossi, and A. Tonielli. Variable structure controller for ac/dc boost converter. In *Proc. IEEE Int. Conf. Industrial Electronics, Control and Instrumentation*, pages 1449–1454, 1994.

[60] R. Ortega, A. Astolfi, G. Bastin, and H. Rodríguez. Stabilization of food-chain systems using a port-controlled hamiltonian systems. In *Proc. of the American Control Conference*, 2000.

[61] R. Ortega, M. Galaz, A. Astolfi, Y. Sun, and T. Shen. Transient stabilization of multimachine power systems with nontrivial transfer conductances. *IEEE Trans. on Automatic Control*, 50(1):60–75, 2005.

[62] R. Ortega and E. Garcia-Canseco. Interconnection and Damping Assignment Passivity-Based Control: A Survey. *European Journal of Control*, 10(5), 2004.

[63] R. Ortega, A. Loria, P.J. Nicklasson, and H. Sira-Ramirez. *Passivity-based control of Euler-Lagrange systems*. Spring-Verlag, 1998.

[64] R. Ortega, M.W. Spong, F. Gómez-Estern, and G. Blankenstein. Stabilization of a class of underactuated mechanical systems via interconnection and damping assignment. *IEEE Trans. on Automatic Control*, 47:1218–1233, 2002.

[65] R. Ortega, A. van der Schaft, I. Mareels, and B. Maschke. Putting energy back in control. *IEEE Control Systems Magazine*, pages 18–33, 2001.

[66] R. Ortega, A. van der Schaft, B. Maschke, and G. Escobar. Interconnection and damping assignment passivity-based control of port-controlled Hamiltonian systems. *Automatica*, 38(4):585–596, 2002.

[67] H.M. Paynter. *Analysis and design of engineering systems*. MIT Press, Cambridge, MA, 1961.

[68] R. Peña, J. C. Clare, and G. M. Asher. Doubly fed induction generator using back-to-back pwm converters and its application to variable speed wind-energy generation. In *IEEE Proc. Electric Power Applications*, volume 143-5, pages 231–241, 1996.

[69] R. Peña, J. C. Clare, and G. M. Asher. A doubly fed induction generator using back-to-back pwm converters supplying an isolated load from a variable speed wind turbine. In *IEEE Proc. Electric Power Applications*, volume 143-5, pages 380–387, 1996.

[70] S. Peresada, A. Tilli, and A. Tonelli. Indirect Stator Flux-Oriented Output Feedback Control of a Doubly Fed Induction Machine. *IEEE Trans. Control Systems Technology*, 11(6):875–888, 2003.

[71] S. Peresada, A. Tilli, and A. Tonelli. Power control of a doubly fed induction machine via output feedback. *Control Engineering Practice*, 12:41–57, 2004.

[72] A. Petersson. *Analisys, modeling and control of doubly-fed induction generators for wind turbines*. PhD thesis, Chalmers University of Technology, Sweden, 2005.

[73] V. Petrovic, R. Ortega, and A. Stankovic. Interconnection and damping assignment approach to control of permanent magnet synchronous motor. *IEEE Trans. Control Systems Technology*, 9(6):811–820, 2001.

[74] H. Rodríguez. *On nonlinear control via Interconnection and Damping Assignment*. PhD thesis, Université de Paris XI, 2002.

[75] H. Rodriguez and R. Ortega. Interconnection and damping assignment control of electromechanical systems. *International Journal of Robust and Nonlinear Control*, 13:1095–1111, 2003.

[76] H. Rodríguez, R. Ortega, G. Escobar, and N. Barabanov. A robustly stable output feedback saturated controller for the boost dc-to-dc converter. *Systems & Control Letters*, 40:1–8, 2000.

[77] H. Rodríguez, R. Ortega, and I. Mareels. A novel passivity-based controller for an active magnetic bearing benchmark experiment. In *Proc. of the American Control Conference*, 2000.

[78] H. Rodríguez, H. Siguerdidjane, and R. Ortega. Experimental comparison of linear and nonlinear controllers for a magnetic suspension. In *IEEE Proc. Conference on Control Applications*, 2000.

[79] S.R. Sanders, J.M. Noworolski, X.Z. Liu, and G. C. Verghese. Generalized averaging method for power conversion systems. *IEEE Trans. on Power Electronics*, 6:251–259, 1991.

[80] H. Sira-Ramírez, R. Márquez, F. Rivas-Echeverría, and O. Llanes-Santiago. *Control de sistemas no lineales.* Pearson Educación S.A., Madrid, 2005.

[81] H. Sira-Ramírez, R.A. Pérez-Moreno, R. Ortega, and M. Garcia-Esteban. Passivity-based controllers for the stabilization of dc-to-dc power converters. *Automatica*, 33(4):499–513, 1997.

[82] J.G. Slootweg, H. Polinder, and W.L. Kling. Dynamic modelling of a wind turbine with doubly fed induction generator. In *IEEE Power Engineering Society Summer Meeting 2001*, pages 644–649, 2001.

[83] E.D. Sontag. A Remark on the Converging-Input Converging-State Property. *IEEE Trans. on Automatic Control*, 48(2):313–314, 2003.

[84] G. Tadmor. On approximate phasor models in dissipative bilinear systems. *IEEE Trans. on Circuits and Systems I*, 49:1167–1179, 2002.

[85] A. Tapia, G. Tapia, J. X. Ostolaza, and J. R. Sáenz. Modeling and control of a wind turbine driven doubly fed induction generator. *IEEE Trans. Energy Conversion*, 18:194–204, 2003.

[86] V.I. Utkin. *Sliding Modes and their Applications in Variable Structure Systems.* Mir. Moscow, 1978.

[87] A. van der Schaft. *L_2 gain and passivity techniques in nonlinear control.* Springer, 2000.

[88] A. van der Schaft and B. Maschke. Hamiltonian formulation of distributed-parameter systems with boundary energy flow. *Journal of Geometry and Physics*, 42:166–194, 2002.

[89] L. Xu and W. Cheng. Torque and reactive power control of a doubly fed induction machine by position sensorless scheme. *IEEE Trans. Industry Applications*, 31(3):636–642, 1995.

[90] M. Yamamoto and O. Motoyoshi. Active and reactive power control for doubly-fed wound rotor induction generator. *IEEE Trans. Power Electronics*, 6(4):624–629, 1991.