RESUMEN

Este trabajo está dividido en dos partes. En la primera se presentan y proponen observadores y estimadores para señales sinusoidales de frecuencia desconocida pensados para aplicaciones de sincronización con la red eléctrica. En la segunda se presentan y proponen controladores de corriente para el Convertidor Fuente de Tensión (*Voltage Source Converter*) (VSC), capaces de inyectar una corriente sinusoidal con bajo nivel de distorsión en fase con la componente fundamental de la tensión de la red, los cuales cuentan con adaptación en frecuencia y pueden prescindir del sensor de tensión de red. Todos los esquemas son analizados desde un punto de vista teórico y las conclusiones obtenidas de este análisis son validadas mediante simulaciones, y en algunos casos mediante resultados experimentales. Los algoritmos implementados experimentalmente son optimizados para lograr buena performance con un bajo costo computacional, lo que permite su implementación en procesadores de bajo costo. La obtención de estos resultados experimentales fue posible gracias al diseño y construcción de un prototipo industrial de Sistema de Generación Distribuida de Potencia (*Distributed Power Generation System*) (DPGS), el cual se muestra también en este trabajo.

ABSTRACT

This work is divided in two parts. Part I analyzes and proposes estimators and observers of sinusoidal signals with an unknown frequency for the purpose of synchronizing DPGS to the power grid. Part II analyzes and proposes current controllers for the VSC capable of injecting low distortion sinusoidal currents in phase with the fundamental component of the grid voltage. Some of these are frequency adaptive and can be made grid voltage sensorless. All the schemes are analyzed from a theoretical viewpoint and the conclusions drawn from these analysis are validated through simulations, and in some cases through experimental results. The experimentally implemented algorithms are optimized to achieve a good performance with low computational burden, which makes them suitable for implementation in low cost processors. The obtention of these experimental results was possible thanks to the design and construction of a DPGS industrial prototype, which is also shown in this work.

Referencias Bibliográficas

[1] A. Kornelakis and E. Koutroulis, "Methodology for the design optimisation and the economic analysis of grid-connected photovoltaic systems," IET Renewable Power Generation, vol. 3, no. 4, pp. 476 – 492, December 2009.

[2] F. Delfino, R. Procopio, M. Rossi, and G. Ronda, "Integration of large-size photovoltaic systems into the distribution grids: a p-q chart approach to assess reactive support capability," IET Renewable Power Generation, vol. 4, no. 4, pp. 329 – 340, July 2010.

[3] H. Bevrani, A. Ghosh, and G. Ledwich, "Renewable energy sources and frequency regulation: survey and new perspectives," IET Renewable Power Generation, vol. 4, no. 5, pp. 438 – 457, September 2010.

[4] "Editorial special issue on distributed power generation," IEEE Transactions On Power Electronics, vol. 19, no. 5, September 2004.

[5] R. Nasiri and A. Radan, "Adaptive robust pole-placement control of 4-leg voltage-source inverters for standalone photovoltaic systems: Considering digital delays," Energy Conversion and Management, vol. 52, no. 2, pp. 1314–1324, February 2011.

[6] L. Ayompe, S. Duffy, A. an McCormack, and M. Conlon, "Measured performance of a 1.72 kw rooftop grid connected photovoltaic system in ireland," Energy Conversion and Management, vol. 52, no. 2, pp. 816–825, February 2011.

[7] A. Al-Salaymeh, Z. Al-Hamamre, F. Sharaf, and M. Abdelkader, "Technical and economical assessment of the utilization of photovoltaic systems in residential buildings: The case of jordan," Energy Conversion and Management, vol. 51, no. 8, pp. 1719–1726, August 2011.

[8] F. Blaabjerg, Z. Chen, and S. Kjaer, "Power electronics as efficient interface in dispersed power generation systems," IEEE Transactions on Power Electronics, vol. 19, pp. 1184–1194, Septiembre 2007.

[9] F. Blaabjerg, R. Teodorescu, M. Liserre, and A. V. Timbus, "Overview of control and grid synchronization for distributed power generation systems," IEEE Transactions On Industrial Electronics, vol. 53, no. 5, pp. 1398–1409, October 2006.

[10] M. Cacciato, A. Consoli, R. Attanasio, and F. Gennaro, "Soft-switching converter with hf transformer for grid-connected photovoltaic systems," IEEE Transactions on Industrial Electronics, vol. 57, no. 5, pp. 1678 –1686, May 2010.

[11] J. Carrasco, L. Franquelo, J. Bialasiewicz, E. Galvan, R. Guisado, M. Prats, J. Leon, and N. Moreno-Alfonso, "Power-electronic systems for the grid integration of renewable energy sources: A survey," IEEE Transactions on Industrial Electronics, vol. 53, no. 4, pp. 1002–1016, June 2006.

[12] T. Zhou and B. Francois, "Energy management and power control of a hybrid active wind generator for distributed power generation and grid integration," IEEE Transactions on Industrial Electronics, vol. 58, no. 1, pp. 95–104, January 2011.

[13] H. Zhang and L. Tolbert, "Efficiency impact of silicon carbide power electronics for modern wind turbine full scale frequency converter," IEEE Transactions on Industrial Electronics, vol. 58, no. 1, pp. 21–28, January 2011.

[14] M. Mohr, W. Franke, B. Wittig, and F. Fuchs, "Converter systems for fuel cells in the medium power range-a comparative study," IEEE Transactions on Industrial Electronics, vol. 57, no. 6, pp. 2024 –2032, June 2010.

[15] A. E. León, J. A. Solsona, and M. Valla, "Exponentially convergent estimator to improve performance of voltage source converters," IET Power Electronics, vol. 3, no. 5, pp. 668 – 680, September 2010.

[16] ——, "Control strategy for hardware simplification of vsc-based power applications," IET Power Electronics, vol. 4, no. 1, pp. 39–50, January 2011.

[17] "IEEE standard for interconnecting distributed resources with electric power systems," IEEE Std 1547-2003, pp. 1–16, 2003.

[18] M. Singh, V. Khadkikar, and A. Chandra, "Grid synchronisation with harmonics and reactive power compensation capability of a permanent magnet synchronous generator-based variable speed wind energy conversion system," IET Power Electronics, vol. 4, no. 1, pp. 122 – 130, January 2011.

[19] W. Zhao, A. Luo, Z. Shen, and C. Wu, "Injection-type hybrid active power filter in high-power grid with background harmonic voltage," IET Power Electronics, vol. 4, no. 1, pp. 63 – 71, January 2011.

[20] Z. Wang, L. Chang, and M. Mao, "Dc voltage sensorless control method for three-phase grid-connected inverters," IET Power Electronics, vol. 3, no. 4, pp. 552 – 558, July 2010.

[21] J. Eloy-Garcia, S. Arnaltes, and J. Rodriguez-Amenedo, "Direct power control of voltage source inverters with unbalanced grid voltages," IET Power Electronics, vol. 1, no. 3, pp. 395 – 407, September 2008.

[22] A. Elnahdy and M. Salama, "Voltage enhancement in industrial distribution systems using narrow-band filters," IET Generation, Transmission & Distribution, vol. 5, no. 1, pp. 108 – 118, January 2011.

[23] R. Cardoso, R. de Camargo, H. Pinheiro, and H. Grundling, "Kalman filter based synchronisation methods," IET Generation, Transmission & Distribution, vol. 2, no. 4, pp. 542 – 555, July 2008.

[24] J. Svensson, "Synchronisation methods for grid-connected voltage source converters," IEE Proceedings-Generation, Transmission and Distribution, vol. 148, no. 3, pp. 229 – 235, May 2001.

[25] Y. Pantazis, O. Rosec, and Y. Stylianou, "Iterative estimation of sinusoidal signal parameters," IEEE Signal Processing Letters, vol. 17, no. 5, pp. 461–464, May 2010.

[26] I. Djurovic, "Estimation of the sinusoidal signal frequency based on the marginal median dft," IEEE Transactions on Signal Processing, vol. 55, no. 5, pp. 2043–2051, May 2007.

[27] L. Hsu, R. Ortega, and G. Damm, "A globally convergent frequency estimator," IEEE Transactions on Automatic Control, vol. 44, no. 4, pp. 698 – 713, April 1999.

[28] B.-Z. Guot and J.-Q. Han, "A linear tracking-differentiator and application to the online estimation of the frequency of a sinusoidal signal," Proceedings of the 2000 IEEE. International Conference on Control Applications, September 2000.

[29] M. Mojiri and A. R. Bakhshai, "An adaptive notch filter for frequency estimation of a periodic signal," IEEE Transactions On Automatic Control, vol. 49, no. 2, pp. 314–318, February 2004.

[30] G. Escobar, M. Martinez-Montejano, A. Valdez, P. Martinez, and M. Hernandez-Gomez, "A globally convergent frequency estimator," IEEE Transactions on Automatic Control, vol. 58, no. 5, pp. 1943 – 1951, May 2011.

[31] M. Padua, S. Deckmann, and F. Marafao, "Frequency-adjustable positive sequence detector for power conditioning applications," IEEE 36th Power Electronics Specialists Conference, pp. 1928–1934, June 2005.

[32] S. Oliveira da Silva, R. Novochadlo, and R. Modesto, "Single-phase pll structure using modified p-q theory for utility connected systems," IEEE Power Electronics Specialists Conference, pp. 4706–4711, June 2008.

[33] F. Hassan and R. Critchley, "A robust pll for grid interactive voltage source converters," 14th International Power Electronics and Motion Control Conference, pp. T2–29 – T2–35, September 2010.

[34] F. Liccardo, P. Marino, and G. Raimondo, "Robust and fast three-phase PLL tracking system," IEEE Transactions on Industrial Electronics, vol. 58, no. 1, pp. 221–231, January 2011.

[35] P. Rodriguez, A. Luna, I. Candela, R. Mujal, R. Teodorescu, and F. Blaabjerg, "Multiresonant frequency-locked loop for grid synchronization of power converters under distorted grid conditions," IEEE Transactions on Industrial Electronics, vol. 58, no. 1, pp. 127–138, January 2011.

[36] M. Mojiri, M. Karimi-Ghartemani, and A. Bakhshai, "Time-domain signal analysis using adaptive notch filter," IEEE Transactions on Signal Processing, vol. 55, no. 1, pp. 85 – 93, January 2007.

[37] M. Mojiri and A. Bakhshai, "Estimation of frequencies using adaptive notch filter," IEEE Transactions on Circuits and Systems II: Express Briefs, vol. 54, no. 4, pp. 338 – 342, April 2007.

[38] G. Xiaoqiang, W. Weiyang, and C. Zhe, "Multiple-complex coefficient-filter-based phase-locked loop and synchronization technique for three-phase grid-interfaced converters in distributed utility networks," IEEE Transactions on Industrial Electronics, vol. 58, no. 4, pp. 1194–1204, April 2011.

[39] S. Naidu, A. Mascarenhas, and D. Fernandes, "A software phase locked loop for unbalanced and distorted utility conditions," International Conference on Power System Technology, vol. 2, pp. 999–1004, November 2004.

[40] S. da Silva and E. Coelho, "Analysis and design of a three-phase pll structure for utility connected systems under distorted utility conditions," 9th IEEE International Power Electronics Congress, pp. 218–223, October 2004.

[41] S. da Silva, E. Tomizaki, R. Novochadlo, and E. Coelho, "Pll structures for utility connected systems under distorted utility conditions," 32nd Annual Conference on IEEE Industrial Electronics, pp. 2636–2641, November 2006.

[42] H. Akagi, E. H. Watanabe, and M. Aredes, Instantaneous Power Theory and Applications to Power Conditioning. ISBN: 978-0-470-10761-4. Wiley-IEEE Press, 2007.

[43] P. C. Krause, O. Wasynczuk, and S. D. Sudhoff, Analysis of Electric Machinery. IEEE Press, 1995.

[44] P. Rodriguez, R. Teodorescu, I. Candela, A. Timbus, M. Liserre, and F. Blaabjerg, "New positive-sequence voltage detector for grid synchronization of power converters under faulty grid conditions," 37th IEEE Power Electronics Specialists Conference, June 2006.

[45] P. Rodriguez, J. Pou, J. Bergas, J. Candela, R. Burgos, and D. Boroyevich, "Decoupled double synchronous reference frame pll for power converters control," IEEE Transactions On Power Electronics, vol. 22, no. 2, pp. 584–592, March 2007.

[46] P. Rodriguez, A. Luna, R. Munoz-Aguilar, I. Etxeberria-Otadui, R. Teodorescu, and F. Blaabjerg, "A stationary reference frame grid synchronization system for three-phase grid-connected power converters under adverse grid conditions," IEEE Transactions on Power Electronics, June 2011, digital Object Identifier: 10.1109/TPEL.2011.2159242.

[47] F. Freijedo, A. Yepes, O. López, A. Vidal, and J. Doval-Gandoy, "Three-phase plls with fast postfault retracking and steady-state rejection of voltage unbalan-

ce and harmonics by means of lead compensation," IEEE Transactions on Power Electronics, vol. 26, no. 1, pp. 85 – 97, January 2011.

[48] P.-T. Cheng, S. Bhattacharya, and D. Divan, "Experimental verification of dominant harmonic active filter for high-power applications," IEEE Transactions on Industry Applications, vol. 36, no. 2, pp. 567 – 577, March 2000.

[49] A. C. Busada, H. G. Chiacchiarini, and J. C. Balda, "Synthesis of sinusoidal waveform references synchronized with periodic signals," IEEE Transactions on Power Electronics, vol. 23, no. 2, pp. 581–590, March 2008.

[50] F. Freijedo, J. Doval-Gandoy, O. Lopez, and E. Acha, "A generic open-loop algorithm for three-phase grid voltage/current synchronization with particular reference to phase, frequency, and amplitude estimation," IEEE Transactions on Power Electronics, vol. 24, no. 1, pp. 94 – 107, January 2009.

[51] E. Robles, S. Ceballos, J. Pou, J. Martín, J. Zaragoza, and P. Ibañez, "Variable-frequency grid-sequence detector based on a quasi-ideal low-pass filter stage and a phase-locked loop," IEEE Transactions on Power Electronics, vol. 25, no. 10, pp. 2552 – 2563, October 2010.

[52] D. Yazdani, M. Mojiri, A. Bakhshai, and G. Joos, "A fast and accurate synchronization technique for extraction of symmetrical components," IEEE Transactions on Power Electronics, vol. 24, no. 3, pp. 674 – 684, March 2009.

[53] D. Yazdani, A. Bakhshai, and P. Jain, "Adaptive notch filtering based grid synchronization techniques for converter interfaced distributed generation systems," 35th Annual Conference of IEEE Industrial Electronics, November 2009, digital Object Identifier : 10.1109/IECON.2009.5415356.

[54] M. Mojiri, D. Yazdani, and A. Bakhshai, "Robust adaptive frequency estimation of three-phase power systems," IEEE Transactions on Instrumentation and Measurement, vol. 57, no. 7, pp. 1793 – 1802, July 2010.

[55] J. Svensson, M. Bongiorno, and A. Sannino, "Practical implementation of delayed signal cancellation method for phase-sequence separation," Power Delivery, IEEE Transactions on, vol. 22, no. 1, pp. 18–26, jan. 2007.

[56] G. Saccomando, J. Svensson, and A. Sannino, "Improving voltage disturbance rejection for variable-speed wind turbines," Energy Conversion, IEEE Transactions on, vol. 17, no. 3, pp. 422–428, sep. 2002.

[57] P. W. Lehn and M. R. Iravani, "Discrete time modeling and control of the voltage source converter for improved disturbance rejection," IEEE Trans. Power Electron., vol. 14, no. 6, pp. 1028–1036, Nov. 1999.

[58] H.-S. Song, I.-W. Joo, and K. Nam, "Source voltage sensorless estimation scheme for PWM rectifiers under unbalanced conditions," IEEE Trans. Ind. Electron., vol. 50, no. 6, pp. 1238–1245, Dec. 2003.

[59] A. A. Girgis, W. Chang, and E. B. Makram, "Analysis of high-impedance fault generated signals using a Kalman filtering approach," IEEE Trans. Power Del., vol. 5, no. 4, pp. 1714–1724, Oct. 1990.

[60] R. A. Flores, I. Y. H. Gu, and M. H. J. Bollen, "Positive and negative sequence estimation for unbalanced voltage dips," IEEE Power Engineering Society General Meeting, vol. 4, pp. 2498–2502, July 2003.

[61] F. Chih-Peng and S. Guo-An, "Novel recursive discrete fourier transform with compact architecture," The 2004 IEEE Asia-Pacific Conference on Circuits and Systems, 2004. Proceedings., vol. 2, pp. 1081 – 1084, December 2004.

[62] R. Garcia-Retegui, S. Gonzalez, M. Funes, and S. Maestri, "Implementation of a novel synchronization method using sliding goertzel dft," IEEE International Symposium on Intelligent Signal Processing., pp. 1 – 5, October 2007.

[63] S. Shinnaka, "A novel fast-tracking d-estimation method for single-phase signals," IEEE Transactions on Power Electronics, vol. 26, no. 4, pp. 1081 – 1088, April 2011.

[64] P. Roncero-Sanchez, X. del Toro Garcia, and V. Torres, A.P.and Feliu, "Robust frequency-estimation method for distorted and imbalanced three-phase systems using discrete filters," IEEE Transactions on Power Electronics, vol. 26, no. 4, pp. 1089 – 1101, April 2011.

[65] C.-M. Ho, V. Cheung, and H.-H. Chung, "Constant-frequency hysteresis current control of grid-connected VSI without bandwidth control," IEEE Transactions on Power Electronics, vol. 24, no. 11, pp. 2484–2495, November 2009.

[66] Q. Zeng and L. Chang, "An advanced SVPWM-based predictive current controller for three-phase inverters in distributed generation systems," IEEE Transactions on Industrial Electronics, vol. 55, no. 3, pp. 1235–1246, March 2008.

[67] M. 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.

[68] A. Timbus, M. Liserre, R. Teodorescu, P. Rodriguez, and F. Blaabjerg, "Evaluation of current controllers for distributed power generation systems," IEEE Transactions on Power Electronics, vol. 24, no. 3, pp. 654–664, March 2009.

[69] C. D. Schauder and R. Caddy, "Current control of voltage-source inverters for fast four-quadrant drive performance," IEEE Transactions on Industry Applications, vol. IA-18, no. 2, pp. 163–171, March 1982.

[70] P. Hsu and M. Behnke, "A three-phase synchronous frame controller for unbalanced load," in Power Electronics Specialists Conf., 1998. PESC 98 Record. 29th Annual IEEE, vol. 2, May 1998, pp. 1369–1374.

[71] S. Park, S.-B. Han, B.-M. Jung, S.-H. Choi, and H.-G. Jeong, "A current control scheme based on multiple synchronous reference frames for parallel hybrid active filter," in Power Electronics and Motion Control Conf., 2000. Proc. IPEMC 2000. The Third International, vol. 1, 2000, pp. 218–223.

[72] T. M. Rowan and R. J. Kerkman, "A new synchronous current regulator and an analysis of current-regulated PWM inverters," IEEE Transactions on Industry Applications, vol. IA-22, no. 4, pp. 678–690, July 1986.

[73] Y. Sato, T. Ishizuka, K. Nezu, and T. Kataoka, "A new control strategy for voltage-type PWM rectifiers to realize zero steady-state control error in input current," IEEE Transactions on Industry Applications, vol. 34, no. 3, pp. 480–486, May/June 1998.

[74] D. Zmood, D. Holmes, and G. Bode, "Frequency domain analysis of three phase linear current regulators," in Industry Applications Conf., 1999. Thirty-Fourth IAS Annual Meeting. Conference Record of the 1999 IEEE, vol. 2, 1999, pp. 818–825.

[75] D. Zmood and D. Holmes, "Stationary frame current regulation of PWM inverters with zero steady-state error," IEEE Transactions on Power Electronics, vol. 18, no. 3, pp. 814–822, May 2003.

[76] Y. Xiaoming, M. Willi, S. Herbert, and A. Jost, "Stationary-frame generalized integrators for current control of active power filters with zero steady-state error for current harmonics of concern under unbalanced and distorted operating conditions," IEEE Transactions on industry applications, vol. 38, no. 2, pp. 523–532, March/April 2002.

[77] G. Shen, X. Zhu, J. Zhang, and D. Xu, "A new feedback method for PR current control of LCL-filter-based grid-connected inverter," IEEE Transactions on Industrial Electronics, vol. 57, no. 6, pp. 2033–2041, June 2010.

[78] E. Blanco, E. Bueno, F. Espinosa, S. Cobreces, F. Rodriguez, and M. Ruiz, "Fast harmonics compensation in VSCs connected to the grid by synchronous-frame generalized integrators," in Industrial Electronics, 2005. ISIE 2005. Proc. of the IEEE International Symposium on, vol. 2, June 2005, pp. 751–755.

[79] R. Bojoi, G. Griva, V. Bostan, M. Guerriero, F. Farina, and F. Profumo, "Current control strategy for power conditioners using sinusoidal signal integrators in synchronous reference frame," IEEE Transactions on Power Electronics, vol. 20, no. 6, pp. 1402–1412, November 2005.

[80] M. Liserre, R. Teodorescu, and F. Blaabjerg, "Multiple harmonics control for three-phase grid converter systems with the use of PI-RES current controller in a rotating frame," IEEE Transactions on Power Electronics, vol. 21, no. 3, pp. 836–841, May 2006.

[81] K. Ahmed, A. Massoud, S. Finney, and B. Williams, "Stationary frame-based predictive sensorless current control with zero steady state error," IEEE Power Electronics Specialists Conference, pp. 1495–1501, June 2008.

[82] S. Eren, M. Pahlevaninezhad, A. Bakhshai, and P. Jain, "Grid-connected voltage source inverter for renewable energy conversion system with sensorless current control," Twenty-Fifth Annual IEEE Applied Power Electronics Conference and Exposition, pp. 1048–2334, February 2010.

[83] K. Lee, T. Jahns, T. Lipo, V. Blasko, and R. Lorenz, "Observer-based control methods for combined source-voltage harmonics and unbalance disturbances in pwm voltage-source converters," IEEE Transactions on Industry Applications, vol. 45, no. 6, pp. 2010–2021, September 2009.

[84] P. Rodriguez, A. Timbus, R. Teodorescu, M. Liserre, and F. Blaabjerg, "Flexible active power control of distributed power generation systems during grid faults,"

IEEE Transactions on Industrial Electronics, vol. 54, no. 5, pp. 2583–2592, October 2007.

[85] A. Yazdani and R. Iravani, "A unified dynamic model and control for the voltage-sourced converter under unbalanced grid conditions," in Power Engineering Society General Meeting, 2006. IEEE, 2006, pp. 1–6.

[86] H.-S. Song and K. Nam, "Dual current control scheme for PWM converter under unbalanced input voltage conditions," IEEE Transactions on Industrial Electronics, vol. 46, no. 5, pp. 953–959, October 1999.

[87] S. Gómez Jorge, C. A. Busada, and J. Solsona, "Adaptive reduced order observer for grid synchronisation in presence of unbalanced voltages," En revisión IET Generation, Transmission & Distribution, Septiembre 2011.

[88] ——, "Frequency adaptive discrete filter for grid synchronization under distorted voltages," Sugerido para publicación en IEEE Transactions on Power Electronics, Septiembre 2011.

[89] S. Gómez Jorge, J. Solsona, and C. A. Busada, "A voltage sensorless current control for inverters connected to distorted grid voltages," A ser enviado a la IET-Power Electronics, Octubre 2011.

[90] S. Gómez Jorge, C. A. Busada, and J. Solsona, "Low memory and computational burden fundamental component estimator for harmonic contaminated grid voltage suitable for grid synchronization," Aceptado RPIC2011, Noviembre 2011.

[91] S. Gómez Jorge, C. A. Busada, J. Solsona, A. Oliva, and A. Aymonino, "Implementación de un prototipo para generación distribuida utilizando energía solar," XXII Congreso Argentino de Control Automático AADECA. Buenos Aires (2010), Agosto 2010.

[92] C. A. Busada, S. Gomez-Jorge, A. E. Leon, and J. A. Solsona, "Current controller based on reduced order generalized integrators for distributed generation systems," IEEE Transactions on Industrial Electronics, September 2011, digital Object Identifier: 10.1109/TIE.2011.2167892.

[93] C. A. Busada, S. Gomez Jorge, A. E. Leon, and J. A. Solsona, "Pll-less current controller for grid-connected photovoltaic systems," Aceptado RPIC2011, Noviembre 2011.

[94] G. F. Franklin, J. D. Powell, and A. Emami-Naeini, Feedback Control of Dynamic Systems. Addison-Wesley Longman Publishing Co., Inc., 1993.

[95] R. J. Vaccaro, Digital Control. A State-Space Approach. McGraw-Hill, Inc, 1995.

[96] C. L. Phillips and H. T. Nagle, Digital Control System Analysis and Design. Prentice Hall, 1995.

[97] W. M. Haddad and V. Chellaboina, Nonlinear Dynamical Systems and Control: A Lyapunov-Based Approach. Princeton University Press, 2008.

[98] M. Vidyasagar, Nonlinear systems analysis. ISBN 0-13-623463-1. Prentice Hall., 1993.

[99] R. H. Park, "Two-reaction theory of synchronous machines-generalized method of analysis-part i," AIEE Transactions., vol. 48, pp. 716–727, Julio 1929.

[100] W. Leonhard, Control of Electrical Drives, 2 ed. Germany: Springer, 1996.

[101] K. Martin, "Complex signal processing is not complex," Circuits and Systems I: Regular Papers, IEEE Transactions on, vol. 51, no. 9, pp. 1823 – 1836, sept. 2004.

[102] A. E. León and J. A. Solsona, "On state estimation in electric drives," Energy Conversion and Management, vol. 51, no. 3, pp. 600–605, March 2010.

[103] ——, "Design of reduced-order nonlinear observers for energy conversion applications," IET Control Theory and Applications, vol. 4, no. 5, pp. 724–734, May 2010.

[104] P. Vas., Electrical Machines and Drives, A space-vector theory approach. Clarendon Press., 1992.

[105] "IEEE recommended practice for monitoring electric power quality," IEEE Std 1159-2009 (Rev.of IEEE Std 1159-1995), pp. 1–81, 2009.

[106] F. Rodriguez, E. Bueno, M. Aredes, L. Rolim, F. Neves, and M. Cavalcanti, "Discrete-time implementation of second order generalized integrators for grid converters," in Industrial Electronics, 2008. IECON 2008. 34th Annual Conf. of IEEE, November 2008, pp. 176–181.

[107] MathWorks, "Mathlab r2011b documentation, control system toolbox, dlqr," http://www.mathworks.com/help/toolbox/control/ref/dlqr.html.

[108] S. Yang, Q. Lei, F. Peng, and Z. Qian, "A robust control scheme for grid-connected voltage-source inverters," IEEE Transactions on Industrial Electronics, vol. 58, no. 1, pp. 202–212, January 2011.

[109] B. Singh, P. Jayaprakash, and D. Kothari, "A t-connected transformer and three-leg vsc based dstatcom for power quality improvement," IEEE Transactions on Power Electronics, vol. 23, no. 6, pp. 2710 – 2718, November 2008.

[110] B. Singh, K. Al-Haddad, and A. Chandra, "A t-connected transformer and three-leg vsc based dstatcom for power quality improvement," IEEE Transactions on Industrial Electronics, vol. 46, no. 5, pp. 960 – 971, October 1999.

[111] G. Zeng, T. Rasmussen, L. Ma, and R. Teodorescu, "Design and control of lcl-filter with active damping for active power filter," IEEE International Symposium on Industrial Electronics (ISIE), July 2010, digital Object Identifier : 10.1109/ISIE.2010.5637575.

[112] J.-M. Shen, H.-L. Jou, and J.-C. Wu, "Grid-connected power converter with islanding detection and active power filter functions," 2nd IEEE International Symposium on Power Electronics for Distributed Generation Systems (PEDG), June 2010, digital Object Identifier : 10.1109/PEDG.2010.5545927.

[113] S. Rahmani, N. Mendalek, and K. Al-Haddad, "Experimental design of a nonlinear control technique for three-phase shunt active power filter," IEEE Transactions on Industrial Electronics, vol. 57, no. 10, pp. 3364 – 3375, October 2010.

[114] R. Hudson, M. Behnke, R. West, S. Gonzalez, and J. Ginn, "Design considerations for three-phase grid connected photovoltaic inverters," Conference Record of the Twenty-Ninth IEEE Photovoltaic Specialists Conference, pp. 1396–1401, Mayo 2002.

[115] N. Femia, G. Petrone, G. Spagnuolo, and M. Vitelli, "Optimization of perturb and observe maximum power point tracking method," IEEE Transactions on Power Electronics, vol. 20, pp. 963–973, Julio 2005.

[116] W. Bower and M. Ropp, "Evaluation of islanding detection methods for utility-interactive inverters in photovoltaic systems," Sandia National Laboratories, Albuquerque, New Mexico 87185 and Livermore, California 94550, Report, November 2002.