A REVISION OF THE STATE OF THE ART IN ACTIVE FILTERS

Ricardo Ferreira Pinheiro
DEE – UFRN
Caixa Postal 1532 – Ag. UFRN - Natal – RN - CEP: 59078-970
ricpinh@ufrnet.br

Cursino Brandão Jacobina, Antônio Marcus Nogueira Lima, Edison Roberto Cabral da Silva
DEE - UFPB
Caixa Postal 10 105 - UFPB - Campus II - Campina Grande – PB - CEP: 58 109-970
jacobina@dee.ufpb.br - marcus@dee.ufpb.br - edison@dee.ufpb.br

***Abstarct* - This work presents the result of a research about the state of the art in Active Power Filters (APF's). The study envolved 125 references analyzing aspects such as types of converters, types of switchs used and switching techniques, functions of the APF's, topologies of the APF's and electric systems, and, finally, control strategies.**

According to the bibliography it relates the main characteristics of the APF's. In some cases these references take into account their chronological factors in order to point out its thecnological evolution. Concludes for emphasizing that the field of technological development is still open for employing these equipments.

1. INTRODUCTION

The increase of loads and non-linear equipments in the power systems have been demanding the compensation of the disturbances caused for them.

Clark [1], mention that, in agreement with EPRI (Electric Power Research Institute), 35 to 40% of the energy flow through the electronic equipments. Until the year 2000, they will be around 60%.

Created during the 70's [4], the APF's has been technically developing in a way to assist new demands and requirements, with na incressing efficiency. The evolution of the technology of the semiconductor switchs, the converters of the power electronics, the mensuration strategies and the control have been allowing a broader of the APF's.

The instantaneous power theory proposed by Akagi [2,3] finds an important application in the APF's generating new alternatives for the compensation of harmonic and unbalances.

Initially, APF's assisted only a small capacity. However, nowadays, they reach powers around MW allowing them to be used in the distribution systems and the transmission lines.

In [4], Akagi, affirms that in 1995, more than 300 shunt (or parallel) APF's with PWM control using IGBT's or GTO's were operating in Japan, with ratings ranging of 50 kVA to 50 MVA.

2. TYPES OF CONVERTERS

The majority of the PWM converters analized in this study is voltage source converters (VSC) [5-14], or current souce convertrs (CSC) [15]. However, the majority of them is VSC, because the present stage of technological development still finds large difficulties with the CSC's. There for, this work was mainly devoted to VSC's (Fig.1). Some converters PWM, have just the aim of the reactive compensation [2,3,5,8,10,12,14, 15-29,31,32,47-49,57,58,61,64,66,67,73-75,77,78,87,88, 90-93,97,100,102,105,106,111-113,116,117]. They control the power factor of the loads or the flow of the reactive power in the transmission lines therefore, regulating the tension and/or improving the stability either dynamic or static. They are also denominated APF's.

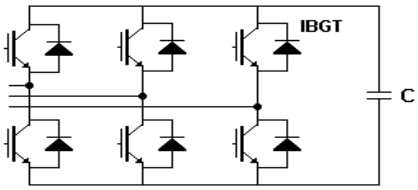

Figure 1 - Three-Phase 3-Wire Active Power filter, VSC

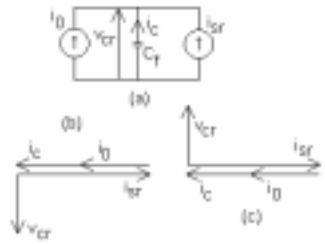

Figure 2 – Shunt Active Power Filter atuation.

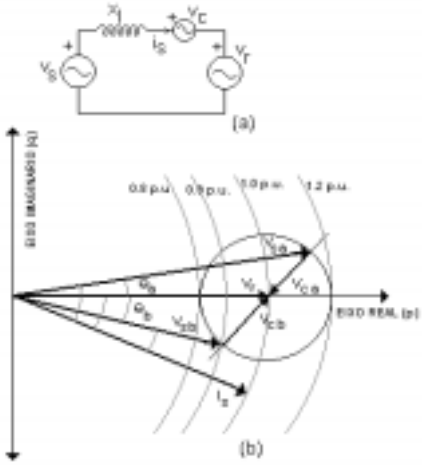

Figure 3 – Series Active power Filter atuation.

Strictly, the denomination active power filter should be adopted for converters destined to the compensation of harmonics. Many authors refer to APF's mentioning reactives of compensators or unbalances compensators PWM. In this study it will be used APF's to all of PWM converters used to accomplish some of these compensations. The combination of all these compensations, that is, reactive, harmonic, unbalance and " flicker", will be treated as "universal compensation" [30-32].

The APF may be connected in parallel (APFP) or in series (APFS). The figures 1 and 2 show, the action of these filters through eschematics and fasorials diagrams. In Fig. 2, two situations are considered to present the regulation of the voltage positive and negative.

Passive filters LC (FLC's) were considered in the study, when participating in the called hybrid active filters (HAF's) [37-45].

They were also found multinivels converters [25, 46,47] that has the disadvantage of involving an elevated number of semicondutor switchs.

3. SEMICONDUTOR DEVICES AND TECHNICAL OF SWITCHING

As presented in the table 1, IGBT is predominant. It was also found MOSFET, GTO and TRANSISTOR. In the present days it has been found that the larger the FA power and frequency more IGBT has been present. In a very high rating GTO's are used.

TABLE 1

DEVICE	REFERENCES	YEAR
IGBT	50 works	92 to 98
MOSFET	[37,38,42,77,89,95, 97,99,108]	94 to 98
TRANSISTOR	[2,3,46,48,78,79,92]	1983,84,86,91,9495, e 98
GTO	[20,21,35,36,45,96, 102, 107,109]	94 to 98

PWM is the more common technique of the switching. References signs of the converter are compared with a triangular wave carrier, to select the switchs for working. This technique can be implemented analogicaly and digitaly.

Recently, techniques of digital switching have been used, in order to obtain the same characteristics of PWM and other advantages, mainly the minimization of stresses, losses, or increase of frequency. In this sense, the technique of the Vectorial Modulation (MV) in $\alpha\beta$ plane it is one of the most important. The table 2 summarizes the found techniques of the switching.

TABLE 2

SWITCHING	REFERENCES	YEAR
Analogical PWM	[2,20,22,41,42,44,47,49 to 52,83,90,100,112]	83[2], 87[100] and 92 to 98
Vectorial modulation	[5,7,8,11,16,25,33,48,53 to 57]	97 to 98
Digital PWM (other)	[6 to 11,13 to 15,19,24,26, 27,31 to 33,36,40,42,48, 56,57 to 60, 85,96,99,113]	95 to 98
Histerese	[3,10,12,27,30,35,45,53,54,61, 63 to 65,78 to 80,91,87,114]	84[3] and 94 to 98

A very used technique for its efficiency and easiness implementation it is the bang-bang or histerese control.

4. TOPOLOGIES OF THE APF'S AND OF THE ELECTRIC SYSTEMS

The study emphasized three-phase APF's. They were found converters with three and four wires. The one of three wires usually involved six switchs, while the one of four wires involved as six (three lags) as eight switchs (four lags).

Frequently, the APFS's, meet three one-phase independent converters (fig.4a), one for phase, with four switchs each (fig.4b), and one capacitor in the side cc [20,52,55,65,68,69]. It also meets APF's with only one capacitor cc (fig.5) to the three converters [20] and only one three-phase converter with one capacitor cc (fig.1) [52,55,65].

An innovative technique is the one addopted in [48]: whitout passive and active elements in the converter neither on the side cc. The treatment of the energy is made by a strategy of control of the bi-directional semicondutor switch.

Passive filters are used in the entrance of APF's to absorb the high frequencies transitory of switching. They are usualy small inductances (VSC's, 40 cases), or capacitances (CSC's 1 case). However, in VSC's they also meet combinations LC, CL, RLC, LRCL and LCL.

5. THE ACTIVE FILTERS FUNCTIONS

The first active filters were of the type APFP. Important examples of them are found in the works of Kataoka [70]

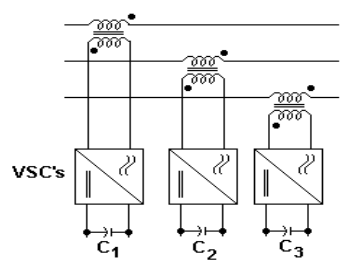

Figura 2(a) FA S with three VSC's and Capacitors.

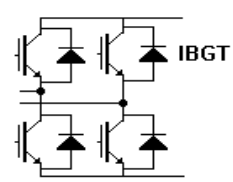

Figura 2(b) - VSC onlyphase with four IGBT's.

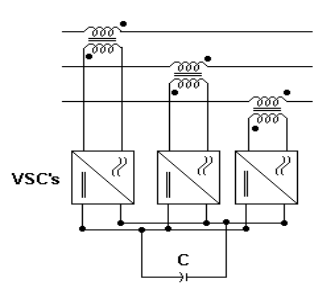

Figura 3 – FA S with three VSC's and one Capacitor

(use of the PWM technics in a CSC for control of the own power factor and minimization of the harmonic), and [71] (use of the PWM technics in a CSC switched for GTO's, minimizing the 5th and 7th harmonics) and, Takahashi [101] (use a asymmetric rule of switching of SCR's for the reduction of the 5th and 7th harmonics).

They are many APFP's applications for compensation reactives and harmonics [2,3,5,8,10,12,15,24-28,31,32, 47-49,57,61,64,66,73-75,77,87,9193,97,100,106,112,113, 117]. New control strategies allowed the compensation of negative sequences currents [31,32,48,49,54,57,61,64,73-75,91,93,116,118], of the zero sequences currents [49,53,54,57,62,64,89,91,93] (also harmonic and zero sequence currents).

FPAS's were applied to hinder the injection of harmonic currents in the system of the concessionary through PCC, providing an elevated impedance in the frequencies different from the fundamental [52,65]. Today, this functions includes harmonic voltages compensation, voltages regulation ("flicker") and voltages unbalances [55,68].

The speed of the power compensator brouth out to the APF's the possibility of adapting to the control of transmission lines, which assures a wanted value of the tension in a point of the line, therefore improving the static and dynamic stability.

Starting from these characteristics, a combination of APFP's with APFS's, developed UPFC's, APQC's, UPQC's, STATCOM's and some types of FACTS's equipaments. In This regard the TABLE 3 is illustrative.

Them APFH's [37-45], are combinations of APFS's and LCF's, where, the APFS's produce an elevated impedance for the passage of the harmonic currents of the load to the concessionary system, which aids the LCF to make the filtering. In same cases APFP's, can be used in series together with LCF's, adjusting the quality factor and incresing the efficiency in the filtering. This association

TABLE 3

COMPENSATOR	APPLICATION	REFERENCE
APQC (active power quality conditioner)	Reactive and harmonic Compensator PWM: distribution	[30]
UPQC (unified power quality conditioner)	Universal compensator PWM to loads	[31,32]
UPFC (unified power flow controller, fig.4)	Reactive compensation and stability control of transmission lines through PWM converters	[22,36,20,96]
STATCOM (static synchronous compensator, fig.5)	PWM converter to reactives and voltage control and soften oscillations in tie lines	[16,33-35,84,107]
FACTS (flexible ac transmission system)	Controll of great loads with series compensators	[20,24,34,35, 45,49,93]

allows to minimize the rating of the APF and/or gives a margin of tolerance in the adjustment of syntony of LCF.

6. STRATEGIES OF CONTROL

The main found control strategies are in the the table 4. A technique one very powerful and that it has been very much used, is the instantaneous power theory (IPT).

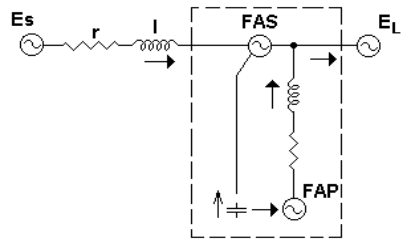

Figura 4 – Unified power quality conditioner (UPFC)

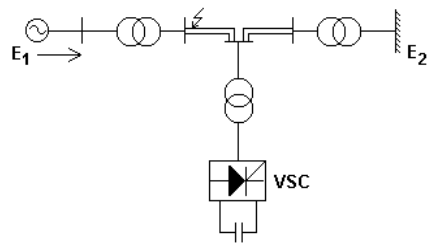

Figure 5 – Static Synchronous Compensator (STATCOM)

According to it, starting from the instantaneous values of the tensions and currents (in phase components [66], dq [5,9,10,13,14,17,18,20-23,28,29,32,33,36,40,53,54,59,60, 65,67,68,73,74,90,96,99,105,107,114,118,120,125] or αβ [6,7,10,12,14,17,18,20,22,25,26,29,30,32,33,40,44,48,50, 53,54, 57,60,62-64,66,67, 73-75,91,93, 109-111,113,121, 122]) is possible to calculate the real and imaginary instantaneous powers. For compensating reactives, its suficient the action of APF for canceling the instantaneous imaginary power. For compensating harmonics and components of negative and zero sequencies in the real power, it is necessary to separate the oscilating components real power leaving the source, to supply only the constant real power.

TABLE 4

TYPE OF CONTROL	REFERENCES
P	[119,22]
PI	[15,17,18,23,33,55,79,82,88,90,96,102,105, 112,118,121]
PID	[30,45]
Adaptative	[60]
Dead Beat	[7,13,14,31, 69,76]
Predictive	[6, 16,85]
Sliding modes	[10,26]
Fuzzy	[66,85]
IPT	[2,3,12,20,22,23,26,30,32,33,40,43,44,46, 47,49,50,52-54,61-64,66,67,73-75,91,93, 95,99,109,110,111,113,115,121,122,125]
IdIq	[29,32,41,43,57,65,73,74]
Linearization	[8,9,14,20,21,58,59]
H_∞ or RH	[28,116]
Pseudo-hybrid	[60]

7. CONCLUSIONS

The study found out a graet investment in the researchs and technological development of APF's. The development of new switchings techniques and of the semicondutors devices will continue enlarging perspectives of applications to the APF's. Particularly, the combined filters (universal compensators) and the FACTS

systems are still demanding efforts of the researchers, mainly in the field of hight potencies.

8. BIBLIOGRAPHY

[1] S.L. Clark, P. famouri, W.L. Cooley, "Elimination of Supply Harmonics: an Evolution of Current Compensation and Active Filtering Methods", IEEE, IAS 94, Denver, Colorado, USA, Oct./1994, pp-1699-1704.

[2] H. Akagi, Y. Kanazawa, K. Fujita E A. Nabae, "Generalized Theory of Instantaneous Reactive Power and Its Application", Electrical Engineering in Japan, vol.103, nº 4, pp. 58-66, 1983.

[3] H. Akagi, Y. Kanazawa, A. Nabae, "Instantaneous Reactive Power Compensators Comprising Switching Devices Without Energy Storage Components", IEEE Trans. on Industry Applications, vol.IA-20, nº 3, pp. 625-630, May/June, 1984.

[4] H. Akagi, "New Trends Active Filters", VI European Conference on Power Electronics and Applications, Sevilla, Espain, vol. 0, Sept/1995, pp. 0.017-0.026.

[5] T. Nishijima, M. Tanaka, A. Imayanagita, Y.F. Chen, K. Fujikawa and H. Kobayashi, "Direct Instantaneous Harmonic Distortion Minimization Control for Three Phase Sinusoidal Current Converter", IEEE, PESC 98, Fukuoka, Japão, May/1998, pp. 510-516.

[6] S.L. Jung, H. S. Huang e Y.Y. Tzou, "A Three-Phase PWM AC-DC Converter With Low Switching Frequency and High Power Factor Using DSP-Based Repetitive Control Technique", IEEE, PESC 98, Fukuoka, Japão, May/1998, pp. 517-523.

[7] L. Malesani, P. Mattavelli e S. Buso, "Robust Dead-Beat Current Control for PWM Rectifiers and Active Filters", IEEE, IAS 98, St. Louis, Mo, USA, Oct./1998.

[8] D.C. Lee, K.D. Lee E G. Lee, "Voltage Control of PWM Converters Using Feedback Linearization", IEEE, IAS 98, St. Louis, Mo, USA, Oct./1998.

[9] J. Jung, S. Kyoung E K. Nam, "A Feedback Linearizing Control Scheme for a PWM Converter-Inverter Having A Very Small DC-Link Capacitor", IEEE, IAS 98, St. Louis, Mo, USA, Oct./1998.

[10] J.F. Silva e J.F. Martins, "Space Vector Alfa Beta Current Regulator for Sliding Mode Controlled Unity Power Factor PWM Rectifiers", IEEE, IECON 98, Aachen, Alemanha, Sept./1998, pp. 1877-1882.

[11] S.M. Ali e M. P. Kazmierkowski, "Current Regulation of Four-Leg PWM-VSI", IEEE, IECON 98, Aachen, Alemanha, Sept./1998, pp. 1853-1858.

[12] P.G.Barbosa, L.G.B. Rolim, V.V. Tavares, E.H. Watanabe, R. Hanitsch, "Novel Control Strategy for Grid-Connected DC-AC Converters With Load Power Factor and MPPT Control", SOBRAEP, COBEP 95, São Paulo, Dec./1995, pp. 327-332.

[13] M. Lindgren e J. Svensson, "Control of a Voltage-Source Converter Connected to the Grid Through AN LCL-Filter-Application to Active Filtering", IEEE, PESC 98, Fukuoka, Japão, May/1998, pp. 229-235.

[14] J. Svensson e M. Lindgren, "Vetor Current Controlled Grid Connected Voltage Source Converter-Influence of Non-Linearities on the Performance" IEEE, PESC 98, Fukuoka, Japão, May/1998, pp. 531-537.

[15] T.C. Green, M.H. Taha, N.A. Rahim e B.W. Williams, "Three-Phase Step-Down Reversible AC-DC Power Converter", IEEE - Trans. on Power Electronics, vol. 12, no. 2, pp. 319-324, March/1997.

[16] G.W. Moon e S.H. Yoon, "Predictive Current Control of Distribution Static Condenser (D-Statcon) for Reactive Power Compensation in Flexible AC Transmission System (FACTS)", IEEE, PESC 98, Fukuoka, Japão, May/1998, pp. 816-822.

[17] R.Pena, J.C.Clare e G.M.Asher, "A Doubly Fed Induction Genertor Using Back-to-Back PWM Converters Supplying an Isolated Load from a Variable Speed Wind Turbine", IEE Proc-Electr. Power Appl., vol.143, nº 5, pp. 380-387, Sept./1996.

[18] R.Pena, J.C. Clare e G.M. Asher, "Doubly Fed Induction Genertor Using Back-to-Back PWM Converters and Its Application to Variable-Speed Wind Energy Generation, IEE Proc-Electr. Power Appl., vol.143, nº 3, pp. 231-241, May/1996.

[19] J. Dixon, J.Contardo e L. Moran, "DC Link Fuzzy Control for an Active Power Filter, Sensing The Line Current Only", IEEE, PESC 97, St. Louis, Mo, USA, June/1997, pp. 1109-1114.

[20] P. G. Barbosa, E. H. Watanabe, "Advanced Series Reactive Power Compensator Based on Voltage Source Inverters", SOBRAEP, COBEP 95, São Paulo, Dec./1995, pp. 03-08.

[21] Z. Yao, D.O. Neacsu, V. Rajagopalan, "Exact Linearization for Advanced Reactive Power Compenstors", IEEE, PESC 96, Baveno, Italy, June/1996, pp. 521-526.

[22] H. Fujita, Y. Watanabe e H. Akagi, "Control and Analysis of a Unified Power Flow Controller", IEEE, PESC 98, Fukuoka, Japão, May/1998, pp.805-811.

[23] H.S. Kim, H.S.Mok, G.H. Choe, D.S. Hyun e S.Y. Choe, "Design of Current Controller for 3-Phase PWM Converter With Unbalanced Input Voltage", IEEE, PESC 98, Fukuoka, Japão, May/1998, pp. 503-509.

[24] J. Yanchao e W. Fei, "100 KVAR Generalized Active Power Filter", IEEE, IAS 98, St. Louis, Mo, USA, Oct./1998.

[25] V. Aburto, M. Schneider, L. Moran e J. Dixon, "An Active Power Filter Implemented With a Three-Level NPC Voltage-Source Inverter", IEEE, PESC 97, St. Louis, Mo, USA, June/1997, pp. 1121-1126.

[26] V. Cardenas, N.Vazquez e C. Hernandez, "Sliding Mode Control Applied to a 3phase Shunt Active Power Filter Using Compensation With Instantaneous Reactive Power Theory", IEEE, PESC 98, Fukuoka, Japão, May/1998, pp. 236-241.

[27] J.A. Lambert, E.A.A. Coelho, J.B. Vieira JR., L.C. de Freitas e V.J. Farias, "Active Power Filter Control Based on Imposition of Input Sinusoidal Current, IEEE, PESC 97, St. Louis, Mo, USA, June/1997, pp. 406-411.

[28] Z. Yao , S. Lahaie, V. Rajagopalan, "Robust Compensator Of Harmonics And Reactive Power", IEEE, PESC 95, Seattle, Washington, USA, June/1993, pp. 215-221.

[29] V. Soares, P. Verdelho e G. Marques, "Active Power Filter Control Circuit Based On The Instantaneous Active And Reactive Current ID-IQ Method, IEEE, PESC 97, St. Louis, Mo, USA, June/1997, pp. 1096-1101.

[30] N.R. Raju, S.S. Venkata, R.A. Kagalwala, V.V. Sastry, "An Active Power Quality Conditioner For Reactive Power And Harmonics Compensation", IEEE, PESC 95, Seattle, Washington, USA, June/1993, pp. 209-214.

[31] F. Kamran, T. G. Habetler, "Combined Deadbeat Control Of A Series-Parallel Converter Combination Used As A Universal Power Filter", IEEE, PESC 95, Seattle, Washington, USA, June/1993, pp. 196-201.

[32] H. Fujita, H. Akagi, "The Unified Power Quality Conditioner: The Integration Of Series Active Filters And Shunt Active Filters", IEEE, PESC 96, Baveno, Italy, June/1996, pp. 494-501.

[33] P. Garcia-Gonzalez e A. Garcia-Cerrada, "Control System For A Upfc In A Transmission Line", IEEE, IECON 98, Aachen, Alemanha, Sept./1998, pp. 462-466

[34] T.J. Hammons E S.K. Lim, "Flexible Ac Transmission Systems (FACTS)", Electric Machines And Power Systems, vol. 25, nº 1, University of Kentucky, USA, pp. 73-85, January, 1997.

[35] C. Li, Q. Jiang, Z. Wang e D. Retzmann, "Design Of A Rule-Based Controller For Statcom", IEEE, IECON 98, Aachen, Alemanha, Sept./1998, pp. 467-472.

[36] Q. Yu, S.D. Round, L.E. Norum, T.M. Undeland, "Dynamic Control Of A Unified Power Flow Controller", IEEE, PESC 96, Baveno, Italy, June/1996, pp. 508-514.

[37] F.B. Libano, J.A. Cobos e J. Uceda, "Simplified Control Strategy For Hybrid Active Filters", IEEE, PESC 97, St. Louis, Mo, USA, June/1997, pp. 1102-1108.

[38] H. Fujita, T. Yamasaki e H. Akagi, "A Hibrid Active Filter For Damping Of Harmonic Resonance In Industrial Power Systems", IEEE, PESC 98, Fukuoka, Japão, May/1998, pp. 209-216.

[39] R. Elshatshat, M. Kazerani e M.M.A. Salama, "Modular Approach To Active Power-Line Harmonic Filtering", IEEE, PESC 98, Fukuoka, Japão, May/1998, pp. 223-228.

[40] GU H. Jung e GYU H. Cho, "New Active Power Filter Eith Simplw Low Cost Structure Without Tuned Filters", IEEE, PESC 98, Fukuoka, Japão, May/1998, pp. 217-222.

[41] P.T. Cheng, S. Bhattacharya e D. Divan, "Experimental Verification Of Dominant Harmonic Active Filter (DHAF) For High Power Applications", IEEE, IAS 98, St. Louis, Mo, USA, Oct./1998.

[42] F. B. Libano, J. A. Cobos e J. Uceda, "Controle Simplificado de Filtros Híbridos de Potência", SBA, CBA 98, Uberlandia, MG, BR, Sept/1998, pp. 657-663.

[43] F. B. Libano, D. S. L. Simonetti, J. Uceda, "An Overview On Hybrid Active Filters", SOBRAEP, COBEP 95, São Paulo, Dec./1995, pp. 333-337.
[44] J. A. R. Monteiro, E. H. Watanabe, R. Hanitsch, "Filtros Ativos Mistos em Derivacao Aplicados a Grandes Cargas Nao-Lineares - uma solucao de custo reduzido".
[45] N.R. Raju, S.S. Venkata, V.V. Sastry, "A Decoupled Series Compensator For Voltage Regulation And Harmonic Compensation", IEEE, PESC 96, Baveno, Italy, June/1996, pp. 527-531.
[46] H. Akagi, A. Nabae e S. Atoh, "Control Strategy Of Active Power Filters Using Multiple Voltage-Source PWM Converters", IEEE, Trans. on Industry Applications, vol. IA-22, no. 3, pp. 460-465, May-June/1986.
[47] L. Rosseto e P. Tenti, "Using AC-Fed PWM Converters As Instantaneous Reactive Power Compensators", IEEE, Trans. on Power Electronics, vol. 7, no. 1, pp. 224-230, Jan/1992.
[48] A. Dastfan, D. Platt e V.J. Gosbell, "Design and Implementation of a New Three-Phase Four-Wire Active Power Filter With Minimum Components", IEEE, IAS 98, St. Louis, Mo, USA, Oct./1998.
[49] M. Aredes, P. G. Barbosa e E. Watanabe, "New Control Algorithms For Shunt Three-Phase Four-Wire Active Power Filters", SOBRAEP, COBEP 95, São Paulo, Dec./1995, pp. 1165-1170.
[50] A. Nakata, A. Ueda e A. Torii, "A Method Of Current Detection For An Active Power Filter Applying Moving Average To Pq-Theory", IEEE, PESC 98, Fukuoka, Japão, May/1998, pp. 242-247.
[51] H. Akagi, H. Fujita e K. Wada, "A Shunt Active Filter Based On Voltage Detection For Harmonic Termination Of A Radial Power Distribution Line", IEEE, IAS 98, St. Louis, Mo, USA, Oct./1998.
[52] L. Moran, P. Werlinger, J. Dixon, R. Wallace, "A Series Active Power Filter Which Compensates Current Harmonics And Voltage Unbalance Simultaneously", IEEE, PESC 95, Seattle, Washington, USA, June/1993, pp. 222-227.
[53] P. Verdelho, "Space Vector Based Current Controller In Alfa/Beta/Zero Coordinate System For The PWM Voltage Converter Connected To The AC Mains", IEEE, PESC 97, St. Louis, Mo, USA, June/1997, pp. 1115-1120.
[54] P.Verdelho e G.D.Marques, "A Current Control System Based In Alfa/Beta/Zero Variables For A Four-Leg PWM Voltage Converter", IEEE, IECON 98, Aachen, Alemanha, Sept./1998, pp. 1847-1852.
[55] S.-Y. Lee, Y.-M. Chae, J.-S. Cho, G.-H Choe, H.-S. Mok E D.-H. Jang, "A New Control Strategy For Instantaneous Voltage Compensator Using 3-Phase PWM Inverter, IEEE, PESC 98, Fukuoka, Japão, May/1998, pp. 248-254.
[56] J. Svensson e R. Ottersten, "Shunt Active Filtering Of Vector-Current Controlled VSC AT a Moderate Switching-Frequency, IEEE, IAS 98, St. Louis, Mo, USA, Oct./1998.
[57] L. A. Pittorino, J.A. du Toi e J.H.R. Enslin, "Evaluation Of Converter Topologies And Controllers For Power Quality Compensators Under Unbalanced Conditions", IEEE, PESC 97, St. Louis, Mo, USA, June/1997, pp. 1127-1133.
[58] A. Tahri, A. Draou e M. Benghanem, "A Fast Current Control Strategy Of A Pwm Inverter Used For Static Var Compensation", IEEE, IECON 98, Aachen, Alemanha, Sept./1998, pp. 450-455.
[59] G.D. Marques E P. Verdelho, "Control Of An Active Power Filter Based On Input-Output Linearization", IEEE, IECON 98, Aachen, Alemanha, Sept./1998, pp. 456-461.
[60] Y. Sato, S. Nagayama, H. Chigira e T. Kataoka, "An Adaptative Control Strategy For Active Power Filters With Voltage Detection", IEEE, IAS 98, St. Louis, Mo, USA, Oct./1998.
[61] D. Gonzalez, J. Balcells, S. Lovera e R. Lima, "Comparison Between Unity Power Factor And Instantaneous Power Theory Control Strategies Applied To A Three Phase Active Power Filter", IEEE, IECON 98, Aachen, Alemanha, Sept./1998, pp. 843-847
[62] P. Verdelho e G.D. Marques, "A Neutral Current Electronic Compensator", IEEE, IECON 98, Aachen, Alemanha, Sept./1998, pp. 831-936.
[63] M. Aredes, J. Hafner e K. Heumann, "Three-Phase Four-Wire Shunt Active Filter Control Strategies", Trans. on Power Electronics, vol. 12, no. 2, pp. 311-318, March/1997.
[64] M. Aredes, K. Heumann, E. H. Watanabe, J. Hafner, "A Three-Phase Four-Wire Shunt Active Filter Using Six IGBT'S", SOBRAEP, COBEP 95, São Paulo, Dec./1995, pp. 21-26.
[65] S. Bhattacharya, D. Divan, "Design And Implementation Of A Hybrid Series Active Filter System", IEEE, PESC 95, Seattle, Washington, USA, June/1993, pp. 189-195.
[66] F.Z. Peng, G.W. Ott e D. J. Adams, "Harmonic And Reactive Power Compensation Based On The Generalized Instantaneous Reactive Power Theory For 3-Phase 4-Wire Systems", IEEE, PESC 97, St. Louis, Mo, USA, June/1997, pp. 1089-1095.
[67] A. Nabae e T. Tanaka, "A Quasi-Instantaneous Reactive Power Compensator For Unbalanced And Non-Sinusoidal Three-Phase Systems", IEEE, PESC 98, Fukuoka, Japão, May/1998, pp. 823-828.
[68] A. Nabae, Y. Nakajima, L. Cao, T. Tanaka e S. Ariga, "A Series Active Capacitance For Compensating Voltage Drops Caused By Source Impedances In Power Systems", IEEE, PESC 97, St. Louis, Mo, USA, June/1997, pp. 351-355.
[69] C. A. Claro e A. campos, "Analise de Compensador Serie de Tensao e Filtragem de Harmonicos Empregando Filtro Ativo e a Tecnica de Controle Dead Beat", SBA, CBA 98, Uberlandia, MG, BR, Sept./1998.
[70] T. Kataoka, K. Mizumachi, S. Miyairi, "A Pulsewidth Controlled AC - to- DC Converter To Improve Power Factor And Waveform Of AC Line Current", IEEE Trans. on Industry Applications, vol. IA-15, n° 6, pp. 670-675, Nov.-Dec./1979.
[71] T. Kataoka, K. Kawakami, E.H. Watanabe, "Retificador Trifasico com Modulaçao de Largura de Pulso da Corrente de Entrada Usando GTO", SBA, CBA 82, Campinas, SP, BR, Sept./1982, pp. 388-393.
[72] I. Takahashi e A. Nabae, "Universal Power Distortion Compensator Of Line Commutated Thyristor Converter", IEEE, IAS-1980, pp. 858-864.
[73] P. Verdelho, "Voltage Type Reversible Rectfiers Control Methods In Unbalanced And Non-Sinusoidal Conditions", IEEE, IECON 98, Aachen, Alemanha, Sept./1998, pp. 479-484.
[74] G.D. Marques, "A Comparison Of Active Power Filter Control Methods In Unbalanced And Non-Sinusoidal Conditions", IEEE, IECON 98, Aachen, Alemanha, Sept./1998, pp. 444-449.
[75] A. Nava-Segura, M. Carmona-Hernandez, "A Detailed Instantaneous Harmonic And Reactive Compensation Analysis Of Three-Phase AC/DC Converters", in ABC e Alfa/Beta Coordinates, IEEE, IECON 98, Aachen, Alemanha, Sept./1998, pp. 825-830.
[76] L. Malesani, P. Mattavelli E S. Buso, "Dead-Beat Current Control For Active Filters", IEEE, IECON 98, Aachen, Alemanha, Sept./1998, pp. 1859-1864.
[77] M. Machmoum, N. Bruyant, S. Siala, R. le Doeuff, " A Practical Approach to Harmonic Current Compensation by a Single-Phase Active Filter", VI European Conference on Power Electronics and Applications, Sevilla, Espain, Sept/1995, pp. 2.505-2.510.
[78] B. Dakyo, J.C. le Bunetel, L. Protin, " Single-Phase Active Filter Power Factor Correction", VI European Conference on Power Electronics and Applications, Sevilla, Espain, Sept/1995, pp. 3.286-3.291.
[79] J. Nastran, R. Cajhen, M. Seliger, P. Jereb, " Active Power Filter for Nonlinear ac Loads", IEEE - Trans. on Power Electronics, vol. 9, no. 1, pp. 92-96, Jan./1994.
[80] M. Ohshima and E. Masada, "Novel Error Tracking Mode ac Current Weveform Control Method and its ac Filter Design Procedure", VI European Conference on Power Electronics and Applications, Sevilla, Espain, Sept/1995, pp. 2.472-2.477.
[81] Z.D. Koozehkanani, P. Mehta and M.K. Darwish, "Active Symmetrical Lattice Filter for Harmonic Current Reduction", VI European Conference on Power Electronics and Applications, Sevilla, Espain, Sept/1995, pp. 1.869-1.873.
[82] M. Carpita, G. Giannini, E. Gilard and P. Leonardelli, "Line Filter for High Power Inverter Locomotive Using Active Circuit for Harmonic Reduction. Prototype Tests Results.", VI European Conference on Power Electronics and Applications, Sevilla, Espain, Sept/1995, pp. 1.898-1.903.
[84] A. Campos, G. Joos, P.D. Ziogas and J.F. Lindsay, "Analysis and Design of a Series Voltage Unbalance Compensator Based on a Three-Phase VSI Operating with Unbalanced Switching Functions", IEEE - Trans. on Power Electronics, vol. 9, no. 3, pp. 269-274, May./1994.
[84] M. Rastogi, N. Mohan and A.-A. Edris, "Filtering of Harmonic Currents and Damping of Resonances in Power Systems with a Hybrid-Active Filter", IEEE, APEC 95, Dalas, Texas, USA, Mars/1995, pp. 607-612.
[85] H. Pouliquen, P. Lemerle and E. Plantive, "Voltage Harmonics Source Compensation Using a Shunt Active Filter", VI European

Conference on Power Electronics and Applications, Sevilla, Espain, Sept/1995, pp. 1.117-1.122.
[86] M. Pereira and K. Sadek, "Damping Harmonics in the Power System with Active Filters", VI European Conference on Power Electronics and Applications, Sevilla, Espain, Sept/1995, pp. 1.123-1.128.
[87] A.A.B. Rulula and M.S. Badia, "A New Approach to Harmonic Compensation with Hybrid Active Filters", VI European Conference on Power Electronics and Applications, Sevilla, Espain, Sept/1995, pp. 1.925-1.928.
[88] R.L.A. Ribeiro, C.B. Jacobina, E.R.C. da Silva and A.M.N. Lima, " AC/AC Converter with Four Switch Three Phase Structures", IEEE, PESC 96, Baveno, Italy, June/1996, pp. 134-139.
[89] G. Kamath and N. Mohan, "A Novel, Reduced Rating Active Filter for 3-Phase, 4-Wire Loads", IEEE, IAS 94, Denver, Colorado, USA, Oct./1994, pp-936-940.
[90] M.E. Fraser and C.D. Manning, "Four-Wire Power Factor Corrected Boost Rectifier", VI European Conference on Power Electronics and Applications, Sevilla, Espain, Sept/1995, pp. 3.351-3.355.
[91] M.Aredes, J. Hafner and K. Heumann, " A Three-Phase Four-Wire Shunt Active Filter Using Six IGBT's", VI European Conference on Power Electronics and Applications, Sevilla, Espain, Sept/1995, pp. 1.874-1.879.
[92] W. Koczara, B. Dakyo and L. Potin, "AC/AC Three Phase Converter Operating with Unity Power Factor and Sinusoidal Input Current", VI European Conference on Power Electronics and Applications, Sevilla, Espain, Sept/1995, pp. 1.920-1.924.
[93] M. Aredes and E. H. Watanabe, "New Control Algorithms for Series and Shunt Three-Phase Four-Wire Active Power Filters", IEEE - Trans. on Power Delivery, vol. 10, no. 3, pp. 1649-1656, July/1995.
[94] A. Campos, G. Joos, P. Ziogas, J. Lindsay, " Analysis and Design of a Series Voltage Compensator for Three-Phase Unbalanced Sources", IEEE Trans. on Industrial Electronics, vol.-39, nº 2, pp. 159-167, April, 1992.
[95] H. Akagi, " Trends in Active Power Line Conditioners", IEEE - Trans. on Power Electronics, vol. 9, no. 3, pp. 263-268, May/1994.
[96] Q. Yu, S.D. Round, L.E. Norum and T.M. Undeland, " A New Control Strategy for a Unified Power Flow Controller", VI European Conference on Power Electronics and Applications, Sevilla, Espain, Sept/1995, pp. 2.901-2.906.
[97] W. Koezara, R. Teofilak, M.Rukat and L. Grzesiak, "New Strategy for Non-Active Power Compensation", VI European Conference on Power Electronics and Applications, Sevilla, Espain, Sept/1995, pp. 2.517-2.521.
[98] S. Bhowmik, R. Spee and J.H.R. Enslin, "Performance Optimization for Doubly-Fed Power Generation Systems", IEEE, IAS 98, St. Louis, Mo, USA, Oct./1998.
[99] H. Akagi and H. Fujita, "A New Power Line Conditioner for Harmonic Compensation in Power Systems", IEEE - Trans. on Power Delivery, vol. 10, no. 3, pp. 1570-1575, July/1995.
[100] L. Malesani and P. Tenti, "Three-Phase AC/DC PWM Converter with Sinusoidal ac Currents and Minimum Filter Requirements", IEEE Trans. on Industry Applications, vol.IA-23, nº 1, pp. 71-77, January/February, 1987.
[101] Y. Hayashi, N. Sato and K. Takahashi, "A Novel Control of a Current-Source Active Filter for ac Power System Harmonic Compensation", IEEE Trans. on Industry Applications, vol.IA-27, nº 2, pp. 380-385, March/April, 1991.
[102] G. Joos and J. Espinoza, "Three Phase Series VAR Compensation Based on a Voltage Controlled Current Source Inverter with Supplemental Modulation Index Control", IEEE, IAS 94, Denver, Colorado, USA, Oct./1994, pp. 1437-1442.
[103] E. Muljadi and T.A. Lipo, "Series Compensated PWM Inverter with Battery Supply Applied to an Isolated Induction Generator", IEEE Trans. on Industry Applications, vol.IA-30, nº 4, pp. 1073-1082, July/August, 1994.
[104] G. Vaupel, "Wide-Band Filter with Actively Reduced Losses for Power-Systems", VI European Conference on Power Electronics and Applications, Sevilla, Espain, Sept/1995, pp. 1.892-1.897.
[105] Roberto Leidhold and G. Garcia, "Variable Speed Field-Oriented Controlled Induction Generator", IEEE, IAS 98, St. Louis, Mo, USA, Oct./1998.
[106] Santiago Dominguez Rubira and M.D. Mcculloch, "Control of Doubly Fed Wind Generators Connected to the Grid by Asymmetric Transmission Lines", IEEE, IAS 98, St. Louis, Mo, USA, Oct./1998.
[107] K.R. Padiyar and A.L. Devi, "Control and Simulation of Static Condenser", IEEE, APEC 94, Orlando, Flórida, USA, February/1994, pp. 826-831.
[108] A. Von Jouanne, P. Enjeti, "A New Three-Phase Series Ressonant Active Power Filter", IEEE, IAS 94, Denver, Colorado, USA, Oct./1994, pp. 929-935.
[109] C. Lott, O. Lapierre and H. Pouliquen, "High-Power Voltage Source PWM Active Filter with Low Switching Effect", VI European Conference on Power Electronics and Applications, Sevilla, Espain, Sept/1995, pp. 1.908-1.913.
[110] L.F. Penello, E.H. Watanabe and M. Aredes, " Filtro Ativo de Potência Tipo Shunt com Seleção da Potência a Ser Compensada", SBA, CBA 92, Vitória, ES, BR, Sept/1992, pp. 786-791.
[111] A. Cavallini and G.C. Montanari, "Compensation Strategies for Shunt Active-Filter Control", IEEE - Trans. on Power Electronics, vol. 9, no. 6, pp. 587-593, November/1994.
[112] J.W. Dixon, L. Moran and R.R. Wallace, "A Three-Phase Active Power Filter Operating with Fixed Switching Frequency for Reactive Power and Current Harmonic Compensation", IEEE Trans. on Industrial Electronics, vol.-42, nº 4, pp. 402-408, August, 1995.
[113] M.F.M.M. Siam, B.W. Williams and S.J. Finney, " Improved Active Power Filter with Triplen Deadband PWM", IEEE, PESC 96, Baveno, Italy, June/1996, pp. 1899-1905.
[114] S. Bhattacharya, A. Veltman, D.M. Divan and R.D. Lorenz, "Flux-Based Active Filter Controller", IEEE Trans. on Industry Applications, vol.IA-32, nº 3, pp. 491-502, May/June, 1996.
[115] P. Delarue and R. Bausiere, " New Control Method for Active Power Filter Needing Line Current Measurement Only", VI European Conference on Power Electronics and Applications, Sevilla, Espain, Sept/1995, pp. 1.914-1.919.
[116] J.W. Dixon, J.J. Garcia and L. Moran, " Control System for Three-Phase Active Power Filter which Simultaneously Compensates Power Factor and Unbalanced Loads", IEEE Trans. on Industrial Electronics, vol.-42, nº 6, pp. 636-641, December, 1995.
[117] R. Strzelecki, L. Frackowiak, J.Zyborski and G. Benysek, "Section Hybrid Filter for Current Harmonics in a Test Stand to Regenerative Braking of Internal Combustion Locomotives", VI European Conference on Power Electronics and Applications, Sevilla, Espain, Sept/1995, pp. 1.886-1.891.
[118] P. Verdelho and G.D. Marques, "An Active Power Filter and Unbalanced Current Compensator Control Circuit", VI European Conference on Power Electronics and Applications, Sevilla, Espain, Sept/1995, pp. 1.929-1.934.
[119] H. Pouliquen, M.M. Bettega and W. Miaoxin, "A New Control Strategy of Combined System of Series Active and Shunt Passive Filters for Minimising Passive Filter Number", VI European Conference on Power Electronics and Applications, Sevilla, Espain, Sept/1995, pp. 1.135-1.139.
[120] H. Pouliquen and P. Rioual, "Vector Control of Shunt Active Filters", VI European Conference on Power Electronics and Applications, Sevilla, Espain, Sept/1995, pp. 1.880-1.885.
[121] S. Loudot, H. Pouliquen, T. Meynard and Y. Cheron, "Active Current Filter for MV/HV Networks", VI European Conference on Power Electronics and Applications, Sevilla, Espain, Sept/1995, pp. 1.129-1.134.
[122] Y. Komatsu and T. Kawabata, "A Control Method of Active Power Filter in Unsymmetrical Voltage System", VI European Conference on Power Electronics and Applications, Sevilla, Espain, Sept/1995, pp. 1.904-1.907.
[123] A. K. Guru, J.C. Balda, K.C. and Y.Q. Xiang, "Design of a Switching-Ripple Filter for a Shunt-Connected Active Power Filter", IEEE, IAS 98, St. Louis, Mo, USA, Oct./1998.
[124] T.H. Putman, L. Gyugyi and R.A. Otto, "Principles and Applications of Static Thyristor-Controlled Shunt Compensators", IEEE Trans. on Power Apparatus and Systems, vol.PAS-97, nº 5, pp. 1935-1945, Sept./Oct. 1984.
[125] E. Destobbeleer and L Protin, "On the Detection of Load Active Currents for Active Filter Control", IEEE - Trans. on Power Electronics, vol. 11, no. 6, November/1996.