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Power Quality Conditioners for Railway Traction - a Review

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Original scientific paper

Railway traction is a more stochastic heavy load connected system. Due to the usage of ac-dc converters and ac-ac converters, the various power quality issues become the major problems in the electric system. This paper presents a review on power quality conditioners suitable for Railway traction based on the configuration, components involved and on the technical and economic considerations. More than 120 publications are listed in the reference for quick review.

Key words: Power Quality Conditioners, Harmonics and Reactive Power Compensation, Active Filters, Shunt Hybrid filter, Power Quality

Poboljšanje kvalitete snage za željezničke sustave - pregled istraživanja. Željeznički električni sustav je prilično stohastički sustav s velikim opterečenjem. Zbog korištenja AC/DC i AC/AC pretvarača, problemi s kvalitetom isporučene energije predstavljaju glavne probleme električnih sustava. U ovome radu predstavljen je pregled područja vezano uz poboljšanje kvalitete energije za željezničke sustave ovisno o konfiguraciji, komponentama uključenim te o tehničkim i ekonomskim aspektima. Više od 120 radova navedeno je u popisu literature.

Ključne riječi: metode za poboljšanje kvalitete energije, kompenzacija haromonika i reaktivne snage, aktivni filtri, šant hibridni filtar, kvaliteta energije

***Nomenclature*:**

UPQC : Unified Power Quality Conditioner
PLL : Phase Lock Loop
PWM : Pulse Width Modulation
DSP : Digital Signal Processor
SVC : Static Var Compensator
TCR : Thyristor Control Rectifier

1 INTRODUCTION

The ac-dc converters and ac-ac converters used in the railway traction lead to various power quality problems. The major power quality problems seen in the railway traction are power factor and harmonics which leads to penalty. The traction loads are of single phase loads that lead to an unbalanced load which draws more neutral currents. Hence, the study of ideal Power Quality Conditioners for the railway traction system becomes essential to avoid the effects of power quality issues.

A study [1-15] has been done to quantify the various power quality problems in the electric networks and to analyze the power quality problems. The power quality problems due to traction loads lead to low efficiency in the system and poor power factor. In order to avoid penalty on poor power factor, capacitors are used conventionally to maintain the power factor either manually or through electronics switching.

To maintain the harmonics in the system within the limits, the passive filters [16-33] widely called Self tuned filters are used initially, which have some drawbacks such as fixed compensation, large size and resonance. Since, the traction loads are variable and increase drastically, it has led to the development of a dynamic solution called active filters [34-56].

The researchers are recently focusing on the compensation for harmonics, reactive power, load balancing and neutral current compensation [57-129].

This paper comprises a survey on various types of compensations, which are suitable for railway traction. More than 100 presentations [1-129] are studied and classified in SIX categories. The first [1-15] is on power quality indices, effects of power quality problems on the system and various algorithms for power quality analysis. The second [16-33] is about passive filters and designing of the self-tuned filters used in railway traction. The third [34-56] and fourth [57-74] deal with active filters and hybrid active filters used for power quality problems like power factor, reactive power and harmonic compensation in railway traction. The fifth [75-81] focuses on unified power quality conditioner, which suits various power quality problems such as power factor, reactive power compensation, voltage and load imbalance. The sixth category [82-129] deals with various compensation methods of power quality problems due to railway traction loads.

This paper mainly focuses on various control strategies and also on economic and technical considerations.

2 STATE OF THE ART

The railway traction system is connected to two phases of the three-phase system, where 110 kV is stepped-down to 21.6 kV and is connected to the load. The imbalance becomes predominant because of the single-phase load. The converters used in railways cause harmonics and poor power factor. In order to avoid penalty, capacitors and passive filters are widely used for power factor and harmonics respectively.

Researches on various power quality problems have been carried over during the past decade. Many research papers are being published with regard to measurements, analysis, causes and effects of power quality problems in power grid and traction [82-89] and the power quality compensation [90-129] in the railway traction.

The traction load is a single-phase load and hence, research has been carried out on single-phase power quality conditioners for railway traction [90-127] in various configurations and control strategies. An extensive study has been made on passive filters [16-33], active filters [34-56] and hybrid active filters [57-74, 119] based on configurations and control strategies, which also provide solution for various power quality problems in railway traction. The configurations such as shunt active filter [35-47,120], series active filter [56] and combination of series and shunt active filters are developed and simulation was done [75-81, 118, 121, 123-127] with the results.

Although traction supply is a single phase supply, a number of papers have been focused on three phase power quality conditioners for unbalanced loads, when the supply has been connected to the railway traction from the supply system through different types of transformers like V/v transformer, Scott transformer etc. There are no extensive publications on three-phase conditioners to the railway traction. Hence, many publications [48-56, 60-74, 80-81, 129] have been reviewed on three-phase power quality conditioners suitable for railway traction with many control strategies. In the three-phase power quality conditioners, active filters can be connected in series, shunt [48-57], combination of series and shunt called unique power quality conditioners [80-81] and passive filters combined with active filters [60-74, 129] are being used.

A work on the comparative study of active filters and passive filters [35, 36, 99], voltage source and current source active filters [38] were reported. Many publications for flicker [39-40,59] and many other publications [57-74, 107-129] on harmonics and reactive power compensation, voltage sag compensation and unbalanced load compensation with more terminologies such as Static Var Compensator, STATCOM, LCL etc., have been considered for literature survey.

The Power Quality Controllers for railway traction have been progressed with the development from Microprocessors to Digital Signal Processors [55, 56,62, 81] and various complex algorithms such as Particle Swarm Optimization [76], Phase Locked Loop [72, 107], Pulse Width Modulations [38, 44, 46, 75, 104, 106], Space Vector PWM [8], Proportional Integral (P-I) [35, 63, 64], Multilevel Direct PWM (122) and Prony Algorithms [48] to improve the dynamic and steady state performance of power quality conditioners.

3 CONFIGURATION

The power quality conditioners are classified based on current source inverter and voltage source inverter, shunt, series or combined on topology and on a number of phases.

3.1 Configuration based on converters

Fig.1 shows the current fed PWM based inverter structure with IGBT based converter. A PWM ac-ac converter with current source [50] provides fast response. Even though it has high response, it cannot be used for multilevel converters because of heavy losses and the need for higher power rating of capacitors.

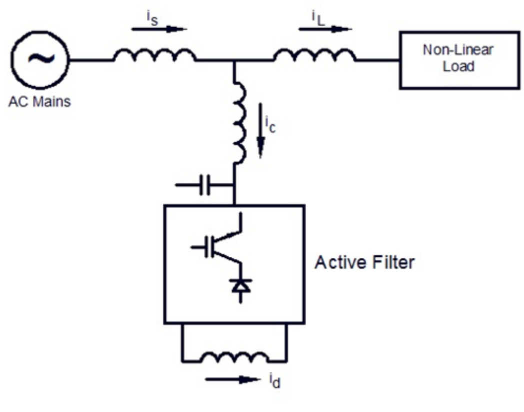

Fig. 1. Current-fed-PWM based active filter

The other type of converter is the voltage source converter shown in Fig.2. This type of converter can be extended for multilevel configuration to improve the performance with reduced switching frequencies because of its

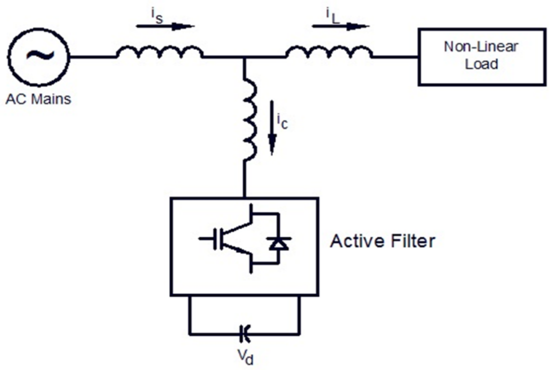

Fig. 2. Voltage-fed active filter

lighter and cheaper structure. Since, the load in the traction is varying very fast, this type of converter is more suitable.

3.2 Classification Based on Topology

Power quality conditioners for railway traction based on topology are classified as passive filter [16-33], active filter in series [50, 56] shunt [37,38, 40, 43,46, 47, 49, 51, 52, 54, 55, 108] and combination of active filter and passive filters connected in shunt known as hybrid filters [36, 43, 60, 62, 63, 65, 66, 67, 69, 70, 71, 73, 74, 107, 119], half bridge [112], TCR with fixed capacitors [108, 129] TCR with passive [68, 95, 98, 100]. SVC with active filter [64], Series passive filter with TCR based variable impedance [61], combination of active filter both in shunt and series called unified power quality conditioners [76-81, 121, 123-127] and multilevel PQ compensators [72, 73, 75, 76, 77, 81, 122, 124,128].

The shunt type active filter is normally used for various power quality problems such as reactive power compensation, current harmonics and imbalanced currents and is shown in Fig.2. Shunt active filters are mainly used at the point of common coupling of traction load, that is on the LV side of the traction station transformers to inject the equal compensating currents opposite to phase for harmonics and reactive power. The series active filters are connected in series with the incoming supply to compensate the voltage harmonics and to maintain the terminal voltage [50, 56] as shown in Fig.3

The unified power quality conditioner, a combination of both active filter in shunt and series [76-81, 121, 123-127] is shown in Fig.4. This type of conditioner is used for unbalanced loads, reactive power compensation and to maintain the terminal voltage. It can be configured as multilevel [77, 81, 122,124], single-phase [78, 79, 121, 123, 125, 126, 127] and three-phase [80] UPQC and hence, this type of power quality conditioner can be considered as an

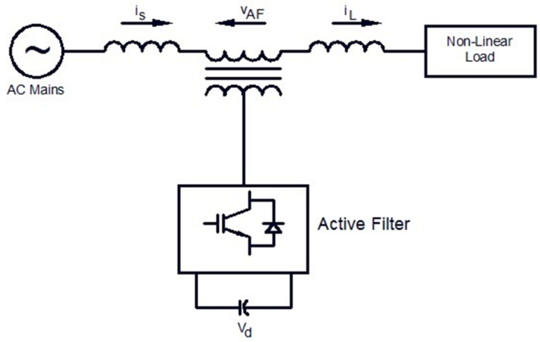

Fig. 3. Series type active filter

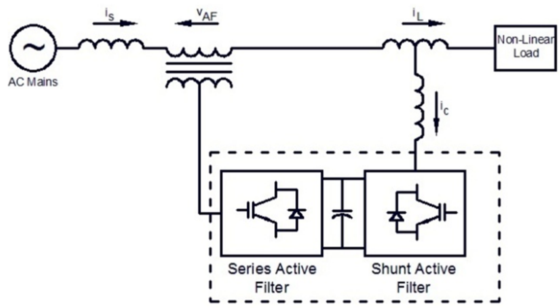

Fig. 4. Unified power quality conditioner (Combination of both active filter in shunt and series)

optimum controller for Railway traction. Since, Railway traction is a high capacity service, the main draw backs of this type of conditioner are high cost and complexity in control because of large number of static devices.

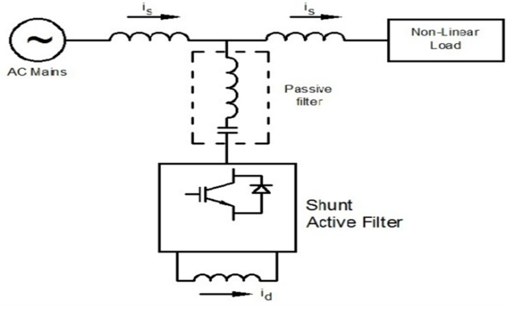

Fig. 5. Hybrid filter, a combination of shunt active and passive filter

A hybrid filter, a combination of shunt active and passive filter is shown in Fig.5. [129]. Usage of this type of conditioner will reduce the rating of the solid state devices and in turn reduce the cost of the conditioners (about 5%). LCL is used with back to back converter [116] to improve the performance of the compensator. LC coupling with UPQC [126] is used to reduce the unbalanced currents and harmonics and reactive power compensation with reduced converter ratings.

An Impedance-matching-transformer with multilevel converter [114] used in traction system balances the three-phase in power grid. The Shunt Hybrid Power Filter combined with Thyristor Controlled Reactor [74] is used to compensate various power quality problems with reduced cost (about 20%) and lower rating of solid state devices. Other type of hybrid filters can be found in the references [64, 68, 95, 98, 100,108, 129].

3.3 Classification based on supply

The railway traction load is a typical single-phase load and the supply has been taken on two phases from a three phase system. Since the traction load is single phase, many publications on single phase, two wire controllers for railway traction [93 – 127] have been reviewed. Even though the traction load is single phase, publications on three phase controllers for railway traction [128, 129] are also reviewed. The three phase power quality controllers are used, when the traction supply is connected to the system through various types of transformers.

3.3.1 Single phase

The power quality conditioners can be configured in active filters in shunt [35-47,120], series [56], combination of both series and shunt called unified power quality conditioners [75-81, 118, 121,123-127,] and hybrid power quality conditioner [57-59, 107,108,]. A regenerative PWM rectifier system in series [104] is used to interface the traction converters to the railway power system. A two H-type UPQC with two TCR and two Thyristor controlled rectifier [124] is used to solve negative sequence and harmonics current. Single phase conditioners can be developed in multilevel [122] composing two single phase with DC capacitors. Different kinds of transformers like Scott, Woodbridge and impedance-matching-transformers to connect three phase supply to two phase traction load system are discussed and found that Y/Δ transformers are more effective [125].

3.3.2 Three phase - three wire power quality conditioners

Publications on three-phase – three wire power quality conditioner to solve the harmonic problems and unbalance in three-phase voltage caused by negative sequences [128 – 129] due to single phase traction loads have been reviewed. Also, other publications on three-phase quality conditioners in series configuration [56], shunt [48–57] and combination of both [60 – 74, 129] have been surveyed. Three single-phase converters based on a chain circuit inverters [128] are connected to the power system through isolation transformer, where two phases are connected to two feeders of traction sub-station and the third phase is connected to the ground. The three-phase power quality conditioner can be developed in single mode or in hybrid mode like fixed capacitors combined with TCR [129], active filter with TCR [74], active filter in series with passive filters [73, 70] and series active filter with shunt passive filter [71]. These types of hybrid power quality conditioners are more popular because of cost effectiveness of the solid state devices and complexity in control.

4 CONTROL STRATEGIES

Control strategy is very important for effective compensation by the power quality conditioner. The control strategy is being implemented in three stages. Primarily, the signals like power factor, current, voltage, and frequency are collected through CT, PT and sensors. Then the received signals are converted into instantaneous signals. Later, various methods [117 – 129] are used to derive compensating signals in terms of voltage and current. Subsequently, gating signals for the solid state devices of power quality conditioners [62, 73, 76-81] are generated using PWM techniques, hysteresis and fuzzy logic based control techniques. Then the signals to the solid state devices have been realized through Digital signal Processors, Microelectronic devices, etc.

4.1 Signal conditioning

To implement the control algorithm in open loop or closed loop, voltage and current signals on 110 kV side and 25 kV side are measured and converted into instantaneous signals. To compensate the power quality problems in the railway traction, the control signals to the solid state devices are generated from the above instantaneous signals. PTs or Hall Effect sensors or isolation amplifiers can be used to measure voltage. CTs or Hall Effect sensors can be used to measure current. The hardware or software based type filters are sometimes used to filter voltage and current signals to avoid noise problems.

4.2 Compensating signal derivation

Frequency or time domain based control strategies have been developed in terms of voltage and current compensating signals. These are very essential for steady state performance of the power quality compensators and to control the rating of the solid state devices.

4.2.1 Compensation through frequency domain

Compensating commands for frequency domain are extracted from distorted voltage and current signals through Fourier analysis [56, 67, 72, 73, 75] and Lyapunov function [61, 62, 66]. The harmonic polluted signals are analyzed using Fourier or Lyapunov transformation, and the compensating harmonic components are derived. The switching frequency of the solid state devices in the power quality conditioners is generally kept more than the highest compensating harmonic frequency for effective compensation. The online Fourier transformation is usually used for high response time.

4.2.2 Compensation through time domain

Various control methods to derive the compensating commands from distorted voltage and current signals through time domain are synchronous orthogonal d-q reference frame method [52, 65, 71,74, 121], slip control [111], PSO technique [76], instantaneous p-q theory [42, 46, 47, 86,112, 118], single variable linear controllers [81], flux base control [68], SPX algorithm of Nelder and need for optimization [64], abc-dq coordinate method [129], PLL control [72, 104, 107, 123], etc. In the above mentioned various control methods, the widely used control methods are instantaneous p-q theory [42, 46, 47, 86, 112, 118] and α-β transformation to d-q frame [63, 67]. The command signals are derived from extracted fundamental signals using α-β transformation. The compensating commands are derived after extracting the load current and the reference supply current, where the desired value and reference value are maintained in the controllers like P-I controller and sliding mode controllers. Various other types of controllers can be found in [42-52,57-68, 72-75,112-123].

4.3 Getting signals to solid state devices of power quality conditioners

The control signals to the solid state devices in terms of voltage or current are generated based on the derived compensating commands. The PWM voltage or current control, phase shifted PWM current control, Multi direct PWM current control, Regenerative PWM, Space Vector PWM and Fuzzy based current control are implemented for switching of solid state devices in power quality conditioners either through hardware or software (in DSP-based).

5 SELECTION OF COMPONENTS AND DIFFERENT FEATURES OF POWER QUALITY CONDITIONERS

The railway traction load is high rated and hence, the selection of solid state device is very much essential. Even though GTO are used for high rated, IGBT is the ideal one because of its characteristics. The inductor (L) is normally used to act as buffer between the supply and power quality conditioner. The selection of the inductor is important for an optimum operation of power quality conditioners. Large amount of dc supply is injected into the system when small value of inductor is selected. The tracking of the compensating current will be difficult when large value of inductor is selected. Hence, the optimum value of inductor selection is necessary. Selection of DC line capacitor is another important parameter for the optimization of power quality conditioners [54]. Large fluctuations and large ripples are observed for small values of capacitors. When large values of capacitors are selected, the cost and the size of the capacitor are increased, even though the fluctuations and ripples are reduced.

In general, power quality conditioners are used to compensate voltage and current harmonics. In addition, sometimes, they may be used for reactive power compensation, unbalanced current, flickers and for voltage regulation. For voltage problems such as voltage sag, fluctuations and voltage unbalance, the power quality conditioners are connected in series [50, 56]. For current related problems such as reactive power compensation, current unbalance etc., the power quality conditioners are connected in shunt [35, 57, 120]. If it is required for both the above problems, the power quality conditioners are to be connected both in series and shunt configuration [60-81, 118, 121, 123-127, 129].

6 TECHNICAL AND ECONOMIC CONSIDERATION

Even though technical literature is being developed since 1971, it has not been possible to develop power quality conditioners for higher rated railway traction because of the cost complexity in solid state devices, complex control strategies, etc.. Later, many developments like passive filters connected with active filters [36, 58, 60, 62, 63, 65-67, 69- 74,107, 119], Thyristor Controlled Reactor coupled with fixed capacitors [108] and TCR combined with static hybrid active filter [129] for reactive power compensation with the reduction in the rating of the solid state devices have been developed. To reduce the installation cost, the UPQC is connected to load connected phase via LC branch and coupling transformer to the other phase [117] . In these types of conditioners, passive filters are used to compensate low order harmonics and active filters for high order harmonics. The size and cost of the power quality conditioners have been reduced by using these types of power quality conditioners. Hence, these are cost effective and economic power quality conditioners for a high rated traction supply.

7 SELECTION OF POWER QUALITY CONDITIONER FOR SPECIFIC APPLICATIONS

Selection of power quality conditioners based on the application requirement is an important task for the consumers as well as the scientists for voltage and current based compensation. The criteria for selection of power quality conditioner is discussed and listed in Table 1.

7.1 Power quality conditioners for current based compensation

The compensation for current harmonics, reactive power, neutral currents and load balancing are based on the current. An individual user may select conditioners for individual compensation or for the combination. The active filters are most suitable for current harmonics. Combining active filter with passive filter in shunt is most suitable because of the reduction in cost due to the low rating of solid state devices in power quality conditioners. The shunt type active filters can be used in reactive power compensation for varying loads and capacitors for fixed loads. Load balancing and neutral current compensation can be done by shunt type active filters. Shunt type active filters are most suitable for the current based compensation, while hybrid active filters combined with passive filters may be preferred for combined compensation with reduced cost.

7.2 Power quality conditioners for voltage based compensation

The compensation for voltage harmonics, voltage balancing, voltage flickering reduction, voltage sag and dips are based on the voltage. The series type active filters are most suitable for voltage based compensation. The power quality conditioners for voltage based compensation are listed in the order of preference in Table 1.

7.3 Power quality conditioners for voltage and current based compensation

Almost all the voltage and current based power quality problems are present in all railway tractions because of single phase load and usage of ac-dc converters and ac-ac converters. Hence, the combination of both series and shunt type active filter, usually called Unified Power Quality Conditioner (UPQC) is the most suitable one for this type of compensation. This type of conditioner can be used for individual compensation, but the cost of the conditioner is too high because of its high rating solid state devices. Hence, these conditioners can be used for few combination of compensation like voltage and current harmonics. The selection of power quality conditioner for this type of compensation is listed in Table 1 in the order of preference.

Table 1. Selection of Power Quality Conditioners for specific application

Compensation for specific application	Power quality conditioner for railway traction			
	Active filter in series	Active filter in Shunt	Hybrid Active Filter/SVC	Active filter both in series and shunt (UPQC)
Current Harmonics		**	***	*
Reactive Power		***	**	*
Load balancing		*		
Neutral current		**	*	
Voltage Harmonics	***		**	*
Voltage Regulation	***	*	**	*
Voltage Balancing	***		**	*
Voltage Flicker	**	***		*
Voltage Sag and Dips	***	*	**	*
(1+2)		***	**	*
(1+2+3)		**		*
(1+2+3+4)		*		
(5+6)	**			*
(5+6+8+9)	**			*
(1+5)			**	*
(1+2+5+6)			*	**
(6+7)	**		*	
(2+3)			*	
(2+3+4)			*	
(1+2+7)			**	*
(1+3)			*	
(1+4+7)			*	**

8 CONCLUSION

It is seen that, there is difficulty in maintaining the power quality at the consumer‘s end and in turn the consumers may pay penalty directly or indirectly. An exclusive review on power quality conditioners for railway traction provides a clear idea to researchers, engineers and consumers. It provides suggestions to the consumers to select a suitable power quality conditioner based on its application and cost.

REFERENCES

[1] H. Siahkali, "Power quality indexes for continue and discrete disturbances in a distribution area", 2nd IEEE International Conference on Power and Energy (PECon 08), December 1-3, 2008, Johor Baharu, Malaysia, pp 678-683.

[2] C.Gopalakrishnan, K.Udayakumar, "Survey of Harmonic distortion from power quality measurements and the application of standards including simulation", Transmission and Distribution Conference and Exhibition 2002: Asia Pacific. IEEE/PES, Vol. 2, pp 1054-1058, 6 Oct 2002.

[3] Arfat Siddique, G.S. Yadava, "Effects of voltage unbalance on induction motors", IEEE International Symposium on Electrical Insulation, Indianapolis, IN USA, 2004, 19-22 September 2004, pp 26 – 29.

[4] Cristiano Augusto Gomes Marques, Danton Diego Ferreira, "Improved Disturbance Detection Technique for Power – Quality Analysis", IEEE Transactions on Power Delivery, Vol.26, No.2, April 2011.

[5] D.Granados-Lieberman, R.J.Romero-Troncoso, "Techniques and methodologies for power quality analysis and disturbances classification in power systems: a review", IET Gener. Transm. Distrib., 2011, Vol.5, lss.4, pp.519-529, D.O.I: 10.1049/iet-gtd.2010.0466.

[6] Md.Shamim Reza, Mihai Ciobotaru, "Power Quality Analysis Using Piecewise Adaptive Prony’s Method", IEEE 2012 Reza, M.S.; Ciobotaru, M.; Agelidis, V.G. Industrial Technology (ICIT), 2012 IEEE International Conference on Digital Object Identifier: 10.1109/ICIT.2012.6210057 Publication Year: 2012 , Page(s): 926 - 931

[7] Alexander Apostolov, "Power Quality Analysis and Corrections", IEEE 2005. Cement Industry Technical Conference, 2005. Conference Record Digital Object Identifier: 10.1109/CITCON.2005.1516373 , Publication Year: 2005 , Page(s): 320 – 329

[8] Alex McEachern, Andreas Eberhard, “A New, Ultra low cost Power Quality and Energy Measurement Technology – The Future of Power Quality Monitoring”, Electricity Distribution - Part 1, 2009. CIRED 2009. 20th International Conference and Exhibition on Publication Year: 2009 , Page(s): 1 - 4 IEEE 2009

[9] Martin Valtierra-Rodriguez, Rene de Jesus Romero-Troncoso, "Detection and classification of single and combined power quality disturbances using neural networks", IEEE Transaction on Industrial Electronics, Vol.61, No.5, May 2014.

[10] A.Jain, R.Balasubramanian, "Power system topological observability analysis using artificial neural networks", IEEE Power Engineering Society General Meeting, 2005, 12-16 June 2005, Vol. 1, pp 497 – 502, DOI:10.1109/PES.2005.1489679.

[11] Zhao Jianmming, Liu Jinjun, "Wavelet – based Neural Network Approach for Power Quality Event Monitoring and Analysis", IEEE 2008. Control and Decision Conference, 2008. CCDC 2008. Chinese Digital Object Identifier: 10.1109/CCDC.2008.4597566 Publication Year: 2008 , Page(s): 1492 - 1494

[12] Chakphed Madtharad, Kritsada Kleebmek, "Application of Neural Network to Forecast Power Quality Index in PEA Distribution System", The 2009 ASEAN Symposium on Power and Energy Systems - EEE.RC.ASPES 2009, September 28–29, 2009

[13] Khan, R.A.J., Junaid, M., "Analysis and monitoring of 132 kV grid using ETAP software", International Conference on Electrical and Electronics Engineering, 2009. ELECO 2009, 5-8 Nov. 2009, pp I-113 - I-118.

[14] A.M. Alkandari, S.A.Soliman, "Simulated Annealing Optimization Algorithm for Electric Power Systems Quality Analysis: Harmonics and Voltage Flickers", IEEE 2008. Power System Conference, 2008. MEPCON 2008. 12th International Middle-East Digital Object Identifier: 10.1109/MEPCON.2008.4562403 Publication Year: 2008 , Page(s): 287 – 293.

[15] M.A. Mostafa, "Kalman Filtering Algorithm for Electric Power Quality Analysis: Harmonics and Voltage Sags Problems", IEEE 2003. Power Engineering, 2007 Large Engineering Systems Conference on Digital Object Identifier: 10.1109/LESCPE.2007.4437371 Publication Year: 2007 , Page(s): 159 – 165.

[16] Paul A.Cartwright, "A Passive Compensator for Voltage Flicker", Electrical Engineering Vol. 71 , Issue: 11 Digital Object Identifier: 10.1109/EE.1952.6437794, Publication Year: 1952 , Page(s): 1032 – 1035

[17] He Yi-Hong, "A new method of designing double tuned filter", proceedings of 2nd International Conference on Computer Science and Electronics Engineering, ICCSEE 2013, March 22-23, 2013 Hangzhou, China

[18] M.Shuja Khan, M.S. Raheel, "Implementation of a Passive Tune Filter to Reduce Harmonics in Single Phase Induction Motor with Varying Load", International Journal of Engineering & Technology IJET-IJENS June 2011, Vol. 11, No. 03.

[19] Julio C. Estrada, Manuel Servin, "A self-tuning phase-shifting algorithm for interferometry", Feb 2010, Vol.18, No.3, OPTICS EXPRESS 2632.

[20] Ravisegala, Avdhesh Sharma, "A self tuning power system stabilizer based on artificial neural network", International Journal on Electrical Power and Energy Systems, Vol.26, Issue 6, July 2004, pp 423-430.

[21] Bernt M. Akesson, John Bagterp Jørgensen, "A Tool for Kalman filter tuning", 17th European Symposium on Computer Aided Process Engineering – ESCAPE17, 01-2007, 24:859-864, DOI:10.1016/S1570-7946(07)80166-0.

[22] G. Zatorre Navarro, S. Celma Pueyo, "Digital self tuning technique for continuous time filters", 12th IEEE International Conference on Electronics, Circuits and Systems, 2005. ICECS 2005. 11-14 Dec. 2005, pp 1 – 4.

[23] Shizhuo yin, "A highly sensitive long period grating based tunable filter using a unique double cladding layer structure", optics communications 188(2001), pp 301 – 305, 15 Feb 2001.

[24] M.Gabriela Marques, K.W.Tam, "MMIC lumped and transversal filter with LC tuned amplifiers", GAAS99 - Munich 1999, Gallium Arsenide Applications Symposium. GAAS 1999, 4-5 October 1999, Bologna, Italy.

[25] Young – sikcho, "Single tunned passive harmonic filter design considering variances of tuning and quality factor", Journal of International Council on Electrical Engineering. Vol. J.No.1. PP 7-13, 2011.

[26] K.J. Astrom, "Theory and applications of self tuned regulators", Automatica, Vol. 13, pp 457 – 476, 1977.

[27] Abdelsalam A. Eajal, M.E. El-Hawary, "Optimal Capacitor Placement and Sizing in Unbalanced Distribution Systems With Harmonics Consideration Using Particle Swarm Optimization", IEEE Transactions on Power Delivery, Vol. 25, No. 3, July 2010.

[28] Pravin Chopade, Bikdash, M., "Minimizing cost and power loss by optimal placement of capacitor using ETAP", IEEE 43rd Southeastern Symposium on System Theory (SSST), 2011, 14-16 March 2011 , pp 24 – 29, IEEE 2011.

[29] Robert L. Borwick, Philip A. Stupar, "A high Q, large tuning range MEMS capacitor for RF filter systems", Sensor and Actuators A: Physical, Vol. 103, Issue 1-2, Jan 2003, pp 33-41.

[30] Majid Ghadimi, Amin Ramezani, "Energy Efficiency and Power Quality Optimization Using a Modified Capacitor Bank: An Industrial Case Study", Computer Modeling and Simulation, 2009. EMS '09. Third UKSim European Symposium on Digital Object Identifier: 10.1109/EMS.2009.47 Publication Year: 2009 , Page(s): 384 - 388 D.O.I 10.1109/EMS.2009.47 IEEE 2009.

[31] Edward S. Thomas, "Application of Adaptive VAr Compensator for Transmission System Flicker Correction", IEEE Rural Electric Power Conference, 2006, IEEE Digital Object Identifier: 10.1109/REPCON.2006.1649044 Publication Year: 2006 , Page(s): 1 – 10

[32] "Guide to Harmonics and Harmonic resonance with capacitors" by high voltage technology Southern Africa (Pvt) Ltd, South Africa, *www.scribd.com/doc/129400806*

[33] Ying-Tung Hsiao, "Design of Filters for Reducing Harmonic Distortion and Correcting Power Factor in Industrial Distribution Systems", Tamkang Journal of Science and Engineering, Vol. 4, No. 3, pp. 193-199 (2001)

[34] Zubair Ahmed Memon, Mohammad Aslam Uquaili, "Harmonics Mitigation of Industrial Power System Using Passive Filters", Mehran University Research Journal of Engineering & Technology, Volume 31, No. 2, April, 2012.

[35] H.Akagi, "Modern active filters and traditional passive filters", Bulletin of the Polish Academy of Sciences, Technical Sciences, Vol. 54, No. 3, 2006.

[36] Hideaki Fujita, Hirofumi Akagi, "A Practical Approach to Harmonic Compensation in Power Systems – Series Connection of Passive and Active Filters", IEEE 1990 Industry Applications Society Annual Meeting, 1990., Conference Record of the 1990 IEEE Digital Object Identifier: 10.1109/IAS.1990.152323, Publication Year: 1990 , vol.2, Page(s): 1107 – 1112.

[37] Hirofumi Akagi, "Active Harmonic Filters", Proceeding of the IEEE, Vol. 93, Issue: 12, Dec 2005, Digital Object Identifier : 10.1109/JPROC.2005.859603, pp 2128 – 2141.

[38] Mikko Routimo, Mika Salo, "Comparison of Voltage – Source and Current – Source Shunt Active Power Filters", IEEE Transactions on Power Electronics, Vol. 22, No. 2, March 2007.

[39] C. Chen and D.M. Divan, "Simple topologies for single-phase AC line conditioning," in Conf. Rec. IEEE-IAS Annu. Meeting, 1988, pp. 945-951.

[40] G. Buja, S. Castellan, "Compensation strategy for an active flicker compensator", IEEE 2004 35th Annual IEEE Power Electronics Specialists Conference. Power Electronics Specialists Conference, 2004. PESC 04. 2004 IEEE 35th Annual Volume: 2 Digital Object Identifier: 10.1109/PESC.2004.1355573, Publication Year: 2004 , Page(s): 1090 - 1094 Vol.2

[41] Mauricio Angulo, Domingo, "Active Power Filter Control Strategy with Implicit closed – loop current control and Resonant Controller", IEEE Transaction on Industrial Electronics, Vol. 60, No.7, July 2013.

[42] Marek Roch, Juraj Altus, "Control of Single Phase Power Active Filters", Proceeding of Electro Technical Institute, Issue 258, 2012.

[43] Ruben B. Godoy, "Implementation of a single phase active filters with active power supply capability for DC and AC loads", VI International Conference on application of Industries, 17-20 August 2008.

[44] Omar Stihi, Boon-Teck Ooi, "A Single-Phase Controlled-Current PWM rectifier", IEEE Transactions on Power Electronics, Vol.3, No.4, October 1988.

[45] Prof.J.T.Boys, A.W.Green, "Current-forced single-phase reversible rectifier", IEEE Proceedings, Vol.136, Pt. B, No.5, September 1989.

[46] Musa Yusup Lada, Mohindo,O., "Simulation Single phase shunt active filter based on p-q technique using MATLAB/Simulink Development tools environment", IEEE Applied Electronics colloquium (IAPEC), DoC 18-19 April 2011, pp 159 – 164, IEEE 2011.

[47] Himalindu.T., "Performance of Single Phase Shunt Active Filter based on P-Q Technique using MATLAB / Simulink", International Journal of Engineering Research and Technology, Vol.1, Issue 9, Nov.2012.

[48] Li Qi, Lewei Qian, "Initial Results in Prony Analysis for Harmonic Selective Active Filters", IEEE 2006. Li Qi; Lewei Qian; Cartes, D.; Woodruff,S. Power Engineering Society General Meeting, 2006. IEEE Digital Object Identifier: 10.1109/PES.2006.1709581 Publication Year: 2006

[49] M.C. Ben habib, E. Jacquot, "An Advanced Control Approach for a Shunt Active Power Filter", Acta Technica Corvininesis - Bulletin of Engineering . Apr-Jun2013, Vol. 6 Issue 2, p139-143. 5p.

[50] Eddy C. Aeloiza, Prasad N. Enjeti, "Analysis and Design of a New Voltage Sag Compensator for Critical Loads in Electrical Power Distribution Systems", IEEE Transactions on Industry Applications, Vol. 39, No. 4, July/August 2003.

[51] X. Wang, F. Zhuo, J. Li, L. Wang, and S. Ni, “Modeling and control of dual-stage high-power multifunctional PV system in d-q-0 coordinate,” IEEE Trans. Ind. Electron., vol. 60, no. 4, pp. 1556–1570, Apr. 2013.

[52] Y. Tang, P. C. Loh, P. Wang, F. H. Choo, F. Gao, and F. Blaabjerg, “Generalized design of high performance shunt active power filter with output LCL filter,” IEEE Trans. Ind. Electron., vol. 59, no. 3, pp. 1443– 1452, Mar. 2012.

[53] L. Junyi, P. Zanchetta, M. Degano, and E. Lavopa, “Control design and implementation for high performance shunt active filters in aircraft power grids,” IEEE Trans. Ind. Electron., vol. 59, no. 9, pp. 3604–3613, Sep. 2012.

[54] X. Du, L. Zhou, H. Lu, and H.-M. Tai, “DC link active power filter for three-phase diode rectifier,” IEEE Trans. Ind. Electron., vol. 59, no. 3, pp. 1430–1442, Mar. 2012.

[55] P. Flores, J. Dixon, M. Ortuzar, R. Carmi, P. Barriuso, and L. Moran, “Static Var compensator and active power filter with power injection capability, using 27-level inverters and photovoltaic cells,” IEEE Trans. Ind. Electron., vol. 56, no. 1, pp. 130–138, Jan. 2009.

[56] Yuan Chang, Liu Jinjun, "A Novel Control of Series Active Power Filter without Harmonics Detection", IEEE 2007. Yuan Chang ; Liu Jinjun ; Wang Xiaoyu ; Wang Zhaoan Power Electronics Specialists Conference, 2007. PESC 2007. IEEE Digital Object Identifier: 10.1109/PESC.2007.4342148 Publication Year: 2007 , Page(s): 1112 – 1115

[57] R.D. Patidar, "A Single-Phase Hybrid Filter to Improve Power Quality", XXXII National Systems Conference, NSC 2008, Dec 17-19, 2008.

[58] R.D. Patidar, S.P. Singh, "A Single-Phase Hybrid Filter to Improve Power Quality", XXXII National Systems Conference, NSC 2008, December 17 – 19, 2008.

[59] Mikko Routimo, Mika Salo, "Flicker Mitigation with a Hybrid Compensator", IEEE Transaction on Industry Applications, Vol. 44, No. 4, July/August 2008.

[60] C. S. Lam, W. H. Choi, M. C. Wong, and Y. D. Han, “Adaptive dc-link voltage-controlled hybrid active power filters for reactive power compensation,” IEEE Trans. Power Electron., vol. 27, no. 4, pp. 1758–1772, Apr. 2012.

[61] A. Hamadi, S. Rahmani, and K. Al-Haddad, “A hybrid passive filter configuration for VAR control and harmonic compensation,” IEEE Trans. Ind. Electron., vol. 57, no. 7, pp. 2419–2434, Jul. 2010.

[62] A. Luo, X. Xu, L. Fang, H. Fang, J. Wu, and C. Wu, “Feedback feed forward PI-type iterative learning control strategy for hybrid active power filter with injection circuit,” IEEE Trans. Ind. Electron., vol. 57, no. 11, pp. 3767–3779, Nov. 2010.

[63] S. Rahmani, A. Hamadi, N.Mendalek, and K. Al-Haddad, “A new control technique for three-phase shunt hybrid power filter,” IEEE Trans. Ind. Electron., vol. 56, no.8, pp. 2904–2915, Aug. 2009.

[64] A. Luo, Z. Shuai, W. Zhu, and Z. John Shen, “Combined system for harmonic suppression and reactive power compensation,” IEEE Trans. Ind. Electron., vol. 56, no. 2, pp. 418–428, Feb. 2009.

[65] A. Hamadi, S. Rahmani, and K. Al-Haddad, “Digital control of hybrid power filter adopting nonlinear control approach,” IEEE Trans. Ind. Informat., Vol. 9, Issue 4, Nov. 2013, pp 2092 - 2104.

[66] S. Rahmani, A. Hamadi, and K. Al-Haddad, “A Lyapunov-function-based control for a three-phase shunt hybrid active filter,” IEEE Trans. Ind. Electron., vol. 59, no. 3, pp. 1418–1429, Mar. 2012.

[67] A. Luo, S. Peng, C. Wu, J. Wu, and Z. Shuai, “Power electronic hybrid system for load balancing compensation and frequency-selective harmonic suppression,” IEEE Trans. Ind. Electron., vol. 59, no. 2, pp. 723– 732, Feb. 2012.

[68] L.X. Zhou, Z.D. Yin, "Application of Controllable Reactor in Suppressing the Voltage Fluctuation and Flicker under H Control Strategy", IEEE 2006 International Conference on Power System Technology. Published in: Power System Technology, 2006. Power Con 2006. International Conference on 22-26 Oct. 2006 Digital Object Identifier : 10.1109/ICPST.2006.321853

[69] A. Bhattacharya, C. Chakraborty, and S. Bhattacharya, “Parallel connected shunt hybrid active power filters operating at different switching frequencies for improved performance,” IEEE Trans. Ind. Electron., vol. 59, no. 11, pp. 4007–4019, Nov. 2012.

[70] Mohamed Abdusalam, Philippe Poure, "Control of Hybrid Active Filter Without Phase Locked Loop in the Feedback et Feedforward Loops", ISIE, IEEE International Symposium . . . , 2008, aedie.org

[71] Ab. Hamadi, S. Rahmani, "A New Hybrid Series Active Fitter Configuration to Compensate Voltage Sag, Swell, Voltage and Current Harmonics and Reactive Power", IEEE International Symposium on Industrial Electronics (ISIE 2009), Seoul Olympic Parktel, Seoul, Korea,

July 5-8, 2009. Industrial Electronics, 2009. ISIE 2009. IEEE International Symposium on Digital Object Identifier: 10.1109/ISIE.2009.5218895, Publication Year: 2009 , Page(s): 286 - 291 Cited by: Papers (5).

[72] C. A. Silva, L. A. Cordova, P. Lezana, and L. Empringham, “Implementation and control of a hybrid multilevel converter with floating dc links for current waveform improvement,” IEEE Trans. Ind. Electron., vol. 58, no. 6, pp. 2304–2312, Jun. 2011.

[73] M. I. Milanés-Montero, E. Romero-Cadaval, and F. Barrero-González, “Hybrid multiconverter conditioner topology for high-power applications,” IEEE Trans. Ind. Electron., vol. 58, no. 6, pp. 2283–2292, Jun. 2011.

[74] Salem Rahmani, "A Combination of Shunt hybrid power filter and Thyristor controlled reactor for power quality", IEEE Transactions on Industrial Electronics, Vol.6, No.5, May 2014.

[75] Shoji Fukuda, "Auxiliary Supply – Assisted 12 pulse phase – controlled rectifiers with reduced Input current Harmonics, IEEE Transactions on Industry Applications, Vol. 44, No.1, Jan/Feb. 2008.

[76] A.Kashefikaviani, "PSO, an effective tool for harmonics elimination and optimization in multilevel inverters", 4th IEEE Conference on Industrial Electronics and Applications, 2009. ICIEA 2009 : 2902 – 2907.

[77] Velmurugan.V., "Power Quality Conditioning using Hybrid Multilevel Inverter as UPQC", 2013, International Conference on Circuits Power and Computing Technologies, ICCPCT, 20-21 March 2013, pp 43-48.

[78] Malabika Basu, S.P. Das, "Experimental Investigation of Performance of a Single Phase UPQC for Voltage Sensitive and Non-Linear Loads", 4th International Conference on Power Electronics and Drive Systems, Proceeding., 2001, Vol. 1, 22-25 Oct. 2001, pp 218 - 222.

[79] A. Mokhtar pour, H.A. Shyanfar, "Control of a single phase unified power quality conditioner – distributed generation based input, output feedback linearization", Journal of Electrical Engineering Technology, Vol. 8. No. 2, 2013. pp: 742 – 754.

[80] M. Shankar, S. Monisha, "Implementation of space vector pulse width modulation technique with genetic algorithm to optimize unified power quality conditioner", American Journal of Applied Sceines, 11(1), 152 – 159, 2014.

[81] J. A. Munoz, J. R. Espinoza, C. R. Baier, L. A. Moran, E. E. Espinosa, P. E. Melin, and D. G. Sbarbaro, “Design of a discrete-time linear control strategy for a multicell UPQC,” IEEE Trans. Ind. Electron., vol. 59, no. 10, pp. 3797–3807, Oct. 2012.

[82] LIU Yu-quan, HUA Huang-sheng, “Research for the Effects of High-speed Electrified Railway Traction Load on Power Quality”, 2011 4th International Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT), 6-9 July 2011, pp 569 – 573, IEEE 2011.

[83] Wang Jinhao, Xue Lei, Liu Yuzhuo, Li Mengzan, Pan Leilei, Li Shuying, Wang Shuzhong, Liu Yingying, "The interaction research between public grid and traction power supply system", Electricity Distribution, 2008. CICED 2008. China International Conference on Digital Object Identifier: 10.1109/CICED.2008.5211744 Publication Year: 2008, Page(s):1- 8.

[84] Li JinXin, Li Xinran, Deng Wei, Xu ZhenHua, Liu QianYong, Zhang YongWang, "Study on power systems transient stability considering traction power supply system measurement-based load model" Advanced Power System Automation and Protection (APAP), 2011 International Conference on Volume: 2, DoI: 10.1109/APAP.2011.6180597 Publication Year: 2011 , Page(s): 1430 – 1434.

[85] De-qing Lin, Xiao-dong Yuan, Wei Gu, Qun Li, "Measurement analysis about the impact of electrified railway on grid voltage fluctuations and countermeasure research" Electricity Distribution (CICED), 2012 China International Conference on DoI:10.1109 / CICED .2012. 6508453, Publication year 2012, Page(s): 1 – 5

[86] L.A. Snider, T.M. Lal, "Stochastic Power Quality Study of Distribution Supply to Metro Transit Railway", Power Engineering Society Summer Meeting, Vol. 1, pp 283 – 288, IEEE 2001.

[87] R.E.Morrison, “Power Quality Issues on AC Traction Systems”, Ninth International Conference on Harmonics and Quality of Power, Vol. 2, pp 709 – 714, IEEE 2000.

[88] A.Capasso, “The power quality concern in railway electrification studies”, 8th International Conference on Harmonics and Quality of Power Proceedings, 14-18 Oct 1998, Vol.2, pp 647 – 652, IEEE 1998.

[89] J.G. Garcia, "Power Quality analysis in Tramway Systems", ANDESCON, 2010, 15-17 Sept. 2010 Page(s):1 – 5, held at Bogota Digital Object Identifier :10.1109/ANDESCON.2010.5633275

[90] Xiangzheng Xu, Baichao Chen, “Study on Synthesis Control of Power Quality for Electrified Railway”, IEEE Workshop on Power Electronics and Intelligent Transportation System, D.O.I 10.1109/PEITS.2008.56.

[91] Laurence Snider, Edward Lo, “Harmonic Simulation of MTR Traction System by EMTP”, IEEE 1999 International Conference on Power Electronics and Drive Systems, PEDS’99, July 1999, Hong Kong.

[92] Liu Hang, Li Qunzhan, “Traction Power System Model and Simulation for Estimation and Forecast of Traction Load”, 2010 Asia-Pacific Power and Energy Engineering Conference (APPEEC), 28-31 March 2010, pp 1 - 4 , IEEE 2010.

[93] Bhim Singh, G.Bhuvaneswari, “Improved Power Quality AC-DC Converter for Electric Multiple Units in Electric Traction”, 2006 IEEE Power India Conference.

[94] A.Horn, R.H.Wilkinson, “Evaluation of Converter Topologies for Improved Power Quality in DC Traction Substations”, Proceeding of the IEEE International Symposium

on Industrial Electronics, 1996, Vol. 2, pp 802 – 807, 17-20 Jun 1996.

[95] Ma Jianzong, Wu Mingli, Yang Shaobing, "The application of SVC for the power quality control of electric railways", Sustainable Power Generation and Supply, 2009. SUPERGEN '09. International Conference on Digital Object Identifier: 10.1109/SUPERGEN.2009.5347939 Publication Year: 2009, Page(s): 1 – 4.

[96] Xiangzheng Xu, Baichao Chen, "Research on Power Quality Control for Railway Traction Power Supply System", published in Circuits, Communications and Systems, 2009. PACCS '09. Pacific-Asia Conference on Digital Object Identifier: 10.1109/PACCS.2009.117 Publication Year: 2009 , Page(s): 306 – 309.

[97] Xiangzheng Xu, Baichao Chen, "Study on Control State and Development of Power Quality for Railway Traction Power Supply System" Circuits, Communications and Systems, 2009. PACCS '09. Pacific-Asia Conference on Digital Object Identifier: 10.1109/PACCS.2009.173 Publication Year: 2009, Page(s): 310 – 313.

[98] Seyed Hossein Hosseini, Farhad Shahnia, "Power Quality Improvement of DC Electrified Railway Distribution Systems Using Hybrid Filters", Electrical Machines and Systems, 2005. ICEMS 2005. Proceedings of the Eighth International Conference on Electrical Machines and Systems, Vol.2, Pages 1273-1277.

[99] Morris Brenna, Federica Foiadelli, "Analysis of the Filters Installed in the Interconnection Points between Different Railway Supply Systems Smart Grid, IEEE Transactions on Volume: 3 , Issue: 1 Digital Object Identifier: 10.1109/TSG.2011.2162860 Publication Year: 2012 , Page(s): 551 – 558.

[100] Dawid Bula, Marian Pasko, "Dynamical properties of hybrid power filter with single tuned passive filter", Nonsinusoidal Currents and Compensation (ISNCC), 2010 International School on Digital Object Identifier: 10.1109/ISNCC.2010.5524521 Publication Year: 2010 , Page(s): 80 – 83.

[101] R.Mathew, F.Flinders, "Locomotive "Total Systems" Simulation using SIMULINK", International Conference on Electric Railways in a United Europe, 1995, pp 202 – 206, 27-30 Mar 1995, IEEE 1995.

[102] Mihaela Popescu, Alexandru Biloleanu, "Harmonic Current Reduction in Railway Systems", WSEAS TRANSACTIONS on SYSTEMS, Issue 7, Vol.7, pp 689-698, July 2008.

[103] R.K.Y. Poon, K.K. Li, "Power factor correction in a 25 kV Electrified Railway", International Conference on Main Line Railway Electrification, 1989, 25-28 Sep 1989, pp 149 - 153, IEEE 1989.

[104] Sepetci, K., Tamyurek, B., "Design and simulation of a high power quality regenerative PWM rectifier system for 1 MW electric locomotives", Electric Power and Energy Conversion Systems (EPECS), 2013 3rd International Conference on Digital Object Identifier: 10.1109/EPECS.2013.6713010 Publication Year: 2013, Page(s): 1 – 6.

[105] F.Flinders, W.Oghanna, "Energy Efficiency Improvements to Electric Locomotives using PWM Rectifier Technology", International Conference on Electric Railways in a United Europe, 1995, 27-30 March 1995, pp 106 - 110, IEEE 1995.

[106] J.G.Mayordomo, R.Asensi, "A general Treatment of Traction PWM Converters for Load Flow and Harmonic Penetration Studies", 8th International Conference on Harmonics and Quality of Power Proceedings, 1998, Vol. 2, pp 685 – 692, 14-18 Oct 1998, IEEE 1998.

[107] M. Salehifar, M. Ranjbar, "A Combined System of Passive Filter and TCR for Power Quality Improvement in a 25-kV Electrified Railway System", 10. 1109 / TECHPOS. 2009. 5412115 2009. , 2009 International Conference for Technical Postgraduates (TECHPOS), Digital Object Identifier: 10.1109/TECHPOS.2009.5412115 Publication Year: 2009 , Page(s): 1 – 5.

[108] Chi Meidan, Wu Mingli, "The switching transient simulation of SVC used in electric railway traction substation", International Conference on Sustainable Power Generation and Supply, 2009, SUPERGEN '09, DoI: 10.1109 / SUPERGEN.2009.5348348, Page(s): 1 - 5

[109] Keiji Kawahara, Shin-Ichi Hase, "Compensation of Voltage Drop Using Static Var Compensator at Sectioning Post in AC Electric Railway System", IEEE 1997. Proceedings of the Power Conversion Conference - Nagaoka 1997., Volume: 2 DoI: 10.1109/PCCON.1997.638383 , Publication Year: 1997 , Page(s): 955 - 960 vol.2 Cited by: Papers (5)

[110] Z.A.Styczynski, S.Bacha, "Improvement of EMC in Railway Power Networks", IEEE 2002, 10th International Conference on Harmonics and Quality of Power, 2002, Vol.2, 6-9 Oct. 2002.

[111] Madis Lehtla, Hardi Hoimoja, "Slip Control Upgrades for Light-Rail Electric Traction Drives", IEEE 2008, 13th Power Electronics and Motion Control Conference, EPE-PEMC 2008, 1-3 Sept. 2008 Page(s):1581 – 1584

[112] Kaleybar, H.J, Farshad, S, Asadi, M, Jalilian, A, "Multifunctional control strategy of Half-Bridge based Railway Power Quality Conditioner for Traction System", 13th International Conference on Environment and Electrical Engineering (EEEIC), 2013 Date 1-3 Nov. 2013 10.1109/EEEIC-2.2013.6737909

[113] R. Shiju Kumar, "Design of Balanced Harmonic free Traction Power Supply using a Novel Power Electronic Transformer", International Journal of Engineering Associates, 2013, Vol. 2, Issue 5, PP 25-30.

[114] Na Ding, Zeliang Shu, Yuhua Guo, "A railway power quality conditioner based on chain circuit", IECON 2011 - 37th Annual Conference on IEEE Industrial Electronics Society DoI: 10.1109/IECON.2011.6119470, Publication Year 2011, Page(s):1150 - 115410.1109 / IECON. 2011. 6119470

[115] Zeliang Shu, Shaofeng Xie, Ke Lu, Yuanzhe Zhao, Xiaoqiang Nan, Daqiang Qiu, Fulin Zhou, Sibin Gao, Qunzhan Li, "Digital Detection, Control, and Distribution System for Co-Phase Traction Power Supply Application", Industrial Electronics, IEEE Transactions on Volume: 60 , Issue: 5 Digital Object Identifier: 10.1109/TIE.2012.2190959 Publication Year: 2013 , Page(s): 1831 - 183910.1109/TIE.2012.2190959

[116] Keng-Weng Lao, Man-Chung Wong, NingYi Dai, Chi-Kong Wong, "Design of LCL filter for harmonic suppression in co-phase railway power quality conditioner", Future Energy Electronics Conference (IFEEC), 2013 1st International Digital Object Identifier: 10.1109/IFEEC.2013.6687610 Publication Year: 2013 , Page(s): 794 - 79910.1109/IFEEC.2013.6687610

[117] Dai, N.Y., Lao, K.W., Wong, M.C., Wong, C.K., "Hybrid power quality conditioner for co-phase power supply system in electrified railway" Power Electronics, IET Volume: 5 , Issue: 7 Digital Object Identifier: 10.1049/iet-pel.2011.0292, Year: 2012 , Page(s): 1084 - 109410.1049/iet-pel.2011.0292

[118] Lao, K.-W., Dai, N., Liu, W.-G., Wong, M.-C., "Hybrid Power Quality Compensator With Minimum DC Operation Voltage Design for High-Speed Traction Power Systems", Power Electronics, IEEE Transactions on Volume: 28 , Issue: 4 Digital Object Identifier: 10.1109/TPEL.2012.2200909, Publication Year: 2013 , Page(s): 2024 - 203610.1109/TPEL.2012.2200909

[119] Xiangzheng Xu, Baichao Chen, “Research on Power Quality Control for Railway Traction Power Supply System”, D.O.I 10.1109/PACCS.2009.117 IEEE 2009 Pacific-Asia Conference on Circuits, Communications and System.

[120] R. Grunbaum, T. Larsson, "Statcom to Enhance Power Quality and Security of Rail Traction Supply", Advanced Electromechanical Motion Systems & Electric Drives Joint Symposium, 2009. ELECTROMOTION 2009. 8th International Symposium on Digital Object Identifier: 10.1109/ELECTROMOTION.2009.5259136 Publication Year: 2009 , Page(s): 1 – 6

[121] Haned park, Han, "A Novel control algorithm for railway power quality conditioner in AC electrified Railway System", Journal of International Council on Electrical Engineering, Vol. 1. No.2. pp 145 – 150, 2011.

[122] Longhua Zhou, Qing Fu, Xiangfeng Li, Changshu Liu, "A novel Multilevel Power Quality Compensator for electrified railway" Power Electronics and Motion Control Conference, 2009. IPEMC ’09. IEEE 6th International DOIr: 10.1109/IPEMC.2009.5157555, Year: 2009, Page(s): 1141 - 114710.1109/IPEMC.2009.5157555

[123] Chang Min, Luo Longfu, Zhang Zhiwen, Huang Jiyuan, Lei Bo, "Negative Sequence and Harmonic Suppression Unified Control Method for High-Speed Electric Railway", Intelligent Computation Technology and Automation (ICICTA), 2012 Fifth International Conference on Digital Object Identifier: 10.1109/ICICTA.2012.136 Publication Year: 2012 , Page(s): 520 - 52310.1109/ICICTA.2012.136

[124] Lu Fang, An Luo, Xianyong Xu, Houhui Fang, "A Novel Power Quality Compensator for Negative-Sequence and Harmonic Currents in High-Speed Electric Railway", Power and Energy Engineering Conference (APPEEC), 2011 Asia-Pacific Digital Object Identifier: 10.1109/APPEEC.2011.5748427, Publication Year: 2011 , Page(s): 1 - 510.1109/APPEEC.2011.5748427

[125] Ghassemi, A., Maghsoud, I., Farshad, S., Fazel, S.S., "Power quality improvement in Y/Δ electric traction system using a Railway Power Conditioner" Environment and Electrical Engineering (EEEIC), 2013 12th International Conference on Digital Object Identifier: 10.1109/EEEIC.2013.6549565 Publication Year: 2013 , Page(s): 489 - 49410.1109/EEEIC.2013.6549565

[126] Dai, NingYi; Lao, KengWeng; Wong, ManChung, "A hybrid railway power conditioner for traction power supply system", Applied Power Electronics Conference and Exposition (APEC), 2013 Twenty-Eighth Annual IEEE Digital Object Identifier: 10.1109/APEC.2013.6520471 Publication Year: 2013 , Page(s): 1326 - 133110.1109/APEC.2013.6520471

[127] Yingdong Wei, Qirong Jiang, Xiujuan Zhang, "An optimal control strategy for power capacity based on railway power static conditioner", IEEE Asia Pacific Conference on Circuits and Systems, 2008. APCCAS 2008. Publication Year: 2008, Page(s): 236 - 23910.1109/APCCAS.2008.4746004

[128] Na Ding, "A Railway Power Quality Conditioner based on Chain Circuit", IECON 2011 - 37th Annual Conference on IEEE Industrial Electronics Society IEEE, 2011, 7-10 Nov 2011 Digital Object Identifier : 10.1109/IECON.2011.61194, Page(s):1150 - 1154 held at Melbourne, VIC.

[129] Wang, Dan, Yang, Chaoying, Zhang, Xin, Wang, Jinhao, Li, Gengyin, "Research on application of TCR+FC typed SVC in power quality integrated management for power traction system", Sustainable Power Generation and Supply (SUPERGEN 2012), International Conference on Digital Object Identifier: 10.1049/cp.2012.1749 Publication Year: 2012 , Page(s): 1 - 510.1049/cp.2012.1749

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