International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 6, No. 2, June 2015, pp. 185~195
ISSN: 2088-8694

Advanced Techniques in Harmonic Suppression via Active Power Filter: A Review

Ekhlas Mhawi, Hamdan Daniyal, Mohd Herwan Sulaiman
Sustainable Energy & Power Electronics Research Cluster (SuPER), FKEE, Universiti Malaysia Pahang

Article Info

Article history:

Received Jan 31, 2015
Revised Apr 27, 2015
Accepted May 10, 2015

Keyword:

Active power filter
Artificial Intelligence
Harmonic distortion
Non-linear load
PWM

ABSTRACT

This paper intends to present the recent development of artificial intelligence (AI) applications in active power filter (APF). As a result of the development in power electronic technology, (APF) continues to attract ample attention. Compared with the traditional reactive LC filter, active power filter is considered to be more effective in compensating harmonic current generated by nonlinear loads. APF, can correct the power quality and improve the reliability and stability on power utility. A brief explanation of some important areas in AI and a comprehensive survey of the literature along the main categories of AI is presented to introduce the readers into the wide-ranging topics that AI encompasses. Plenty of relevant literatures have been selected in the review, mostly emphasized on better accuracy, robustness, efficiency, stability and tracking ability of the system.

Corresponding Author:

Ekhlas Mhawi
Sustainable Energy & Power Electronics Research Cluster (SuPER),
Fakulti Kejuruteraan Elektrik & Elektronik,
University Malaysia Pahang,
Pekan, Pahang, Malaysia.
Email: ekhlasmhawi@gmail.com

1. INTRODUCTION

There are many studies about harmonic distortion with techniques to improve power quality and compensate distorted signal. Usually, when a passive LC (Inductor and Capacitor) power filter isconnected in parallel with the load, of parallel or series resonances because of which the passive filter cannot provide a complete solution it is used to eliminate current harmonics. This compensation equipment has some defects mainly related to the appearance [1]. For eliminating harmonic pollution in power systems, the active power filter (APF) is a very suitable tool. APF has to respond instantaneously and work with high control precision in current tracking, since the load harmonics may be very complicated and change randomly and quickly. Many advanced control and signal-processing techniques have been applied, such as pulse width modulation (PWM), hysteresis band current control (HBCC), sliding-mode control, fuzzy-logic control, neural-network theory, and adaptive signal processing and etc. [2]. Figure 1 shows the basic principle of an APF. The waveforms of the APF in the situation where the load is assumed to be a three-phase diode rectifier with an inductive load is shown in Figure 2. The APF controlled to make the source current is in the sinusoid, which injects the compensating current i_c into the source to cancel the harmonics contained in the load current il [3]. The target of the active filter is to compensate distorted current drawn by the non-linear loads from the source, so that only the fundamental frequency components remain in the source current. The active filter and its current control must precisely track the sudden slope change in the reference current [4].

The load current consists of fundamental component i_1 and harmonic component i_h. To get the reference harmonic signal, first the load current is measured. The fundamental current is extracted from the measured system load current by using the band pass filter, with appropriate cut-off frequencies. The load current is compared to the fundamental component by using a comparator; the error is the reference harmonics signals [5]. The AI techniques using in electric power has received large consideration from reviewer in the electric power area and the literature on these applications has become enormous in volume. Motion control and power electronics are other areas where neural networks and fuzzy logic (FL) have been applied [6]. This paper aims to presenta survey of harmonic compensation using shunt APF with an application of AI. In the past few years, many AI applications in the active power filter APF have expanded. The following is review of work documented in the literature include the application of AI techniques to APF related issues.

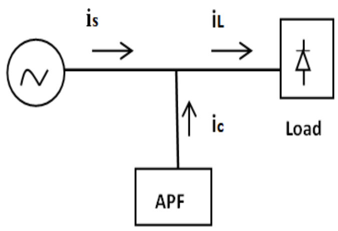

Figure 1. Basic principle of APF

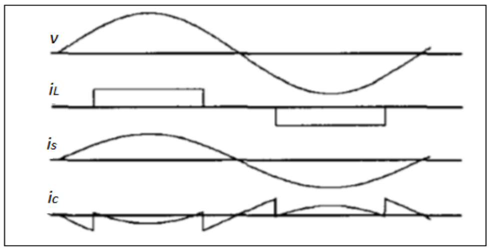

Figure 2. Theoretical waveforms

2. HARMONIC MITIGATION APPROACHES

In power distribution systems harmonic mitigation can be carried out through the following techniques: (1) Passive filter; (2) APF; (3) Hybrid APF. Due to remarkable growth in power electronics, the use of APF has become the dynamic solution for mitigation of harmonics. The fundamental rule of APF is to utilize advances in power electronics switches to produce equal and opposite current signals that eliminate the harmonic currents from the nonlinear loads [7].

2.1. Passive Filtering of Harmonics

To mitigate the harmonic distortion passive filtering is the simplest traditional resolution. The passive harmonic filters works is as follows: A filter connected in parallel with the load and in series with inductance and capacitance is a current acceptor. The harmonic frequency must be reduced to be equal the resonant frequency of the circuit. The impedance of the network and the low impedance of the filter thus eliminate the harmonic current. The general kinds of passive filters and their order are shown in Figure 3 [8]. The use of a passive filter has many disadvantages which decrease the reliability and flexibility of the filter devices such as, tuning, large size and risk of resonance problems [9].

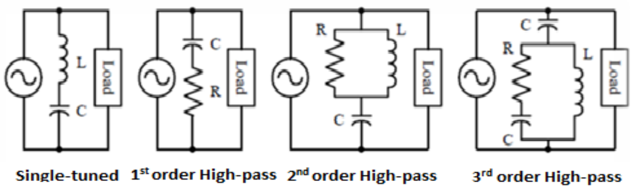

Figure 3. Common types of passive filters and their configurations

2.2. Active Filtering of Harmonics

APF is a kind of stable, highly efficient, flexible optimization power quality machine, which plays an important role in improving power quality. APF is one of most important harmonic mitigation and reactive power compensation electronic devices [10]. Active filters can be divided into single-phase active filters and three-phase (3φ) active filters [11], [12], [13]. Research on single-phase (1φ) active filters has been carried out, and the resultant papers have appeared in technical literature. Because 1φ versions are limited to low-power applications except for electric traction or rolling stock, 1φ AFs attract much less attention than 3φ AFs [13]. For providing harmonic compensation to a system, active filters are commonly used by controlling current harmonics in supply networks at the low to medium voltage distribution level or for reactive power or voltage control at high voltage distribution level. To achieve the various functions mentioned above or in separate active filters which can attack each aspect individually, these functions may be put together in a single circuit [14]. According to its procedure connection in the power system, there are two types of APFs: Series APF and parallel APF. Research and applications show that the series APF is selected to compensate the harmonic voltage-source, while shunt APF is more appropriate to compensate the harmonic current source [15]. APF which is at most used as a current or voltage harmonic compensation, can be divided into AC and DC filters. The APF can be classified as topology-based classification, converter-based classification, and supply-system-based classification, a combination of various types of PPF and APF is HPF [16].

2.3. Shunt APF

As APF eliminate the harmonics and compensate the reactive power, it is also called as active power line conditioners (APLC). The shunt or parallel connection is the more usual APF configuration. The basic scheme of the connection is shown in Figure 4, where the Metal–Oxide–Semiconductor Field-Effect Transistor MOSFET switching device represents the APF power block. The loads with current harmonics can be compensated by this APF configuration [17]. In most industrial processes, parallel active filters are by far the most vastly accept and predominant filter of choice. In parallel at the point of common coupling PCC, the active filter is connected and is supplied from the main power circuit. The SAF objective is to provide opposing harmonic current to the nonlinear load, excellently resulting in a pure harmonic current. This kind of filter can compensate harmonic currents generating from the source I_{hs} and the load I_{h1} without affecting the main component of load current I_f. In case of ideality, the parallel active filter generates a current equal to ($I_{hs} - I_{h1}$). As the internal reactance of the source against harmonic components of load current creates high impedance, these harmonic components are not able to cross the impedance of the source. In addition, harmonic components of the source current are not able to affect nonlinear load. In such a case, the load voltage will be in sine form [10], [18], and [19]. Figure 5 shows the Principle configuration of Voltage Source Inverter VSI based Shunt APF.

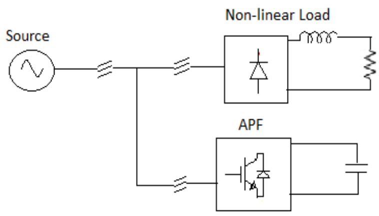

Figure 4. Basic diagram of shunt APF

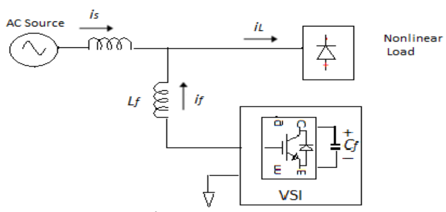

Figure 5. Principle configuration of VSI based Shunt APF

2.4. Series APF

As shown in Figure 6, the series power filter compensates for the harmonics and improves the power quality in the system. The series active filter ideally behaves as a controlled voltage source; subsequently the load voltage will have only a positive-sequence at the fundamental frequency component [20]. Figure 6 shows the basic connection diagram for series APF and Figure 7 shows the principle configuration for a VSI-based APF. By producing a PWM voltage waveform which is subtracted or added against the supply voltage waveform, the main object of the series active filter is to maintain a net sinusoidal voltage waveform across the load is carried out. The voltage-fed PWM inverter without a current minor loop is the choice of power circuit used in most cases. These Series APFs are not commonly used in power system like the shunt APF [21].Series active filters act as voltage sources connected in series with the electrical grid, and they can compensate for voltage harmonics. Three-phase series APFs can also compensate unbalances in the phase voltages. The compensation capabilities of the series APF increases, allowing also the compensation of voltage sags, voltage swells and flicker, If the dc link of the power inverter is connected to other power supplies [22], [23]. Series active power filters were introduced to operate mainly as a voltage regulator and as a harmonics isolator between the nonlinear load and the utility system. The series connected filter protects the system from an in adequate supply voltage quality [24].

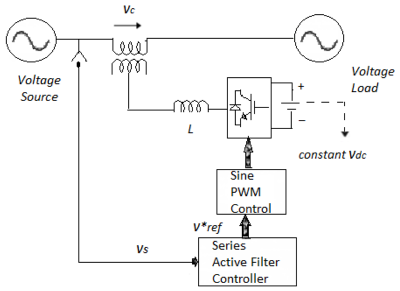

Figure 6. Series Active Power filter

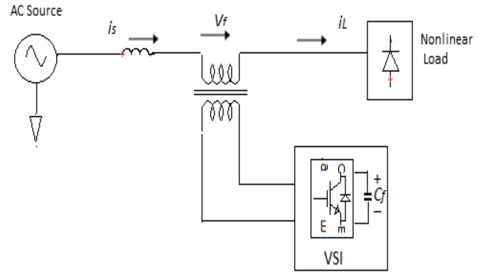

Figure 7. Principle configuration of Voltage Source Inverter (VSI) based APF

2.5. Hybrid Active Power Filter

A combination of static and passive filters using to reduce the cost of the static compensation is called as hybrid active power filter. To cancel the most relevant harmonics of the load, the passive filters are used and the active filter is dedicated to cancel other harmonics components or to improving the performance of passive filters and thus, the total cost decreases without decrease of efficiency [17]. Figure 8 shows the more usual hybrid topologies [25]. Formerly, many of the controllers for APF operation were implemented based on analogue circuits. Due to this, the performance of the APF is affected by the signal deviation. Digital controllers using microcontrollers or Digital Signal Processor DSPs are selected, primarily due to its immunity to noise and flexibility. By using digital methods, the high-order harmonics are not filtered effectively, because of the hardware limitation of sampling rate in real-time application. In addition, the utilization of fast switching power electronic switches (i.e. Insulated-Gate Bipolar Transistor (IGBTs), Metal–Oxide–Semiconductor Field-Effect Transistor (MOSFETs)) in APF application causes switching frequency noise to appear in the compensated source current. Additional filtering circuit is required to reduce this switching frequency noise and to prevent interference with other sensitive equipment [26] [27].

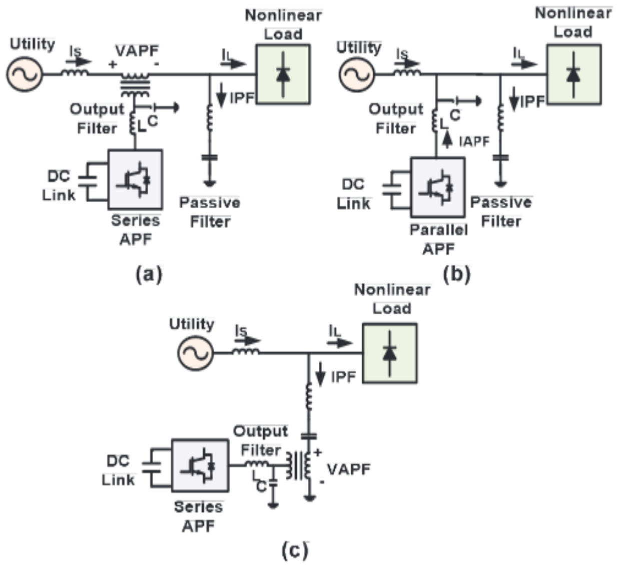

Figure 8. Hybrid active power filter (HAPF) Topologies (a) series active power filter +shunt passive filter, (b) shunt active power filter + shunt passive filter, (c) active power filter connected in series with shunt passive filter

3. ARTIFICIAL INTELLIGENCE (AI)

To detect and compensate harmonic current there are many classical techniques. A general outline for the research literature on how to solve harmonic distortion problems using AI is presented in this paper.

The automation of activities that are associated with human thinking is abroad definition of AI, such as learning, decision making, perception, problem solving, and reasoning. The AI tools of benefit to the electric power community include expert systems, Fuzzy Logic (FL), adaptive FL, genetic algorithms (GAs) and artificial neural networks (ANNs) [6].

3.1. An Application of FL in APF

FL, the logic of approximate reasoning, continues to grow in importance, as its application to a number of practical problems further demonstrates of its usefulness. FL has been used in areas such as control, process, diagnostics, estimation, medicine, identification, agriculture, the stock market, etc. However, process control is by far its most important and visible application [28]. Fuzzy modeling provides the ability to linguistically specify approximate relations between the input and output, when a system is too complex or too poorly understood to be described in accurate mathematical terms. Recently, in more applications, FL controllers (FLCs) have been of interest as a good alternative. The fuzzy systems do not need a precise mathematical model; the advantage of it is that: They can handle non-linearity; can work with imprecise inputs and they are more robust than traditional nonlinear controllers [29]. A FLC divided into four areas: knowledge base, Fuzzification, inference mechanism, and defuzzification.The knowledge base is designed to obtain a good dynamic response under uncertainty in process parameters and for external disturbances and is composed of a data base and rule base and the data base consisting of input and output membership functions provides information for the appropriate fuzzification operations, i.e. the defuzzification and inference mechanism. To convert the input conditions into a fuzzified output, the inference mechanism uses a collection of linguistic rules. At last, defuzzification is used to convert the fuzzy outputs into control signals. The formulation of fuzzy rule set plays a key role in improvement of the system performance in designing of its control system [30], [31]. Structure of a FLC can be seen in Figure 9. In fact, with FL for different working conditions, it's possible to design a control system adjusting the control surface, so the control can follow the reference current even when very high peaks occur. Besides, dc capacitor voltages can be maintained at constant levels with fuzzy control [32], [33]. Fuzzy arithmetic is used for adjustment of the proportional-integral coefficients in a timely fashion, while the generalised integrator is used to divide frequency integral control. Results have shown that the new dividing frequency control method is easy to calculate, implement, and is very effective in reducing harmonics. Figure10. Shows an adaptive fuzzy dividing frequency control method [34]. The most commonly used current control strategy is the fixed band hysteresis method. But it has the disadvantage of uncontrollable high switching frequency. To improve this control, an adaptive hysteresis band current control technique can be programmed as a function of the active filter and supply parameters to minimize the influence of current distortions on modulated waveform. [35]. Figure 11 shows the schematic diagram of fuzzy control scheme.

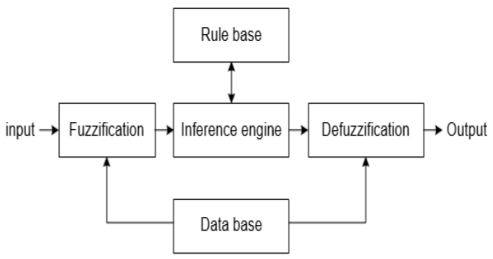

Figure 9. Structure of a fuzzy logic controller

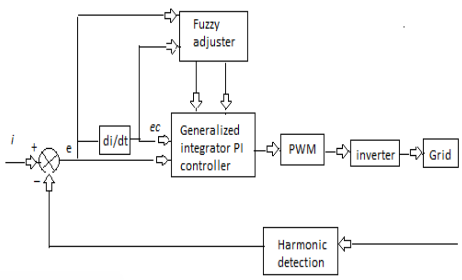

Figure 10. The Adaptive Fuzzy Dividing Controller Configuration

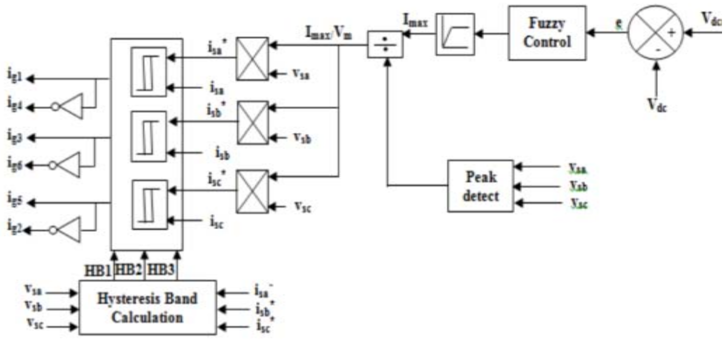

Figure 11. The schematic diagram of fuzzy control scheme

3.2. Neural Networks Application

The non-sinusoidal current distorted by harmonics and the low power-factor are produced by the non-linear loads in electricity supply networks, [36], [37]. AI applications resolving the power quality problem mentioned above by using the parallel APF strategy in two-wire distribution systems. The proposed AI adopted is an ANN responsible for the detection of current harmonics for the active power filtering process. Figure 12 presents the configuration of the modified proposed ANN algorithm which is limited in complexity compared to the classical algorithm [36]. A modified ANN was effectively developed in detecting harmonic components and a PWM was also implemented in generating switching strategies for the filter [38]. To eliminate the harmonics, an adaptive radial basis function (RBF) neural network control system for a three-phase APF is proposed. This method features high control precision, a wide range of applications, and real-time operation, then the total harmonic distortion current can be decrease effectively.

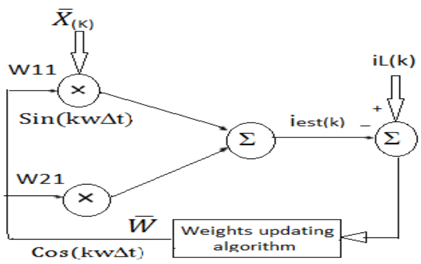

Figure 12. A modified ANN extraction topology

3.3. Genetic Algorithms

GAs were firstly introduced and sophisticated as a system aimed at modeling and explaining the adaptation of natural systems. A basic GA includes selection, mixing, and mutation of components. Selection is driven by an organism's ability like biological systems, to survive in its environment. Mixing is usually implemented by combining genetic information from two or more parents. Mutation is a mechanism for reintroducing information that may not have been contained in the population. As an organism, the population serves with distributed knowledge throughout the genes of the entire population. For finding optimal minimum, GAs are especially good, where the fitness surface is nonlinear, highly convoluted with many local minima and dependent on several parameters simultaneously. To reach these solutions, the time taken by GAs is just a portion of that of other traditional techniques [39], [40]. A GA, improved later, decreased convergence time but was no less complex or easier to implement, hardware-wise or as online control. Hysteresis current control, principled on adaptive noise cancelling, needs both logic and analogue circuits, complicating hardware development. An improved and fast ANN control scheme, for its learning, simplicity, generalization ability, and also for possible control scheme modification through a weights-updating algorithm that expedite harmonics extraction, the APF's response and adaptation [41], [42]. To reduce the % THD of the source current, the GA is used to design the controllers. The parameters for searching are the inductor filter (*Lf*), dc bus voltage (*Vdc*), and the hysteresis band (*HB*) [43]. Figure 13 illustrate how to search the parameters of APF using the GA method.

3.4. GA and a Fuzzy Neural Network

Figure 14 shows the structure of APF with fuzzy neural network predictive control. In the strategy, to predict future harmonic compensating current, the fuzzy neural network is employed, in order to make the predictive model compact and precise i.e. to optimize the model parameter, a GA with an efficient search is developed [44]. Control vector *u* in the form of gating patterns of the inverter switches based on the predictive output, can be figured out by the model predictive control algorithm, which maintains tracking of dynamic reference current without time delay. All results prove that the GA and the fuzzy neural network - based predictive controller cancel voltage distortion and supply current greatly and the performance of harmonic compensation better than a PI controller.

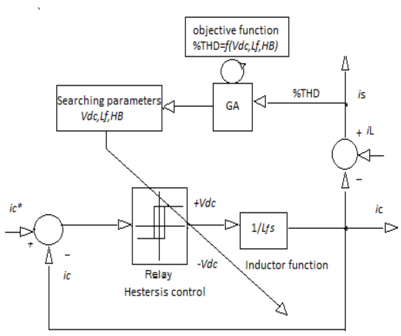

Figure 13. The GA approach for APF design

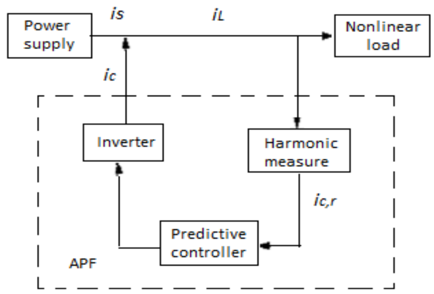

Figure 14. The structure of APF

4. SUMMARY

All AI techniques presented in this paper are summarized in Figure 15, to give the reader an idea of a large percentage of recent developments of artificial intelligence in APF.

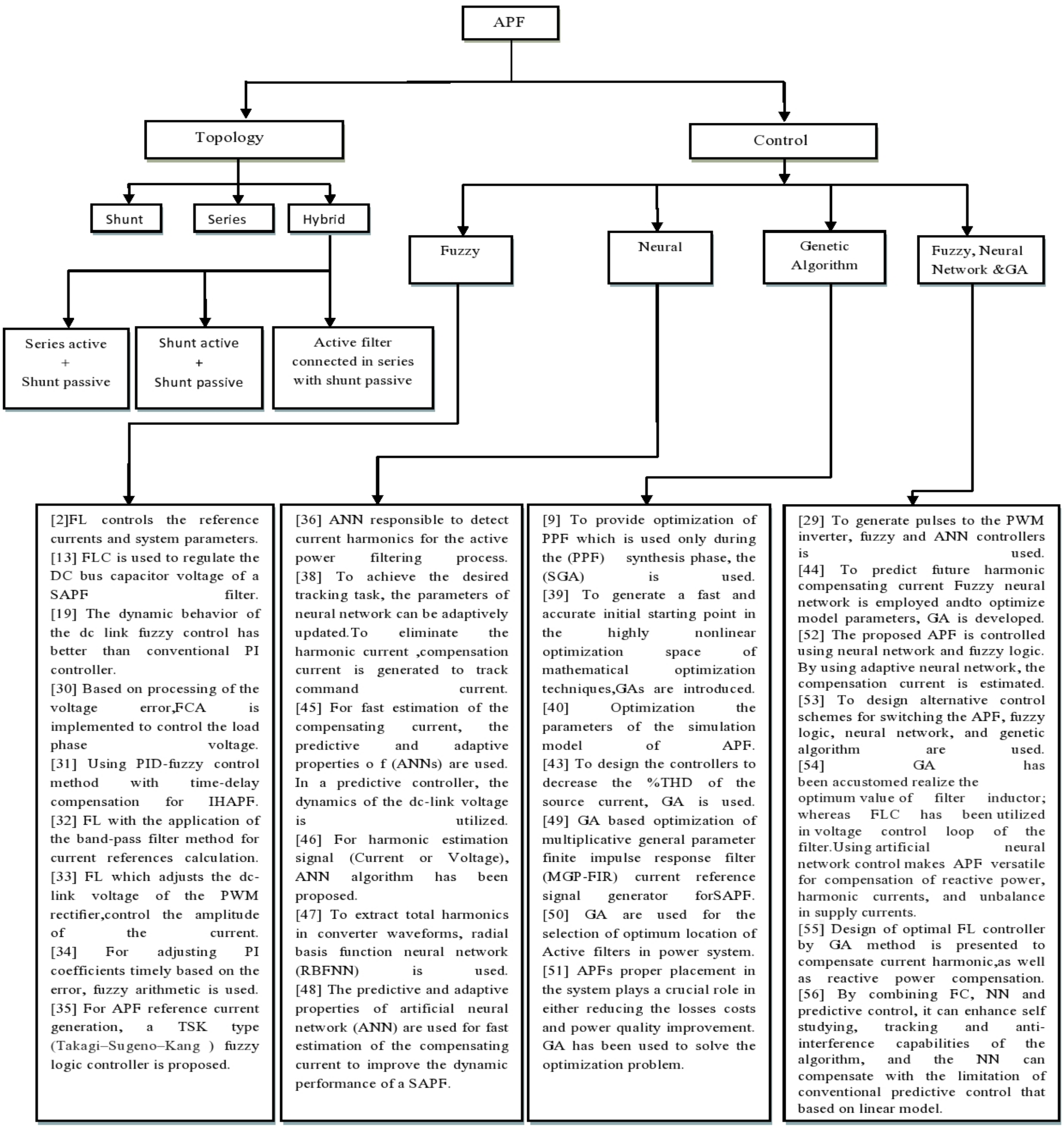

Figure 15. Summary of AI in APF application

5. CONCLUSION

The main focus of the review was the use of FL, neural networks, and GAs in APF applications. This paper suggests different AI approaches to advance signal processing techniques to improve the power quality and the system performance. An extensive literature survey of AI techniques in APF is presented to provide a clear perspective on various aspects of AI to the researchers and engineers working in this field. These methods have the advantages of quick response, good current tracking accuracy of the APF, and minimal current ripple. Simulation and application results have shown that using AI in control methods is not only easy to calculate and implement, but also very effective in reducing harmonics. From the reviews described in the paper, it is revealed that most of FLC has been applied to regulating the dc bus capacitor voltage of an APF filter, while most of ANN has been applied to detecting current harmonics for the active power filtering process. The GA has been applied to optimize the parameters of the simulation model of the APF.

REFERENCES

[1] P. Salmeron, S.P.A Litran, “control strategy for hybrid power filters to compensate four-wire three-phase systems”, *Power Electronics, IEEE Transactions on*, Vol. 25, pp. 1923-1931, 2010.
[2] L. Xia, D. Taihang and T.Shengxue, “A fuzzy logic variable hysteresis band current control technique for three phase shunt active power filter”, *In Control, Automation and Systems Engineering (CASE), IEEE, International Conference on*, pp. 1-4, July 2011.
[3] D. Chen and S. Xie, “Review of the control strategies applied to active power filters”, *In Electric Utility Deregulation, Restructuring and Power Technologies,(DRPT 2004). Proceedings of the IEEE International Conference on*, Vol.2, pp.666-670, April 2004.
[4] J.F. Petit, H. Amarıs and G. Robles, “Control schemes for shunt active filters to mitigate harmonics injected by inverted-fed motors”, *15th Proton Synchrotron &Synchro Cyclotron Committee PSCC*, Liege, 22-26 August, Session 22, 2005.
[5] C.J. Msigwa, B.J. Kundy and B.M. Mwinyiwiwa, “Control Algorithm for Shunt Active Power Filter using Synchronous Reference Frame Theory”, *World Academy of Science, Engineering and Technology*, Vol. 58, 2009.
[6] W.A. Ibrahim and M.M. Morcos, “Artificial intelligence and advanced mathematical tools for power quality applications: a survey”, *Power Delivery, IEEE Transactions on*, Vol. 17, pp. 668-673, 2002.
[7] S. Kim, G. Yoo and J. Song, “Abifunctional utility connected photovoltaic system with power factor correction and UPS facility”, *In Photovoltaic Specialists Conference, May 1996. Conference Record of the Twenty Fifth IEEE*, pp. 1363-1368.
[8] L.S. Czarnecki, “An overview of methods of harmonic suppression in distribution systems”, *In Power Engineering Society Summer Meeting, 2000. IEEE*, Vol. 2, pp. 800-805, 2000.
[9] H.L. Jou, J.C. Wu and H.Y. Chu, “New single-phase active power filter”, *In proc. IEE Electric Power Applications*, Vol. 141, pp. 129-13, 1994.
[10] H. Akagi, “New trends in active filters for power conditioning. Industry Applications”, *IEEE Transactions on*, Vol. 32, pp. 1312-1322, 1996.
[11] P.C. Tan, Z. Sala and A. Jusoh, “A single-phase hybrid active power filter using extension pq theorem for photovoltaic application”, *In Power Electronics and Drives Systems, PEDS 2005. International Conference on IEEE*, Vol. 2, pp. 1250-1255, December 2005.
[12] R. Dehini, B. Berbaoui, C. Benachaiba and O. Harici, “Shunt Hybrid Active Power Filter Improvement Based On Passive Power Filters Synthesis by Genetic Algorithm”, *International Journal of Engineering Science and Technology*, Vol. 2, pp. 1185-1193, 2010.
[13] Z. Xiao , Y. Che and X. Deng, “A Shunt Active Power Filter with Enhanced Dynamic performance using Dual-Repetitive Controller and Predictive Compensation”, *International Journal of Power Electronics and Drive Systems (IJPEDS)*,Vol. 3, pp. 209-217, 2013.
[14] G. Adam , A. Zbant and G. Livint, “New Simulink control block for single phase shunt active power filters”, *In Advanced Topics in Electrical Engineering (ATEE),8th International Symposium on IEEE*, pp. 1-4, May 2013.
[15] I.I. Abdalla, K.S.R. Rao and N. Perumal, “Three-phase four-leg shunt active power filter to compensate harmonics and reactive power”, *Computers& Informatics (ISCI), IEEE Symposium,*20-23 March, pp. 495-500, 2011.
[16] H. Akagi, “Active harmonic filters”, *Proceedings of the IEEE*, Vol. 93, pp. 2128-2141, 2005.
[17] A. Boukadoum, T. Bahi, A. Bouguerne , Y. Soufi and S. Oudina, “Hysteresis band current and fuzzy logic control for active power filter”, *In Ecological Vehicles and Renewable Energies (EVER), 8th International Conference and Exhibition on IEEE*, pp. 1-6, March 2013.
[18] S. Janpong, K.L. Areerak and K.N. Areerak, “A literature survey of neural network applications for shunt active power filters”, *J. World Acad. Sci., Eng. Tech.*, Vol. 60, pp. 392-398, 2011.
[19] K. Chaturvedi, A. Mahor and A.D. Dwivedi, “Active Power Filter Techniques for Harmonics Suppression in Non Linear Loads”, *International Journal of Scientific Engineering and Technology*, Vol. 1, pp. 123-127, 2012.
[20] F. Irannezhad, S.H. Hosseinian, M. Abedi and B. Vahidi, “Using the Instantaneous Power Theory in order to control the current in the parallel active filter to compensate reactive power and reduction of harmonics”, *In Power Electronics, Drives and Energy Systems (PEDES), IEEE International Conference on IEEE*, pp. 1-5, December 2012.
[21] K. Sarasvathi and R. Rajalakshmi, “Performance Analysis Of Shunt Active Filter Using Different Controllers”, *International Journal of Engineering Trends and Technology (IJETT)* ,Vol. 4, pp. 1-6, 2013.
[22] N. Kumar, K.B. Thapa and S. Khalid, “A novel series active power filter scheme using adaptive tabu search algorithm for harmonic compensation”, *Int. J. Appl. Innov. Eng. Manage, (IJAIEM),* Vol. 2, pp. 155-159, 2013.
[23] J.G. Pinto, H. Carneiro, B. Exposto, C. Couto and J.L. Afonso, “Transformerless series active power filter to compensate voltage disturbances”, *In Power Electronics and Applications, Proceedings of the August 2011-14th European Conference on IEEE*, 1-6, 2011.
[24] M.A. Mulla, R. Chudaman and A. Chowdhury, “Series Active Power Filter Using Generalised Instantaneous Power Theory”, *Proceedings of the World Congress on Engineering*, Vol. 2, pp. 1-6, 2012.
[25] A.A. Dutta, M. Sabley, B.S. Sudame and A.N. Kadu, “Harmonic Compensation in Power System using Active Power Filters”, *Int. J. of Multidisciplinary and Current research*, pp. 188-192, 2013.
[26] T. Demirdelen, M. Inci, K.C. Bayindir and M. Tumay, “Review of hybrid active power filter topologies and controllers”, *In Power Engineering, Energy and Electrical Drives (POWERENG), Fourth International Conference on IEEE*, pp. 587-592, May 2013.

[27] I.A. Altawil, K.A. Mahafzah and A.A. Smadi, "Hybrid active power filter based on diode clamped inverter and hysteresis band current controller", *In Advances in Computational Tools for Engineering Applications (ACTEA), 2nd International Conference on IEEE*, pp. 198-203, December 2012.

[28] G.C.D. Sousa and B.K. Bose, "Fuzzy Logic Applications to Power Electronics and Drives An Overview", *Industrial Electronics, Control and Instrumentation, Proceedings of the IECON 21st International Conference on, IEEE*, Vol. 1, pp. 57-62, 1995.

[29] C. Salim and B.M. Toufik, "Intelligent Controllers for Shunt Active Filter to Compensate Current Harmonics Based on SRF and SCR Control Strategies", *International Journal on Electrical Engineering and Informatics*, Vol. 3, pp. 372-393, 2011.

[30] U. Mahesh and M.A. Shaik, "Fuzzy Logic Controller of a Series Active Power Filter for Power Quality Improvement", *International Journal of Modern Engineering Research (IJMER),* Vol. 2, pp. 412-415, 2012.

[31] M. Chau, A. Luo and V. Chau, "PID-Fuzzy Control Method with Time Delay Compensation for Hybrid Active Power Filter with Injection Circuit", *International Journal of Computer Applications*. Vol. 36, 2011.

[32] H. Benalla and H. Djeghloud, "Shunt Active Filter Controlled by Fuzzy Logic", *J. King Saud Univ.* Vol. 18, pp. 231-247, 2005.

[33] J.W. Dixon, J.M. Contardo and L.A. Mor´an, "A Fuzzy-Controlled Active Front-End Rectifier with Current Harmonic Filtering Characteristics and Minimum Sensing Variables", *IEEE Transactions On Power Electronics*, Vol. 14, pp. 724-729, 2013.

[34] N.S. Rao, J. Ayyappa and A.K. Babu, "Development of Hybrid Active Power Filter Based on the Adaptive Fuzzy Dividing Frequency Control Method", *International Journal of Education and Applied Research* (*IJEAR*), Vol. 4, pp. 1-7, 2014.

[35] D.A. Gadanayak and P.C. Panda, "A Novel Fuzzy Variable-Band Hysteresis Current Controller For Shunt Active Power Filters", *ACEEE Int. J. on Control System and Instrumentation,* Vol. 2, pp. 24-28, 2011.

[36] A. Sabo, N.I. Abdul Wahab, M. Radzi, M. Amran and N.F. Mailah, "A modified artificial neural network (ANN) algorithm to control shunt active power filter (SAPF) for current harmonics reduction", *In Clean Energy and Technology (CEAT), IEEE Conference on IEEE*, pp. 348-352 November, 2013.

[37] R. Dehini, A. Bassou and B. Ferdi, "Artificial neural networks application to improve shunt active power filter", *International Journal of Computer and Information Engineering,* Vol. 3, pp. 247-254, 2009.

[38] J. Fei and Z. Wang, "Adaptive control of active power filter using RBF neural network", *In Mechatronics and Automation (ICMA), IEEE International Conference on IEEE,* pp. 767-772, August 2013.

[39] M. El-Habrouk and M.K. Darwish, "A new control technique for active power filters using a combined genetic algorithm/conventional analysis", *Industrial Electronics, IEEE Transactions on*, Vol. 49, pp. 58-66, 2002.

[40] F. Cupertino, M. Marinelli, P. Zanchetta and M. Sumner, "Modelling and design of shunt active power filters using genetic algorithms", *In Power Electronics and Applications, European Conference on IEEE*, pp. 1-5, 2005.

[41] K. Saifullah, D. Bharti and S. Bhim, "New Optimum Three Phase Shunt Active Power Filter based on Adaptive Tabu Search and Genetic Algorithm using ANN control in unbalanced and distributed supply condition", *UTM Jornal of Electrical Engineering*, Vol. 14, 2012.

[42] G.J. Krishna , N.R. Raju and C. Swapna, "Genetic Algorithm tuned PID controller based Shunt Active Filter for harmonic reduction", *IPASJ International Journal of Electrical Engineering(IIJEE*), Vol. 2, pp. 1-9, 2014.

[43] T. Narongri, K.L. Areerak and K.N. Areerak, "Design of an active power filter using genetic algorithm technique", *Proceedings of the 9th WSEAS international conference on Artificial intelligence, knowledge engineering and data bases, World Scientific and Engineering Academy and Society (WSEAS*), PP. 46-50, 2010.

[44] Y. Weike, L. Bin and X. Yong, "Fuzzy Neural Networks and GA based Predictive Control for Active Power Filter", *Measuring Technology and Mechatronics Automation (ICMTMA), Fifth International Conference on*, pp. 598-601, 2013.

[45] A. Bhattacharya and C. Chakraborty, "A Shunt Active Power Filter With Enhanced Performance Using ANN-Based Predictive and Adaptive Controllers", *IEEE Transactions on Industrial Electronics*, Vol. 58, pp. 421-428, 2011.

[46] B. Vasumathi and S. Moorthi, "Harmonic estimation using Modified ADALINE algorithm with Time-Variant Widrow—Hoff (TVWH) learning rule", *In Computers & Informatics (ISCI), IEEE Symposium on IEEE*, pp. 113-118, March 2011.

[47] E. Almaita and J.A. Asumadu, "Harmonic content extraction in converter waveforms using radial basis function neural networks (RBFNN) and pq power theory", *In Power and Energy Conference at Illinois (PECI), IEEE*, pp. 1-7, February 2011.

[48] A. Bhattacharya and C. Chakraborty, "A shunt active power filter with enhanced performance using ANN-based predictive and adaptive controllers", *IndustrialElectronics*, *IEEE Transactions on*, Vol. 58, pp. 421-428, 2011.

[49] J. Talla, Z. Peroutka, S.J. Ovaska and J. Stehlik, "Genetic Algorithm Based Optimization of MGP-FIR Current Reference Generator for Active Power Filters", *In International Joint Conference CISIS'12-ICEUTE´ 12-SOCO´ 12 Special Sessions, Springer Berlin Heidelberg*, pp. 429-438, January 2013.

[50] N.L. Surasmi and M.R. Sindhu, "Optimum Allocation of Active Filters In A 4-Bus System Using Genetic Algorithm", *International Journal of Emerging Technology and Advanced Engineering*, Vol. 2, pp. 251-256, 2012.

[51] H. Hashemi Dezak, M. Mohammad alizadeh-Shabestary, H. Askarian-Abyaneh and M. Rezaei-Jegarluei, "New Approach to Optimize the Apfs Placement Based on Instantaneous Reactive Power Theory by Genetic Algorithm", *Journal of Electrical Engineering,* Vol. 65, pp. 12-20, 2014.

[52] V.S. Kumar, D. Kavitha, K. Kalaiselvi and P.S. Kannan, "Harmonic mitigation and power factor improvement using fuzzy logic and neural network controlled active power filter", *Journal of Electrical Engineering & Technology,* Vol. 3, pp. 520-527, 2008.
[53] P. Kumar and A. Mahajan, "Soft computing techniques for the control of an active power filter", *Power Delivery, IEEE Transactions on*, Vol. 24, pp. 452-461, 2009.
[54] *S.* Khalid, B. Dwivedi, "Simulation and Performance Based Comparison of GA-Fuzzy-ANN Based Shunt Active Power Filter for Power Quality Improvement in High Frequency Aircraft System", *Journal of Aerspace Engineering & Technology*, Vol. 3, 2013.
[55] R. Dehini, B. Ferdi and B. Bekkouche, "Fuzzy Logic Controller Optimization Based on GA for Harmonic Mitigation", *Journal of Artificial Intelligence*, Vol. 5, pp. 26-36, 2012.
[56] L. Jun-tang, Q. Wu and J. Ouyang, "Application of GA based fuzzy neural network predictive control in Active Power Filter", In Electricity Distribution (CICED), *China International Conference on IEEE*, pp. 1-6, September 2012.

BIOGRAPHIES OF AUTHORS

Ekhlas Mhawi obtained the B.S. and the M.S. degrees in electrical engineering from University of Technology/Baghdadin 1995 and 2006, respectively. She is serving as a lecturer in a University of Technology/Baghdad, and currently pursuing her PhD degree at Universiti Malaysia Pahang. The area of interest including Electric Power Quality, Active power filter, PWM techniques, harmonics suppression, and reactive power compensation.

Hamdan Daniyal (M'07) received the B.E. degree in electrical & electronics (2002) from Universiti Teknologi Malaysia, the M.E. degree in mechatronics (2004) from Kolej Universiti Teknologi Tun Hussein Onn and the Ph.D. degree (2011) in digital current control for power electronics converter from The University of Western Australia.

In 2002, he worked as an EE engineer at Smart Ind., a switched mode power supply manufacturing company. Later in 2003, he joined Universiti Malaysia Pahang (formerly known as KUKTEM) as a lecturer. After finished his Ph.D. study, he became one of the key person in Sustainable Energy & Power Electronics Research (SuPER) group, UMP. His research interest include switching strategy, nonlinear control and digital control in power electronics applications such as renewable energy, electric vehicle, battery management, power quality and active power filters. Dr. Hamdan Daniyal is a member of IEEE Power Electronics Society (PELS) and IEEE Industrial Electronics Society (IES).

Mohd Herwan Sulaiman obtained his B. Eng. (Hons) in Electrical-Electronics, M. Eng (Electrical-Power) and PhD (Electrical Engineering) from Universiti Teknologi Malaysia (UTM) in 2002, 2007 and 2012 respectively. He is currently a senior lecturer at Faculty of Electrical & Electronics Engineering, Universiti Malaysia Pahang (UMP). His research interests are power system optimization and swarm intelligence applications to power system studies. He is also a Senior Member of IEEE.