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A Literature Survey of Neural Network Applications for Shunt Active Power Filters

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Abstract**—**This paper aims to present the reviews of the application of neural network in shunt active power filter (SAPF). From the review, three out of four components of SAPF structure, which are harmonic detection component, compensating current control, and DC bus voltage control, have been adopted some of neural network architecture as part of its component or even substitution. The objectives of most papers in using neural network in SAPF are to increase the efficiency, stability, accuracy, robustness, tracking ability of the systems of each component. Moreover, minimizing unneeded signal due to the distortion is the ultimate goal in applying neural network to the SAPF. The most famous architecture of neural network in SAPF applications are ADALINE and Backpropagation (BP).

Keywords**—**Active power filter, neural network, harmonic distortion, harmonic detection and compensation, non-linear load.

I. Introduction

IN recent decades, there are many studies about harmonic distortion with techniques to improve power quality. The harmonic is defined in many literatures as "a component of a periodic wave having a frequency that is an integral multiple of the fundamental power line frequency" [1]. The meaning of the harmonic can be easily explained using the following example. Let "f" represents a fundamental frequency, the 2nd harmonic has frequency 2f Hz, the 3rd harmonic has frequency 3f Hz, and so on [2]. The 2nd, 4th, 6th, etc., are called even harmonics while the 3rd, 5th, 7th, etc., are called odd harmonics [2]. Harmonic distortion occurs when non-linear loads, such as rectifier, inverters, adapters, etc., are feeded from power systems [3], [4], [5] and changes a sinusoidal wave at a fundamental frequency to different non-sinusoidal waves as shown in Fig. 1. The negative effects of harmonic distortion can be listed as follows [6], [7].

1) Premature aging or damaging of the electrical device or consumer equipment.
2) Interfering with power system protection, such as, circuit breaker or blown fuses.
3) Interfering the electronics communication
4) Miss leading to erroneous operation of control system components

Because of the reasons mentioned above, therefore, an operation to eliminate the harmonic components is required to achieve the total harmonic distortion (THD) following on the international standards IEC and IEEE.

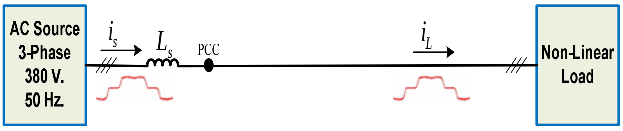

Fig. 1 Non-linear load in the electrical power system

At present, there are three common techniques for harmonic reduction/elimination, which are passive power filter (PPF), active power filter (APF), and hybrid power filter (HPF). PPF is a simple and robust technique with low cost. However, it is sensitive to the environments and easy to overload. APF can be divided into AC and DC filters which is mainly used as a current or voltage harmonic compensation [8]. There are three classification of APF – converter-based classification, topology-based classification, and supply-system-based classification. HPF is a combination of various types of PPF and APF [9].

The aim of this paper is to present a survey of harmonic cancellation using shunt APF with an application of neural network (NN). Next section presents a foundation of Shunt APF and its operations. Section III describes the basic concept of neural network. Section IV presents a review of an application of NN in the APF from the IEEE database from 2006 – 2011. Finally, Section V is the conclusion and recommendation for the future research.

II. Shunt Active Power Filter

Shunt active power filter (SAPF) is commonly used as an effective method in compensating harmonic components in non-linear loads. Fig. 2 shows the basic principle of SAPF in which APF is connected in parallel to the power system at a point of common coupling (PCC) between metropolitan electricity authority (MEA) and power users. The objective of SAPF is to minimize the distortion in power supply using four main components – harmonic detection, compensating current control, DC bus voltage control, and active power filter – as shown in Fig. 3.

In the harmonic detection component, the distorted signal can be detected by several harmonic detection techniques, i.e.,

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the instantaneous reactive power theory (PQ) [10], the synchronous reference frame (SRF) [11] – [13], the d-q axis with Fourier (DQF) [14], and the synchronous detection (SD) [15] – [16] etc. Then, APF injects the compensating currents into the power system [17]. The current control techniques are hysteresis current control [18] – [19], Pulse Width Modulation (PWM) [20] – [22], and Space Vector Modulation (SVM) [23] – [24] etc. For dc bus voltage control, proportional integral (PI) is employed [25]. Commonly, APF uses 6 IGBT devices to build the voltage source inverter for injecting the compensation current to the system at PCC. The architecture of APF with IGBT device is shown in Fig. 4.

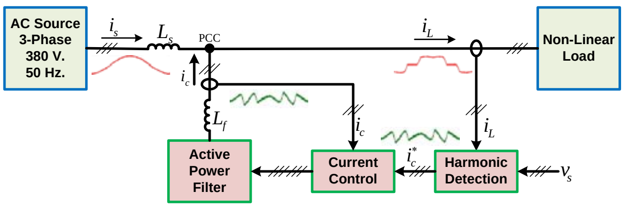

Fig. 2 The system using shunt active power filter

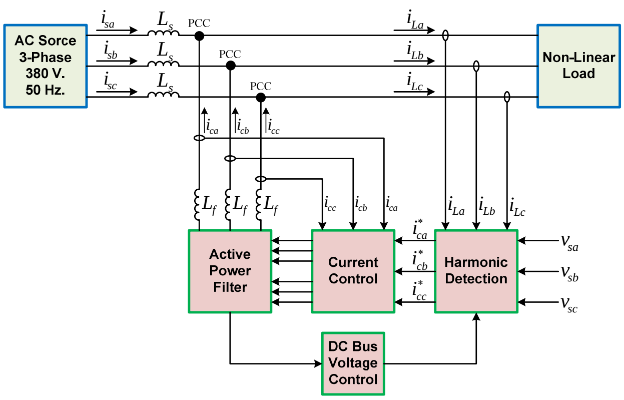

Fig. 3 Three – phase shunt active power filter

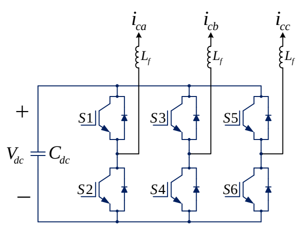

Fig. 4 IGBT bridge inverter in APF

III. Concepts of Neural Network

Neural Network (NN) is the network that has structure and processes like human brain [26]. NN has been adopted to many applications to perform several tasks, e.g., fitting function, pattern recognition, clustering data, etc. Examples of the neural network application are aerospace, automotive, banking, defense, electronics, entertainment, financial, industrial, insurance, manufacturing, medical, oil and gas, robotics, speech, securities, telecommunications, transportation, and so on [27]. The parallel processing with nonlinearity and adaptability property is described in many papers as the strength of NN.

NN architecture consists of three layers – input, hidden, and output layers. In the simplest form of neural network, there is only input and output layer which is directly connected to each other. Like other networks, neural network can be designed or adapted to fit the characteristics of each problem. The following is the suggestion of the designing steps when neural network is chosen to solve any problems.

1. Weight initialization
2. Number of hidden layers
3. Number of neurons in each hidden layer
4. Number of input variables or combination of input variables
5. Learning rate
6. Momentum rate
7. Training cycle
8. Type of activation function
9. Data partitioning and evaluation metrics.

Perceptron, ADALINE or Widrow – Hoff, Backpropagation (BP), Radial Basis Function (RBF), Hopfield, Hebbian, Competitive, and Grossberg are examples of neural network architecture which have been designed for solving different characteristics of problems.

IV. An Application of Neural Network in APF

As mentioned in section III, there are many conventional techniques to detect and compensate harmonic current. This article presents a general outline for the research literature on how to solve harmonic distortion problem by artificial neural network (ANN). ANN is one of the modern techniques which is used in many areas of application including harmonic eliminations. Fig. 5 shows an architecture of three-phase diagram of neural network controlled SAPF. A NN is used to control the compensating current injection with SAPF [28].

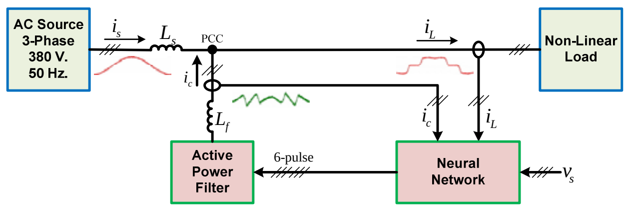

Fig. 5 The active power filter control using NN approaches

Total of 50 papers from IEEE/IET Electronic Library (IEL) from 2006 – 2011 are reviewed. Several facts have been discovered and will be discussed later. Fig. 6 gives a review on which components of SAPF is substituted by neural network in each paper.

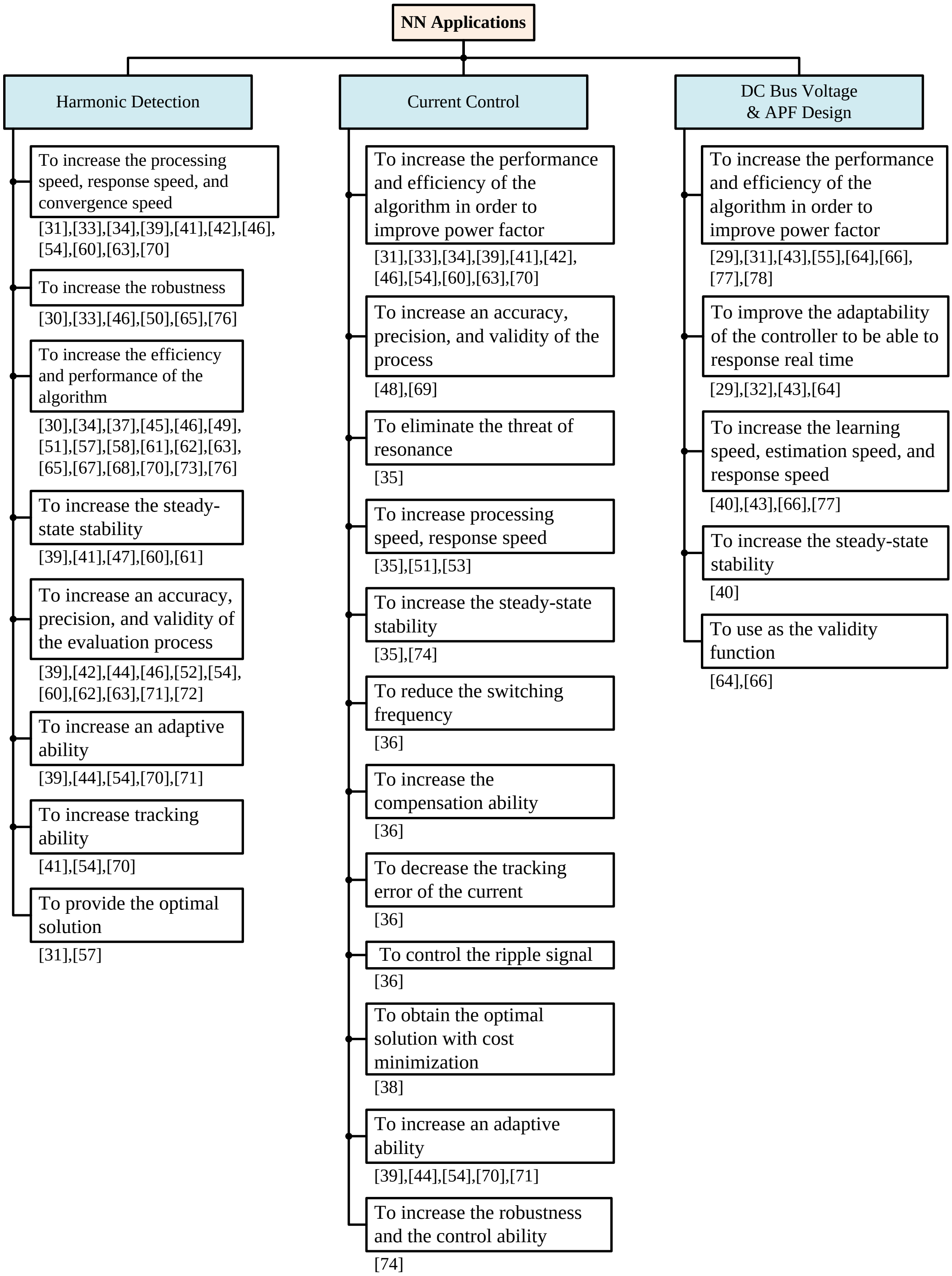

Fig. 6 Review of NN applications for SAPF

From the review, it shows that neural network is employed to substitute a harmonic detection component for the following reasons:

1) To increase the processing speed, response speed, and convergence speed [31], [33], [34], [39], [41], [42], [46], [54], [60], [63], [70].
2) To increase the robustness [30], [33], [46], [50], [65], [72].
3) To increase the efficiency and performance of the algorithm [30], [34], [37], [45], [46], [49], [51], [57], [58], [61], [62], [63], [65], [67], [68], [70], [73], [76].
4) To increase the steady-state stability [39], [41], [47], [60], [61].
5) To increase an accuracy, precision, and validity of the evaluation process [39], [42], [44], [46], [52], [54], [60], [62], [63], [71], [72].
6) To increase an adaptive ability [39], [44], [54], [70], [71], so that it can response in real time.
7) To increase tracking ability [41], [54], [70].
8) To provide the optimal solution [31], [57].

NN is easy and convenient to use [59] as a substitution of the current control component. Furthermore, the following reasons are also given as the merit of the NN for current control process.

1) To increase the performance and efficiency of the algorithm in order to improve power factor [38], [48], [56], [59], [74], [75].
2) To increase an accuracy, precision, and validity of the process [48], [69].
3) To eliminate the threat of resonance [35].
4) To increase processing speed, response speed [35], [51], [53].
5) To increase the steady-state stability [35], [74].
6) To reduce the switching frequency [36].
7) To increase the compensation ability [36].
8) To decrease the tracking error of the current [36].
9) To control the ripple signal [36].
11) To obtain the optimal solution with cost minimization [38].
12) To increase an adaptive ability [39], [44], [54], [70], [71], so that it can response in real time.
13) To increase the robustness and the control ability [74].

For the DC-Bus Voltage Control and SAPF Design, NN has been adopted for many reasons as follows:

1) To increase the performance and efficiency of the algorithm in order to improve power factor [29], [31], [43], [55], [64], [66], [77], [78].
2) To improve the adaptability of the controller to be able to response real time [29], [32], [43], [64].
3) To increase the learning speed, estimation speed, and response speed [40], [43], [66], [77].
4) To increase the steady-state stability [40].
5) To use as the validity function [64], [66].

Table I presents the review of the neural network architecture which has been chosen to use as a part of SAPF components. The results reveal that ADALINE and Backpropagation algorithm are the most popular architectures

TABLE I
NEURAL NETWORK TECHNIQUES FOR SAPF

Authors	ADALINE/ Widrow-Hoff	BP	Perceptron	RBF	Hopfield
[29]	/				
[30]				/	
[31]	/				
[32]		/			
[33]	/				
[34]	/				
[35]				/	
[36]		/			
[37]			/		
[38]					
[39]		/			
[40]		/			
[41]	/				
[42]				/	
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[71]		/			
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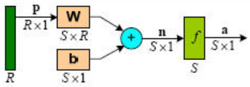
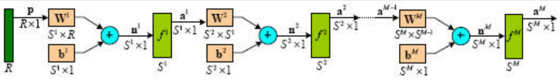
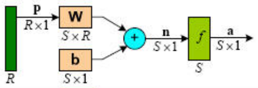
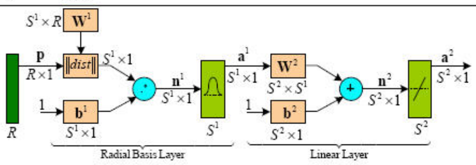
[73]	/	/			
[74]		/			
[75]		/			
[76]	/				
[77]		/			
[78]		/			

that have been applied to SAPF, because both architectures are higher efficiency learning than other architectures for SAPF.

Table II present some detail for NN architecture that use with SAPF.

TABLE II
NEURAL NETWORK ARCHITECTURE

NN ARCHITECTURE	STRUCTURE	LEARNING	TRANSFER FUNCTION
ADALINE/ Widrow-Hoff		Widrow-Hoff weight&bias learning rule	Linear
BP		-Gradient descent weight/bias -Gradient descent with momentum weight/bias	-Log-Sigmoid -Linear -Hyperbolic tangent sigmoid
Perceptron		-Perceptron weight&bias -Normalized perceptron weight&bias	-Hard-limit -Symmetric hard-limit
RBF		Spread parameter	-Radbas -Linear

V. CONCLUSION

From the reviews described in the paper, it reveals that neural network has been applied to several components of SAPF for several purposes, such as increase the processing speed, resist the changed of temperature, maintain the system stability and precision, and so on. Neural network has been claimed in several papers that it is a dual – algorithm – oriented learning, which enhances the simple architecture to the system. Moreover, there are lots of tool and technology which support large number of neural network applications. Therefore, neural network is very popular to all applications. In the future work, the artificial intelligence (AI) techniques will be applied to design the NN controller for shunt active power filter.

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