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Advanced Controlling Schemes for Active Power Filter: A Review

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ABSTRACT: In last decade there is continuous advancement in the field of power quality improvement. Development of artificial intelligence and expert system in the area of control engineering dragged the attention of researcher to incorporate these advance techniques with active power filter to enhance its compensation properties. Numerous control algorithms have been developed in last few years using AI techniques like fuzzy logic, artificial neural network (ANN) and genetic algorithm. Application of these techniques in the area of power quality shows great improvement in results in terms of reduction of % THD. The present work describes modeling and controlling technique of active power filter and presents the detailed review on advance control methodology for APF. This paper also presents the comparative analysis of performance of shunt active power filter with conventional and adaptive controller under varying load condition. A classified list of 32 publications on this topic is also given for the quick reference.

Keywords: Active Power Filter, AI Techniques, Adaptive Control, Total Harmonic Distortion.

I. INTRODUCTION

In modern power distribution systems, majority of loads are nonlinear in nature and draw reactive power and harmonic currents from the AC source. These nonlinear loads cause low efficiency of the power system, poor power factor, destruction of other equipments due to excessive stresses and EMI problems [1, 2]. In this way non-sinusoidal currents, pollute the utility line due to the current harmonics generated by them. Active power filter (APF) is used to provide reactive power and harmonics compensation for nonlinear loads. Shunt APF compensates current harmonics by injecting equal but opposite harmonic compensating current. This principle is applicable to any load considered as a harmonic source. Moreover, with an appropriate control scheme, the active power filter can also compensate the load power factor. In this way, the power distribution system considers the non linear load and the active power filter as an ideal resistor [2].

Various topologies of active power filter have been developed so far [1]. Development of a suitable controller for APF is the task of prime preference for achieving the best possible results. The fixed gain conventional PI controller has been designed and tested for the constant load condition [2]. Under the variable load condition tuning and design of such conventional PI controller is a difficult task. The design of PI controller requires the knowledge of exact mathematical model which is difficult to obtain under parameter variations and load disturbances.

The application of AI based controller such as fuzzy logic controller in place of fixed gain PI controller not only reduces the need of exact mathematical model of the system but also shows the improvement in the transient behavior. Various fuzzy logic based controllers have been developed so far to obtain the optimal performance of Active power filter [3-12].

The design of Mamdani-type fuzzy logic controller for three phase shunt active power filter is presented in [3-4]. This shows that the dynamic behavior of fuzzy logic controller is better than the conventional PI controller. The optimized Takagi-Sugeno-type fuzzy logic controller is then given in [6-9]. This design not only improves the performance of shunt active power filter but it reduces the number of fuzzy sets and rules of previous design. A new adaptive control technique for three phase shunt active power filter using interval type-2 fuzzy logic controller is proposed in [10]. An efficient type reduction method called as Nie-Tan method is used in this paper which gives closed form expression and reduces the computing power needed to implement time reduction. Apart from fuzzy artificial neural network and genetic algorithm may also be the better solution for improved controller for APF [13-17].

The recent applications need faster transient response with minimum power dissipation under the variation of load and the variations in system parameters. The conventional PID controllers with fixed gain are unable to cop up with such problems. The requirement of high performance control system for such applications has produced great research efforts for the application of modern control theory and, in particular, adaptive control [19-27, 32].

Shyu *et al* [21] presented the model reference adaptive control design for single phase shunt active power filter. In this paper Lyapunov's stability theory and Barbalat's lemma, adaptive law is designed to guarantee an asymptotic output tracking of the system. The design procedure for Discrete-Time robust model reference adaptive control for three phase four wire shunt active power filter is described in [20]. The choice of appropriate Lyapunov function for controller design is a complicated task and requires the deep knowledge about the process.

Design of MRAC with MIT rule is simple and less mathematical as compared to the Lyapunov rule. Selection of correct

Lyapunov function greatly affects the design in case of Lyapunov theory. The choice of suitable Lyapunov function is process dependent task and requires a thorough knowledge of process. However this is not the problem in case of MIT rule. Benchouia *et al* [22] gave the concept of fuzzy MRAC for power converters. W. Dazhi *et al* [24] developed the PI controller along with the adaptive variable amplitude limiter based on MRAC scheme for SAPF. The paper is mainly based on the DC bus voltage control. Effect of load and system parameter variations on the performance of APF (especially in terms of %THD) is not discussed for the proposed design. Use of another adaptive control technique based on self tuning of fuzzy logic controller for apf is described in [25]. Another adaptive control scheme for SAPF is proposed in [26]. Here the DC link voltage is regulated by a PI controller with antiwindup. In this control scheme harmonic detection is not used, which reduces the number of current sensors employed in the SAPF. Y Suresh *et al* [27] proposes hybrid adaptive fuzzy hysteresis current controller for shunt active power filter (SAPF) in order to overcome the limitations of conventional PI controller under transient events. The supply system for aircraft requires very accurate and sensitive control strategy for shunt active power filter. Use of adaptive control technique for such cases is the appropriate solution for getting the harmonic free supply [28-30].

II. OPERATION OF SHUNT ACTIVE POWER FILTER

Shunt active power filter compensate current harmonics by injecting equal but opposite harmonic compensating current. Shunt power filter needs to pass bidirectional current and it is typically composed of a full bridge or half bridge with an energy storage capacitor at the DC side.

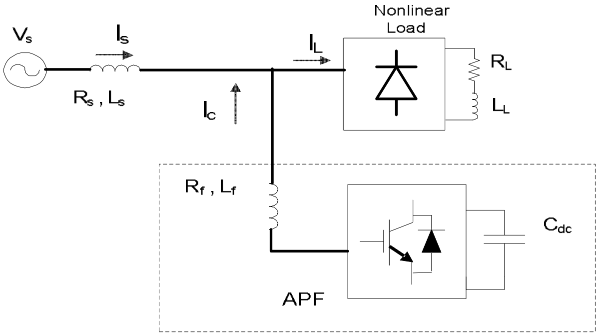

Fig. 1. Operation of shunt active power filter.

As shown in Fig. 1 the APF system connected in parallel with the load could cancel the harmonic/reactive components in the line current (i_s) so that the current flows from the source is sinusoidal and in phase with the supply voltage. The currents of the APF system can be expressed as

$$i_s(t) = i_L(t) + i_c(t) \qquad \ldots(1)$$

where i_L is the nonlinear load current and i_c is the compensation current. The source current after compensation is given by

$$i_s(t) = I_{sm}\, sin\omega t \qquad \ldots(2)$$

Where $I_{sm} = I_1 \cos \theta_1$

To meet the switching losses of PWM inverter, the utility must supply the additional real power apart from the load requirements. This additional power should also meet a small overhead for the capacitor leaking. Hence the total peak current supplied by the source

$$I_{sp} = I_{sm} + I'_s \qquad \ldots(3)$$

For accurate and instantenous compensation of reactive and harmonic power, it is necessary to calculate the fundamental component of load current as the reference current. The peak value of reference current is estimated by regulating the DC link capacitor voltage (V_{dc}).

A. Role of DC side Capacitor (C_{dc}) [2]

The peak value of the source current can be estimated by controlling the DC side capacitor voltage. The ideal compensation requires the main current to be sinusoidal and in phase with the supply voltage irrespective of the nature of the load. The DC side capacitor serves following two purposes:

- In steady state, it maintains a constant voltage (with small ripple)
- In transient period it serves as an energy storage element to supply the real power difference between load and source.

As per the compensation principle, the active filter adjusts the compensating current to compensate the reactive power of load, the source current will be in phase and the compensating current should be orthogonal to source voltage. For the fundamental components only the 3-phase reactive power delivered from the APF can be given as

$$Q_{c1} = 3V_s I_{c1} \qquad \ldots(4)$$

The fundamental component of compensating current is given by

$$I_{c1} = (V_{c1} - V_s)/\omega L_c \qquad \ldots(5)$$

The active filter can compensate the reactive power from utility only when $V_{c1} > V_s$.

B. Estimation of reference current

The DC link capacitor decides the peak value of reference source current given by eq (3). The source current must be sinusoidal and in phase with the supply voltage for the ideal compensation [2], so the desired source current after compensation is given by

$$i^*_{sa} = I_{sp}\, sin\omega t \qquad \ldots(6)$$

$$i^*_{sb} = I_{sp} \sin(\omega t - 120^0) \qquad \ldots(7)$$

$$i^*_{sc} = I_{sp} \sin(\omega t + 120^0) \qquad \ldots(8)$$

The error between the actual capacitor voltage and its reference value is fed to the controller. The output of the controller is considered as the amplitude of the desired source current. The reference current is the estimated by multipling the peak value with the unit sine vectors in phase with the source voltages.

III. MODERN CONTROLLERS FOR SAPF

The conventional fixed gain PID controller has its limitations to control the APF under varying load and environmental conditions. PID controller tuned with AI techniques like Fuzzy, neural and GA makes it more versatile. This section discusses the salient features of modern control techniques to enhance the performance of APF. At the later part of this section adaptive control techniques like gain scheduling, Self tuning regulator and Model reference adaptive controller are also described to show its effectiveness on APF for large variation in load and other working conditions.

A. Fuzzy Logic Controlled SAPF

Fuzzy logic based controllers for shunt active power filters are successfully desigened and implemented to improve the electrical power quality [3-12]. Controlling of shunt active power filter mainly depends on regulating the DC link capacitor voltage (V_{dc}). The value of V_{dc} sould be maintained at its reference value V_{dcr}, irrespective of the nature of load and variations in the system. In simple fuzzy controlling scheme [3], the error between V_{dcr} and V_{dc} is processed through fuzzy logic controller as shown in Fig. 2.

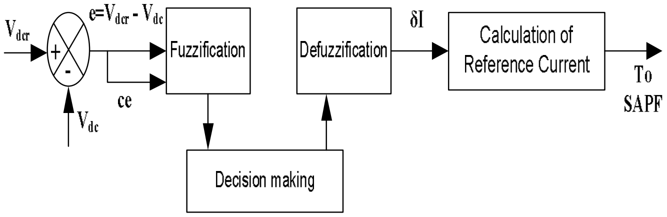

Fig. 2. Fuzzy logic controlled SAPF.

The output of the fuzzy controller after a limit is considered as the amplitude of reference current. This current takes care of the active power demand of load and the losses in the system. In fuzzy logic controller, the control action is determined from the evaluation of a set of simple linguistic rules. The development of the rules requires a thorough understanding of the process to be controlled, but it does not require a mathematical model of the system. The internal structure of the fuzzy controller is shown in Fig. 2. Here, the error '*e*' and change of error '*ce*' are used as numerical variables from the real system. To convert these numerical variables into linguistic variables, some fuzzy levels or sets are chosen. The results obtained by using fuzzy logic controller are found better than the fixed gain PID controller for shunt active power filter.

Fuzzy logic controller along with the conventional PID controller is also developed and implemented to SAPF. Here the gains of PID controller are calculated by fuzzy logic. To minimize the capacity of active power filter, an adaptive fuzzy dividing frequency-control method is proposed by analyzing the bode diagram [4], which consists of two control units: a generalized integrator control unit and fuzzy adjustor unit. The generalized integrator is used for dividing frequency integral control, while fuzzy arithmetic is used for adjusting proportional-integral coefficients timely. Compared to other control methods, the adaptive fuzzy dividing frequency control shows the advantages of shorter response time and higher control precision. Such scheme is shown in Fig. 3.

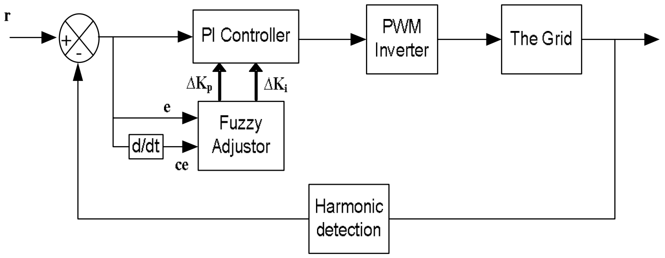

Fig. 3. Fuzzy controlled PI controller for SAPF.

Optimize fuzzy logic controller using Takagi–Sugeno (TS) fuzzy control scheme [6-9] has been used for active power filter regulation. The TS fuzzy controller can provide a wide range of control gain variation and it can use both linear and nonlinear rules in the consequent expression of the fuzzy rule base. The simulation results show that the TS fuzzy controller has improved dynamic response than that of the conventional PI controller.

The TS fuzzy controller performance is more robust than the conventional PI controller for load variations and other system parameter's variations.

Fuzzy logic controller in conjunction with phase locked loop (PLL) synchronization for shunt active power filter [11] for harmonics and reactive power compensation in the distribution grid due to the non-linear loads is shown in Fig. 4. The phase locked loop can operate satisfactorily even under distorted and unbalanced system voltages or currents. PLL determines automatically the system frequency and the fundamental positive sequence components of three-phase line voltages. The active power filter is implemented with current controlled voltage source inverter (VSI) and is connected at the point of common coupling for compensating current harmonics by injecting equal but opposite harmonic components.

The desired reference currents are extracted using FLC with PLL algorithm and this method maintains the DC link capacitor voltage of the inverter nearly constant. The VSI gate switching signals are derived from adaptive-hysteresis current controller. The adaptive-hysteresis controller changes the bandwidth based on instantaneous compensation current variation; it is used to optimize the required switching frequency.

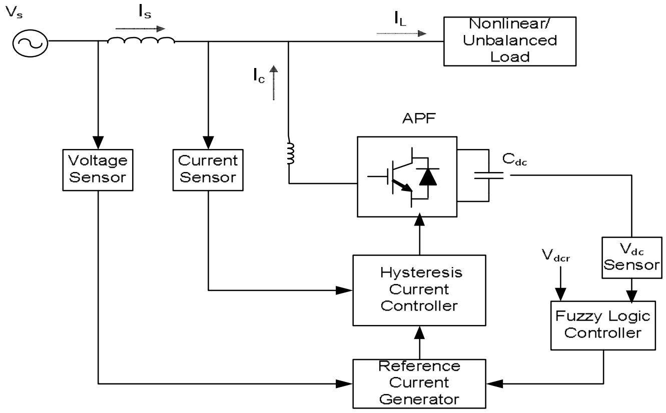

Fig. 4. Fuzzy logic controller with PLL synchronization for SAPF.

B. ANN Based Controlling of SAPF

Artificial neural network [12-16] is also one of the AI techniques used in the field of power quality. A. Hamadi et al [12] used the combination of fuzzy logic and artificial neural network. The fuzzy logic controller implemented uses Sugeno method, and is optimized by using adaptive neuro-fuzzy inference system.

A diagonal recurrent neural network based predictive control strategy [13] for active power filter is presented by Fan Shaosheng and Xiao Hui. In this strategy, diagonal recurrent neural network is employed to predict future harmonic compensating current. In order to make the predictive model compact and accurate, an adaptive dynamic back propagation algorithm is proposed to obtain the optimum number of hidden layer neurons. Based on the model output, branch-and-bound optimization method is adopted, which generates proper gating patterns of the inverter switches to maintain tracking of reference current without time delay. It has the advantages that control scheme does not require the exact model of system so it can be considered as a powerful tool for the control of dynamical system. The schematic diagram of SAPF with predictive neural network control is shown in Fig. 5.

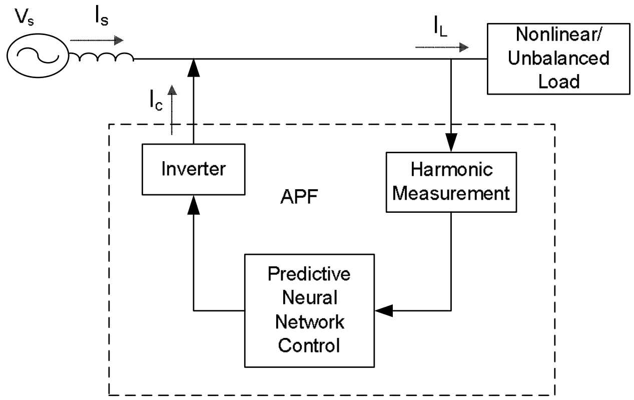

Fig. 5. ANN based controlled SAPF.

Feed-forward neural network is a static mapping and without the aid of tapped delays it does not represent a dynamical system. Recurrent neural network is a dynamic mapping and is better suited for dynamical system than the feed-forward network, but the structure and algorithm of network are always complicated, which limits the role in real-time implementation. Diagonal recurrent neural network (DRNN) has the ability to achieve nonlinear dynamic mappings with simple structure, rapidly convergence and easy implementation; therefore it is employed to predict harmonic compensating current. The number of recurrent neurons is associated directly with the simplicity and accuracy of DRNN. More neurons results in computation complexity, less neurons decreases network accuracy. In order to make the predictive model more simple and accurate, an adaptive dynamic back propagation algorithm can be used to determine the optimum number of the hidden layer neurons. Based on the predictive model, the value of control variable is acquired by means of optimization technique. Iterative optimization techniques are mostly slow due to computational complexity; this hampers its application to fast system. In order to solve the problem, branch-and-bound optimization method is adopted. Model predictive algorithm is used in internal model control scheme to compensate for process disturbances, measurement noise and modelling errors. A neutral adaptive detection approach is presented according to the adaptive noise cancelling technology (ANCT) in [14].

Neural network can also be used to optimize the control effect of DC bus voltage in APF [15, 16]. Back Propagation (BP) neural network is generally adopted for on-line tuning of PID controller.

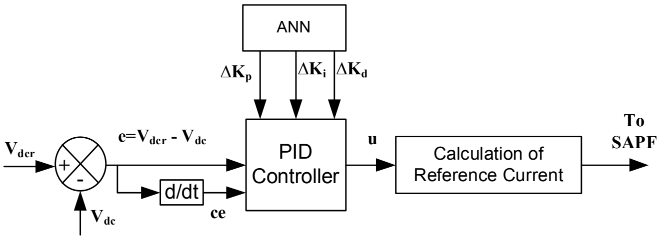

Fig. 6. ANN based controlled PID controller for SAPF.

The two strategies, adding momentum method and adaptive learning rate adjustment, are combined to improve BP network, which can not only effectively suppress the network appearing local minimum but also good to shorten learning time and improve stability of the network furthermore. The improved BP network adjusted the parameters such as gains of PID controller according to the operation state of the system and realized optimum PID control as shown in Fig. 6.

C. GA Based Controlling of SAPF

The genetic algorithm is used to design the controllers to minimize the %THD of source current. GA can be applied to determine the appropriate APF parameters like DC link capacitor voltage v_{dc}, filter inductance L_f, and the hysteresis band (*HB*). The block diagram to explain how to search the parameters of APF using GA method is depicted in Fig. 7 [17].

It can be seen that GA will search the APF parameters in which %THD of the compensated current on supply side is defined as the cost value for GA tuning. This value can be determined from the objective function which is defined in terms of the parameters to be optimized. The GA will try to search the best APF parameters to achieve the minimum %THD as per the specifications of IEEE std. 519-1992.

Fig. 7 shows the compensating current control using the hysteresis approach, where the hysteresis band (*HB*) is the possible boundary of compensating current. In this figure, i_s is the source current, i_L is the nonlinear load current, i_c is the compensating current and i_{cr} is the reference current. According to this approach, current swings between upper and lower hysteresis limits. The compensating current can be increased or decreased depending on the pattern switch of IGBT inside the APF. The compensating current swings inside *HB* following the reference current i_{cr}. The reference current can be identified by PQ harmonic detection. Upper and lower hysteresis limits are controlled by the hysteresis band.

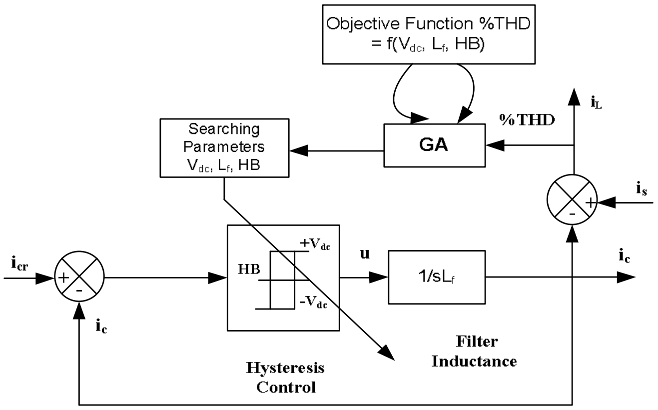

Fig. 7. GA based controlling of SAPF [17].

The steps of searching APF parameters by using GA are as follows, as per the process shown in Fig. 7.

Step 1: Define the boundary of parameters DC link capacitor voltage V_{dc}, filter inductance L_f, and the hysteresis band (*HB*)

Step 2: Define the population encoding scheme for GA.

Step 3: Set the population size

Step 4: Define the initial population by random within the search space of parameters.

Step 5: Define the maximum number of generation for searching.

Step 6: Define the selection process

The parameters, obtained by optimization technique like genetic algorithm, give better results as compared to the conventional controlling method.

D. Adaptive control

The recent applications need faster transient response with minimum power dissipation under the situations where loads and the parameters of the system change drastically. This requires use of adaptive control [19-26] for power quality improvement.

Design procedure for Discrete-Time robust model reference adaptive control for three phase four wire shunt active power filter is described in [20]. Kuo-Kai Shyu *et al* [21] presented the model reference adaptive control design for single phase shunt active power filter. In this paper Lyapunov's stability theory and Barbalat's lemma, adaptive law is designed to guarantee an asymptotic output tracking of the system.

The advantages of using MRAC over conventional proportional-integral control are its flexibility, adaptability, and robustness; moreover, MRAC can self-tune the controller gains to assure system stability. Since the APF is a bilinear system, it is hard to design the adaptive controller. Linearization method should be used to solve the nonlinearity of the system. Moreover, by using Lyapunov's stability theory and Barbalat's lemma, an adaptive law has to be designed to guarantee an asymptotic output tracking of the system. The controlling scheme for APF based on MRAC is shown in Fig. 8.

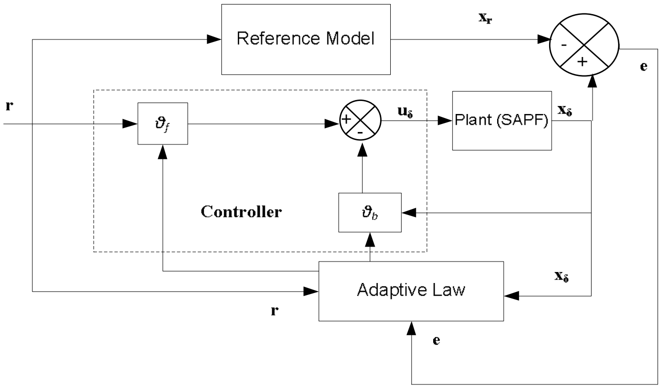

Fig. 8. MRAC based controlling of SAPF.

To simplify the analysis, the following assumptions are made:

1) The DC link capacitance is sufficiently large so that the voltage across it is nearly constant at one switching cycle.

2) The switching frequency is much higher than the line frequency.

After linearization, the plant in this case is defined as

$$\dot{x}_\delta(t) = A_p x_\delta(t) + B_p u_\delta(t) \qquad \ldots(9)$$

Where $x_\delta = x - x_0$ and $u_\delta = u - u_0$, (x_0, u_0) is the equilibrium or operating point.

The reference model for model reference adaptive control is defined as,

$$\dot{x}_r(t) = A_r x_r(t) + B_r u_r(t) \qquad \ldots(10)$$

The error signal which has to be reduced to zero, is defined as,

$$e = x_r - x_\delta \qquad \ldots(11)$$

The control law defines the control signal,

$$u_\delta = [\theta_f \quad \theta_b] \begin{bmatrix} r \\ x_\delta \end{bmatrix} \qquad \ldots(12)$$

Where θ_f and θ_b are the control parameters for forward and backward paths. These control parameters form the update law which defines the control action. Parameter update laws that are used to tune the control gains are derived by the Lyapunov function.

Design of Fuzzy model reference adaptive control of power converter for unity power factor and harmonics minimization is given in [22]. The choice of appropriate Lyapunov function for controller design is a complicated task and requires the deep knowledge about the process.

Singh *et al* [23] developed the control scheme for SAF using an adaptive-linear-element (Adaline)-based current estimator to maintain sinusoidal and unity-power-factor source currents. Three-phase load currents are sensed, and using least mean square (LMS) algorithm-based Adaline, online calculation of weights is performed and these weights are multiplied by the unit vector templates, which give the fundamental-frequency real component of load currents.

Dazhi *et al* [24] developed the PI controller along with the adaptive variable amplitude limiter based on MRAC scheme for SAPF. This paper is mainly based on the DC bus voltage control. Effect of load and system parameter variations on the performance of APF (especially in terms of %THD) is not discussed for the proposed design. Another adaptive control scheme for SAPF is proposed in [26]. Here the DC link voltage is regulated by a PI controller with antiwindup. The phase angle of the power-grid voltage vector θ_s is determined by using a PLL.

This adaptive scheme [26] does not employ the harmonic detection scheme and the compensation requirements are obtained by regulating indirectly the currents of power mains. In this case, the expected controlled grid currents must be sinusoidal, which addresses to control schemes like resonance-based techniques. The amplitude of SAPF reference currents is generated by the DC link voltage controller, based on the active power balance of system. They are aligned to the phase angle of the power mains voltage vector, by using a d-q phase-locked loop system. The current controller is implemented by an *adaptive pole-placement control strategy* integrated to a variable structure control scheme (VS-APPC) in which it introduced the internal model principle (IMP) of reference currents for achieving the zero steady-state tracking error. This results in a controller transfer function with resonance characteristics, which permits more design flexibility. The main feature of such controllers in comparison to the convention resonance-based schemes is that VS-APPC controller gains are determined based on adaptive laws, which employs sliding-mode techniques. This hybrid structure leads to a robust adaptive control strategy with a good dynamic performance.

The supply system for aircraft requires very accurate and sensitive control strategy for shunt active power filter. Use of adaptive control technique for such cases is the appropriate solution for getting the harmonic free supply [28-30].

III. COMPARISON OF SCHEMES

This section presents the comparative analysis of conventional and adaptive control schemes applied to Shunt Active Power Filter (SAPF). In modern power distribution systems, majority of loads are nonlinear in nature and draw reactive power and harmonic currents from the AC source. These nonlinear loads cause low efficiency of the power system, poor power factor, destruction of other equipments due to excessive stresses and EMI problems [2, 31]. In this way non-sinusoidal currents, pollute the utility line due to the current harmonics generated by them. Active power filter (APF) is used to provide reactive power and harmonics compensation for nonlinear loads. SAPF compensates current harmonics by injecting equal but opposite harmonic compensating current.

Development of a suitable controller for APF is the task of prime preference for achieving the best possible results. The fixed gain conventional PI controller has been designed and tested for the constant load condition [2]. Under the variable load condition tuning and design of such conventional PI controller is a difficult task. So the performance of SAPF is not satisfactory with conventional PI controller when the load is increased from its rated value. Under such situation adaptive control schemes are required for SAPF. In this paper the results are compared for the system simulated with fixed gain PI, with

Adaptive controllers (based on MRAC scheme) under steady state and transients to prove the suitability of adaptive controllers in varying conditions.

The three-phase supply voltage is assumed to be balanced and sinusoidal. A load with nonlinear characteristic is considered for the load compensation. The source current (i_s) is equal to the load current (i_L) when the compensator is not connected. The PI controller is properly tuned for the rated load of 1KVA (called as load-1). The compensation property of SAPF is satisfactory (THD is less than 5%) for this value of load. When the load is suddenly incrased (more than the twice of the rated load, (called as load-2) then compensation property of SAPF is badly affected as shown in Fig. 9. There is sudden drop in DC link capacitor voltage (V_{dc}) as shown in Fig. 9 and THD becomes 13.78% which is much beyond the limit imposed by IEEE 519 standards.

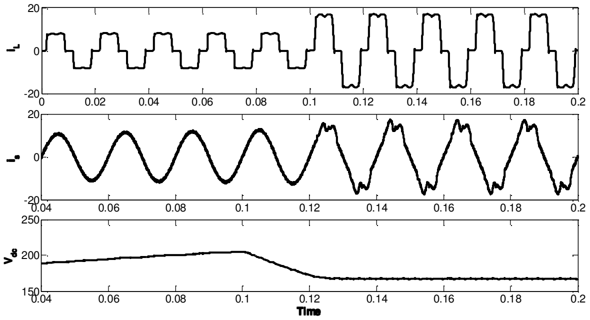

Fig. 9. Uncompensated source current, Compensated source current and DC link voltage with PI controller.

The clear improvement can be observed in performance of SAPF with the application of Adaptive controller (Fig. 10). The THD is reduced from 13.78% to 3.77% in this case and the drop in DC link capacitor voltage is also much less with the increment in load.

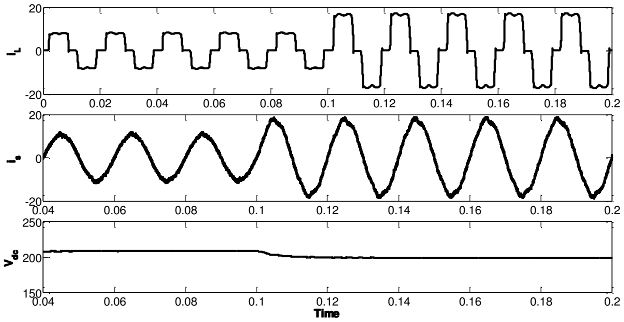

Fig. 10. Uncompensated source current, Compensated source current and DC link voltage with Adaptive Controller.

Table 1: Comparison Between Conventional and Adaptive Controller for SAPF.

	SAPF with Conventional Controller	SAPF with Adaptive Controller
% Drop in V_{dc}	16.8%	4.09%
% THD	1.63% (for Load-1)	3.39% (for Load-1)
	13.78% (for Load-2)	3.77% (for Load-2)

It can be concluded that the Adaptive controller is more effective for compensating the harmonics during the transients as compared to the conventional PI controller. The results are summarized in Table 1.

III. CONCLUSION

This paper presented the detailed theoretical and analytical insight of different adaptive and AI based advanced control schemes used for controlling the Shunt Active Power Filter to improve the power quality on the basis of extensive literature review in this field. All control schemes have their own field of applications with numerous advantages and limitations. However a comparative analysis for conventional and adaptive control schemes is presented in the paper for variable load condition and results are summarized in Table I to provide a quick view to researchers in this area.

REFERENCES

[1]. B. Singh, K. Al-haddad and A. Chandra, (1999). “A review of active filters for power quality improvement”, *IEEE Transactions on Industrial Electronics,* Vol. **46**, No. 5, pp 1-12.

[2]. S.K. Jain, P. Agrawal, H.O. Gupta, (2003). “Design simulation and experimental investigations on a shunt active power filter for harmonics and reactive power compensation”, *Electric Power and Components and Systems, Taylor & Francis Inc*., pp 671-692.

[3]. S.K. Jain, P. Agrawal and H.O. Gupta, (2002). “Fuzzy logic controlled shunt active power filter for power quality improvement”, *IEE Proc. Electrical Power Application*, Vol. **149**, No. 5, pp 317-328.

[4]. An, Luo, Zhikang, Shuai, Wenji, Zhu, Ruixiang, Fan, and Chunming, Tu, (2009). “Development of hybrid active power filter based on the adaptive fuzzy dividing frequency-control method”, *IEEE Transactions on Power Delivery*, Vol. **24**, No. 1, pp 424-432.

[5]. Ahmed A. Helal, Nahla E. Zakzouk, and Yasser G. Desouky, (2009). “Fuzzy logic controlled shunt active power filter for three-phase four-wire systems with balanced and unbalanced loads”, *World Academy of Science, Engineering and Technology*, Vol. **58**, pp 621-626.

[6]. Tsengenes Georgios, Adamidis Georgios, (2011). “Shunt active power filter control using fuzzy logic controller”, *IEEE International Symposium on Industrial Electronics,* pp 365-371, 2011.

[7]. C.N. Bhende, S. Mishra, S.K. Jain, (2006). “TS-Fuzzy-controlled active power filter for load compensation”, IEEE Transactions on Power Delivery, Vol. **21**, No. 3, pp 1459-1465.

[8]. YAN Wen-Xu, JI Zhi-Cheng, HUI Jin, (2009). “Shunt active power filter line current control based on TS Fuzzy model”, *International Conference on Industrial Electronics and Application*, pp 2241-2246.

[9]. Yujia Shang, Aiguo Wu, “TS-Fuzzy-controlled shunt active-power filter for power quality improvement”, *International Conference on Electrical and Control engineering*, pp 1869-1872.

[10]. G.M. Sarhan, A.A. Elkousy, A.A. Hagras, Sh. M. Saad, (2010). “Adaptive control of shunt active power filter using interval type-2 fuzzy logic controller”, *International Middle East Power Systems Conference, Cairo university, Egypt*, December 19-21.

[11]. Karuppanan P, KamalaKanta Mahapatra, (2010). “PLL with Fuzzy logic controller based shunt active power filter for harmonics and reactive power compensation”, India *International Conference on Power electronics*, 2010.

[12]. A. Hamadi, K. Al-Haddad, S. Rahmani and H. Kanaan, (2004). “Comparison of fuzzy logic and proportional integral controller of voltage source active filter compensating current harmonics and power factor”, *IEEE International Conference on Industrial Technology*, pp 645-650.

[13]. Fan Shaosheng and Xiao Hui, (2004). “Diagonal Recurrent Neural Network Based Predictive Control for Active Power Filter”, *International Conference on Power System Technology* – POWERCON, Singapore, pp 759-762, 21-24.

[14]. Huanhuan Li, Xiaozhong Liao, (2005). “A shunt active power filter based on a neural adaptive approach for harmonic current calculation”, *Proceedings of the Fourth China-Japan International Workshop on Internet Technology and Control Applications Hunan, China*, pp 96-98.

[15]. Wang-chonglin, Ma-caoyuan, Li-dechen, Li-xiaobo4, Wang-zhi, Tang-jiejie, (2009). “Study on improved neural network PID control of APF DC voltage”, *International Conference on Information Management, Innovation Management and Industrial Engineering,* pp 179-182.

[16]. Mostafa S. Hamad, Shady M. Gadoue and Barry W. Williams, (2012). “Harmonic compensation of a six-pulse current source controlled converter using neural network-based shunt active power filter”, *IET Power Electron*., Vol. **5**, Issue 6, pp. 747–754.

[17]. T. Narongrit, K.L., Areerak, K.N. Areerak, “Design of an active power filter using genetic algorithm technique”, AIKED'10 *Proceedings of the 9th WSEAS international conference on Artificial intelligence, knowledge engineering and data bases* pp 46-50.

[18]. Charles. S., G. Bhuvaneswari, (2010). “Comparison of Three Phase Shunt Active Power Filter Algorithms”, *International Journal of Computer and Electrical Engineering,* Vol. **2**, No. 1, pp 175-180.

[19]. H. Komurcugil and O. Kulkrer, (2006). “A new control strategy for single phase shunt active power filters using a Lyapunov function”, *IEEE Transaction on Industrial electronics,* Vol. **53**, No. 1.

[20]. M’arcio Stefanello, Jo˜ao Marcos Kanieski, Rafael Cardoso and Hilton Ab´ılio Gr¨undling, (2008). “Design of a robust model reference adaptive control for a shunt active power filter”, *34th IEEE International Conference on industrial electronics*, pp 158-163.

[21]. Kuo-Kai Shyu, Ming-Li Chiang, Yen-Mo Chen, and Yi-Fei Lin (2008). “Model Reference Adaptive control design for a shunt active-power-filter system”, *IEEE Transaction on Industrial electronics,* Vol. **55**, No. 1, pp 97-106.

[22]. M.T. Benchouia, A. Ghamri, M.E.H. Benbouzid, A. Golea, S.E. Zouzou, (2007). “Fuzzy model reference adaptive control of power converter for unity power factor and harmonics minimization”, International Conference on Electrical Machine and System, Seoul, Korea pp 110-113, October 8-11, 2007.

[23]. Bhim Singh, Jitendra Solanki, (2009). “An implementation of an adaptive control algorithm for a three-phase shunt active filter”, *IEEE Transactions on Industrial Electronics*, Vol. **56**, No. 8, pp 2811-2820.

[24]. W. Dazhi, W. Xuming, S. Keling , Li Yiqi, L. Shengli, (2011). “An adaptive control method of shunt active power filter dc bus voltage”, *Second International Conference on Digital Manufacturing & Automation*, pp 172-176.

[25]. Jian Wu, Dian-guo Xu, and Na He, (2005). “Self-tuning fuzzy control for shunt active power filter”, ICIC, Springer, pp. 890–899.

[26]. Ricardo Lucio de Araujo Ribeiro, Christian Cesar de Azevedo, Raphaell Maciel de Sousa, (2012). “A robust adaptive control strategy of active power filters for power-factor correction, harmonic compensation and balancing of nonlinear loads”, *IEEE Transactions on Power Electronics*, Vol. **27**, No. 2, pp 718-730.

[27]. Y. Suresh, A.K. Panda, M. Suresh, (2012). “Real-time implementation of adaptive fuzzy hysteresis-band current control technique for shunt active power filter”, *IET Power Electronics,* vol. **5**, Issue 7, pp. 1188–1195.

[28]. Zhong Chen, Yingpeng Luo, Miao Chen, (2012). “Control and performance of a cascaded shunt active power filter for aircraft electric power system”, *IEEE Transactions on Industrial Electronics*, Vol. **59**, No. 9, pp 3614-3623.

[29]. Haibing Hu, Wei Shi, Ying Lu, and Yan Xing, (2012). “Design considerations for DSP-Controlled 400 Hz shunt active power filter in an aircraft power system”, *IEEE Transactions on Industrial Electronics*, Vol. **59**, No. 9, pp 3624-3634.

[30]. Junyi Liu, Pericle Zanchetta, Marco Degano, and Elisabetta Lavopa, (2012). “Control design and implementation for high performance shunt active filters in aircraft power grids”, *IEEE Transactions on Industrial Electronics,* Vol. **59**, No. 9, pp 3604-3613.

[31]. H. Park, J. Song, and W. M Hosny, (2012). “Comparative study on the position of shunt active power filters in 25 kV AC railway systems,” *IETE Technical Review*, Vol. **29**, no. 5, pp. 421-31.

[32]. Pankaj Swarnkar, Shailendra Jain, R.K. Nema, (2014). “Adaptive Control Schemes for Improving the Control System Dynamics: A Review” *IETE Technical Review (published by Taylor & Francis),* Vol. **31**, No. 1, pp 17-33.

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