CHAPTER 2

LITERATURE SURVEY

2.1 GENERAL

Many researchers focused on the power quality and custom power in the distribution and transmission systems because of widespread use of non-linear loads such as power converters, arc furnaces, gas discharge lighting devices etc. These non-linear loads lead to harmonic or distorted current and reactive power problems. Traditionally passive L-C filters were used to mitigate harmonics. However, the passive filters have the demerits of fixed compensation, bulkiness and occurrence of resonance with other elements (Rathika et al 2010). Recently, active power filters (APF) or active power-line conditioners (APLC) are used for solving these power quality problems. The controller is the most significant part of the APF and currently lot of research is being conducted. Conventional PI and PID controllers have been used to estimate the reference current and control over the dc-bus capacitor voltage of the inverter. However, these controllers require precise linear mathematical model of the system, which is difficult to obtain under parametric variations and load disturbances (Mojtaba et al 2011). Recently, fuzzy logic controller (FLC) and Neural Network controller (NNC) are used in power electronic systems for adjustable motor drives and active power filter applications. For FLCs and NNCs, they do not need accurate mathematical model. They can handle non-linearity and is more robust than conventional controllers (Karuppanan Pitchai Vijaya et al 2011).
2.2 BACKGROUND STUDY

Many literary works dealing with mitigation of harmonics are available in the literature. A review of some of the latest literature works in this topic is discussed in the following. Different control techniques with various controllers used for harmonics elimination are reported in the literature.

Control Schemes for Harmonics Elimination are summarized under four categories. They are

1) Conventional (General) Control Schemes.
2) High Performance feedback Control Schemes.
3) Intelligent Control Schemes.
4) Hybrid Control Schemes.

Around 92 papers have been taken for literature survey in the work and the areas taken can be categorized as in Figure 2.1.

![Figure 2.1 Distribution of Literature Survey](image-url)
2.3 UPS SYSTEMS

Uninterruptable power systems (UPSs) are widely used as backup power for critical loads such as computer and life support systems in hospitals. In such systems, both steady-state performance, such as voltage regulation and total harmonic distortion (THD), and transient performance, such as response to a sudden change in load, are important (Heng Deng et al 2007).

Praveen K. Jain et al (1998) analysed the steady-state and transient performance of a UPS system under different conditions. The input power factor and efficiency as a function of the load level and supply voltage are included. Transient tests such as: 1) supply–battery transition; 2) battery–supply transition; 3) load transients; and 4) supply/battery-voltage transients are also included. A small-signal model of the UPS system is derived to analyse and generalize the experimental transient results. Design guidelines for the key components and controller parameters are also included. Experimental results are obtained on a 1-kVA UPS system.

Ming Tsung Tsai and Chia Hung Liu (2003) presented an improved single-phase passive-standby uninterruptible power supply (UPS) for low-cost applications. The proposed system includes an input rectifier/charger and a switching inverter. It is basically an off-line UPS structure, but has nearly the performance of a line-interactive UPS. It can continuously regulate the sustained voltage swells and sags by injecting a voltage in series with the source voltage in the normal mode, and can be switched smoothly to backup mode when the utility voltage goes outside the specified range, or fails. The regulation range is also larger than conventional off-line and line-interactive UPSs.
Yuedong Zhan et al (2007) developed a 300 W single-phase highfrequency uninterrupted power supply (UPS) with backup proton exchange membrane fuel cell (PEMFC) and battery, DC/AC inverter, DC/DC converter, AC/DC rectifier, and AC/DCrecharger. The principle and structure of the PEMFC/batteryhybrid UPS system are introduced and discussed. Key practical techniques of the design are presented, including the design of the PEMFC generating system, the control technique of the AC/DC rectifier, AC/DC recharger, DC/AC inverter and DC/DC converter based on a microcomputer MC68HC11K4 and other integrated circuit chips. Experimental results show that during the switching process from battery to PEMFC, and vice versa, the UPS can provide an uninterrupted alternate voltage for the load, with lowcost, low weight, small volume and size, great reliability and maintainability.

2.4 CONVENTIONAL (GENERAL) CONTROL SCHEMES

Traditionally passive L-C filters were used to mitigate harmonics. A passive filter is composed of only passive elements such as inductors, capacitors and resistors thus not requiring any operational amplifiers. Passive filters are inexpensive compared with most other mitigating devices (Bindu et al 2012). However it had demerits of aging and tuning, resonance, bulk size and also fixed compensation. Recently, active power filters (APF) or active power-line conditioners (APLC) proposed power-electronic equipment for solving these power quality problems. The APF has the ability to compensate current-harmonics and reactive power simultaneously (Mahalekhmi 2010). But they are not feasible and cost effective for a large-rating nonlinear load due to their high rating requirement. Hybrid series and shunt active filters, characterized by a combination of passive filters and active filers, offer a cost-effective and practical solution for harmonic filtering and harmonic isolation for a large-rated nonlinear load and especially for a group of
nonlinear loads. However, implementation of a hybrid series or hybrid shunt active filter system typically requires a high-bandwidth pulse width modulation inverter (Po-Tai Cheng et al 1998).

Jason Wells et al (2007) have proposed a modulation-based technique for generating pulse waveforms with Selective Harmonic Elimination (SHE). The drawback of this method is the modulation index cannot be set exactly.

Ghennam et al (2008) have proposed a hybrid parallel active filter/offline UPS component for computer loads. The inverter acting as an active filter using the single phase PQ theory control strategy in the active filter mode of operation has achieved harmonic mitigation, reactive power compensation and battery charging. In addition, by employing feedback loop control to provide a pure sinusoidal line current and to regulate the output voltage, they have provided an uninterrupted and reliable power supply in the off-line UPS mode. Zhong Du et al (2008) have presented a reduced switching-frequency active-harmonic-elimination method (RAHEM).

Faiz et al (2009) have proposed a mathematical modeling using three-phase PWM inverter, nonlinear load, control system and multiple-filter for the analysis and design of a system. They have explained the output waveform distortion mechanism of three-phase pulse width modulation (PWM) inverter with nonlinear loads by means of detailed theoretical analysis. A multiple-filter has been employed at the output of the UPS, for eliminating the harmonic components transferred to the load.

Faiz et al (2009) have proposed the dynamic analysis of a three-phase PWM voltage source inverter with the output of multiple-filter in UPS system. They have explained the mathematical model of their proposed filter and the reduction of harmonics in the output waveform because of the use of
multiple-filter has been demonstrated by means of simulation result. Low THD (less than 4%) and low steady-state error have been obtained in the simulation results with linear (resistive) load. Here, the drawback of multiple filters is when the inverter level varies, the filter order gets changed.

The current harmonic compensated by using the Shunt Active Power Filter, Passive Power Filter and the combination of both was proposed by Mahalekshmi (2010). The system has the function of voltage stability, and harmonic suppression. The reference current can be calculated by dq transformation. An improved generalized integrator control was proposed to improve the performance of APF. IGIC is a PI controller used to eliminate error between the filter current and the harmonic current. It consists of several PI controllers. Each controller is tuned to reduce the particular harmonics.

Zainal Salam (2010) has proposed a HEPWM scheme for voltage source inverters (VSI) based on the curve fittings of certain polynomial functions.

2.5 HIGH PERFORMANCE FEEDBACK CONTROL SCHEMES

In recent years, closed-loop regulated pulse-width modulated (PWM) inverters have enjoyed extensive application in many types of ac power conditioning systems such as uninterruptible power supply (UPS), automatic voltage regulator (AVR), and programmable ac source (PACS). In these applications, the PWM inverters must maintain a sinusoidal output waveform under various types of loads, and this is achievable only by employing feedback control techniques. Extensive research has focused on the closed-loop regulation of PWM inverters employing various feedback control schemes to achieve excellent dynamic response and low harmonic distortion. However, most research was concentrated on improving the
transient response through using instantaneous feedback control either by analog or microprocessor-based digital control techniques.

In the deadbeat control approach, the control signal depends on a precise PWM inverter load model, and the performance of the system is sensitive to parameter and load variations. Another drawback of the deadbeat control scheme is that it requires a larger actuating signal to achieve the deadbeat effect. Sliding mode control (SMC) with feed forward nonlinear compensation has been developed for the closed-loop regulation of a PWM inverter. Although the SMC-controlled PWM inverter can achieve fast dynamic response and is insensitive to parameter and load variations, locating a satisfactory sliding surface is extremely difficult. Also, its performance degrades under a limited sampling rate. Applying fuzzy control and optimal state feedback with pole assignment improves the system’s transient responses and its robustness to load variations. Although satisfactory results have been obtained for step-load disturbances, periodic distortions in the output waveform still remain when a rectifier-type of load is connected.

In most ac power conditioning systems, phase-controlled nonlinear loads are major sources of waveform distortion. Due to the periodic characteristics in voltage regulation, this type of nonlinear load results in periodic distortion in its output waveform. Repetitive control theory, which originates from the internal model principle, provides a solution to eliminate periodic errors in a nonlinear dynamic system. A number of modified repetitive control schemes have been developed for use in various industrial applications. Repetitive control theory has also been applied to a PWM inverter employed in UPS systems to generate high-quality sinusoidal output voltage. However, that investigation did not address the synthesis of the repetitive controller, and it has also been limited to fixed-frequency applications.
A predictive instantaneous-current PWM control scheme for reducing ac-side harmonic currents and improving power factor is proposed by Yasuyuki Nishida et al (1997). The rectifier can operate at the unity displacement power factor and has fast response to an input signal as a current reference. The effect of the dc-side voltage ripples is taken into account.

Ying-Yu Tzou et al (1997) proposed a new control scheme based on a two-layer control structure to improve both the transient and steady-state responses of a closed-loop regulated pulse-width modulated (PWM) inverter for high-quality sinusoidal ac voltage regulation. The proposed two-layer controller consists of a tracking controller and a repetitive controller. Pole assignment with state feedback has been employed in designing the tracking controller for transient response improvement, and a repetitive controller scheme was developed in synthesizing the repetitive controller for steady-state response improvement. Design procedure is given for synthesizing the repetitive controller for PWM inverters to minimize periodic errors induced by rectifier-type nonlinear loads. The proposed control scheme has been realized using a single-chip digital signal processor.

Carlos et al (2000) investigated an indirect multivariable model reference adaptive control (MIMO MRAC) algorithm for a three-phase uninterruptible power supply (UPS) using $\alpha\beta0$ transformation. Paolo Mattavelli (2005) proposed a control scheme based on a deadbeat control method both on the output voltage and inductor current, where a state estimator is used for the compensation of the computational delay and a disturbance observer is used for the estimation of the load current and for any other source of errors (such as dead-times, parameter, and model mismatches).
A repetitive-based controller for an uninterruptible power supply (UPS) inverter was proposed by Escobar et al (2007). The repetitive scheme, equivalent to the bank of resonant filters, acts as a refinement term to reject the harmonic distortion caused by the unbalanced and distorted load current, and thus, allowing the UPS inverter to deliver an almost pure sinusoidal balanced voltage.

A new digital deadbeat controller is designed, implemented, and applied to a three-phase series-parallel-line-interactive uninterruptible power supply (UPS) by Adel Nasiri (2007). It provides input power factor correction, output voltage conditioning, and high efficiency. The proposed controller adjusts the current of the parallel converter and voltage of the series converter with two and four sampling periods, respectively. A reduced-parts topology is also introduced that has less number of power electronics components as well as switching functions.

Jose Rodriguez et al (2007) presented a predictive current control method and its application to a voltage source inverter. The method uses a discrete-time model of the system to predict the future value of the load current for all possible voltage vectors generated by the inverter. The voltage vector which minimizes a quality function is selected. The quality function used in this work evaluates the current error at the next sampling time. The performance of the proposed predictive control method is compared with hysteresis and pulse width modulation control. Allag et al (2007) presented an adaptive back stepping control law to the three phase PWM converter for the control of uncertainties of system parameters.

Reza Salehithe et al (2011) have discussed that the quality of the low order harmonics in a broad variety of modulation indexes has been improved by selective harmonic elimination pulse width modulation (SHEPWM). Generally feasible solutions do not exist for all values of M for
the equations associated with SHEPWM. Destructive harmonics like 5th harmonics exists as a result of this. So, they have proposed to avoid solving the equations associated with higher order harmonics. The degrees of freedom have increased as a result of the decrease in the number of eliminated harmonics. Consequently the lower order harmonics have been eradicated in more number of operating points. Thus, the values of modulation index (M) for which the 5th harmonic becomes zero has been increased. Further, the equations have been satisfied for all values of M.

A multiple-feedback-loop control scheme can be utilized to achieve good dynamic response and low total harmonic distortion (THD). Such a scheme is essentially developed from linear system theory. When the loads are nonlinear, the performance degrades. Recently, a number of digital feedback control schemes have also been developed for PWM inverters. Although the performances of these schemes are good, the complicated algorithms and the heavy computational demands make the implementations difficult.

2.6 INTELLIGENT CONTROL SCHEMES

The lack of intelligence, learning and adaptation capability in the control methods discussed in general control schemes reveal the need for continuous expert intervention for the control of nonlinear systems. Conventional controllers require precise linear mathematical model of the system, which is difficult to obtain under parametric variations and load disturbances. Hence intelligent controllers are used power electronics applications with nonlinear loads.

An analogue neural-network controller for UPS inverter applications was presented by Xiao Sun et al (2002). The proposed neural-network controller is trained off-line using patterns obtained from a simulated
controller, which had an idealized load-current-reference. Simulation results show that the proposed neural-network controller can achieve low total harmonic distortion under nonlinear loading condition and good dynamic responses under transient loading condition. Performance of the proposed NN Controller was verified using a hardware inverter with an analogue neural network (NN) controller (using mainly operational amplifiers and resistors).

A novel concept of application of Artificial Neural Networks (ANN) for generating the optimum switching functions for the voltage and harmonic control of DC-to-AC bridge inverters is presented by O. Bouhaliet al (2005). A new training algorithm is developed without using the desired switching angles but it uses the desired solution of the elimination harmonic equation, i.e. first harmonics are equal to zero. Theoretical analysis of the proposed solving algorithm with neural networks is provided, and simulation results are given to show the high performance and technical advantages of the developed modulator.

Rajarajeswari and Thanushkodi (2008) introduced a novel Bidirectional DC-DC converter with artificial neural network controller (ANN). Bidirectional power flow is obtained by the same power components and provides a simple, efficient, and galvanically isolated converter. In the presence of DC mains the converter operates as buck converter and charges the battery. When the DC main fails, the converter operates as boost converter and the battery feeds the load. In both the modes the power switches are controlled by PWM technique and the PWM pulses are generated by application of ANN controller.

The use of artificial intelligence in gate signals control in PWM voltage source inverter (VSI) is tackled, analyzed, and implemented by Basil M. Saied et al (2008). The PWM technique that investigated is the Selective Harmonic Elimination (SHE). For this technique, the single phase H-
bridgeinverter is considered for the study. In the SHE based inverter, the fundamental voltage level and the harmonics selected for deletion are decided using a neural network and fuzzy logics. For the SHE technique, the results of generating switching angle patterns, using the neural and the fuzzy model controllers, for driving H-bridge inverter, show almost exact resemblance, compared to those obtained using conventional controllers. Also the superiority at the intelligent models overcome the problem of delay time and has fast response in selecting and generating the PWM patterns required to regulate the inverter output voltage. Here, the NN based fuzzy rules were affected by any interference problem.

Mohamed S. A. Dahidah and Vassilios G. Agelidis (2008) proposed a generalized formulation for selective harmonic elimination pulse-width modulation (SHE-PWM) control suitable for high-voltage high-power cascaded multilevel voltage source converters (VSC) with both equal and non-equal dc sources used in constant frequency utility applications. This proposes a generalized formulation for selective harmonic elimination pulse-width modulation (SHE-PWM) control suitable for high-voltage high-power cascaded multilevel voltage source converters (VSC) with both equal and non-equal dc sources used in constant frequency utility applications. This formulation offers more degrees of freedom for specifying the cost function without any physical changes to the converter circuit, as compared to conventional stepped waveform technique, and hence the performance of the converter is greatly enhanced. The paper utilizes the merits of the hybrid real coded genetic algorithm (HRCGA) in finding the optimal solution to the nonlinear equation system with fast and guaranteed convergence. It is confirmed that multiple independent sets of solutions exist. Different operating points for both five- and seven-level converters including single and three-phase patterns are documented.
Perumalla (2009) and Rathika et al (2010) have proposed a fuzzy logic controlled shunt active power filter capable of reducing the total harmonic distortion is developed. The instantaneous p-q theory is used for calculating the compensating current. Fuzzy-adaptive hysteresis band technique is adopted for the current control to derive the switching signals for the voltage source inverter. The fuzzy-adaptive hysteresis band current controller changes the hysteresis bandwidth according to the supply voltage and the slope of the reference compensator current wave. A fuzzy logic-based controller is developed to control the voltage of the DC capacitor.

Nayeripour et al (2010) have proposed a nonlinear fuzzy controller to regulate the modulation index of voltage source converter (VSC), which is used to control the grid Volt/Var in an uninterrupted power supply (UPS) application. The UPS has been used to control the voltage at the Point of Common Coupling (PCC). The switching harmonics has been eliminated by linking a LC filter at the output of the VSC. In the fuzzy controller, a fuzzy rule-base defined on PCC voltage error \((e=V_0-V)\) of the point of common coupling has been used to determine the value of modulation index of VSC.

Al-Othman et al (2010) have discussed that equal and constant dc sources supplied multilevel inverters hardly exist in realistic applications. The switching angles necessary for each distinct harmonic profile have been affected and the complexity of the harmonic elimination’s equations has been increased by the variation of the dc sources. Tanaka's fuzzy linear regression formulation has been utilized for obtaining a high-speed optimal solution of harmonic eradication in multilevel inverters with non-equal dc sources. For representing the general output waveform of the multilevel inverter using non-equal dc sources a set of mathematical equations has been formulated. Subsequently, the optimal solution set of switching angles has been computed.
by employing fuzzy linear regression. However, the fuzzy regression model is only applicable for linear optimization problem.

Reza Salehi et al (2011) proposed a system in which the selective harmonic elimination pulse width modulation (SHEPWM) switching strategy has been applied to multilevel inverters to remove low order harmonics. Naturally, the related equations do not have feasible solutions for some operating points associated with the modulation index (M). However, with these infeasible points, minimizing instead of eliminating harmonics is performed. Thus, harmful harmonics such as the 5th harmonic remains in the output waveform. Therefore, it is proposed in this paper to ignore solving the equation associated with the highest order harmonics. A reduction in the eliminated harmonics results in an increase in the degrees of freedom. As a result, the lower order harmonics are eliminated in more operating points. A 9-level inverter is chosen as a case study. The genetic algorithm (GA) for optimization purposes is used. But, the harmful harmonics such as the 5th order harmonic was still remains in the output waveform.

Mohamed Azab (2011) has proposed PSO based SHE technique for controlling PWM inverter. But, it is difficult for adapting undefined switching angles using the proposed PSO based harmonic elimination technique. Albert et al (2011) have proposed a technique, which eliminates the harmonics by generating negative harmonics with switching angles calculated for selective harmonic elimination method. However, the SHE method was incompetent in producing optimal switching angle.

Perumal and Nanjudapan (2011) presented an optimal solution for eliminating pre specified order of harmonics from a stepped waveform of a multilevel inverter topology with equal dc sources. The main challenge of solving the associated nonlinear equation which are transcendental in nature and therefore have multiple solutions is the convergence of the relevant
algorithms and therefore an initial point selected considerably close to the exact solution is required. The paper describes an efficient genetic algorithm that reduces significantly the computational burden resulting in fast convergence. An objective function describing a measure of effectiveness of eliminating selected order of harmonics while controlling the fundamental component is derived. The performance of cascaded multilevel inverter is compared based on computation of switching angle using Genetic Algorithm as well as conventional Newton Raphson approach. A significant improvement in harmonic profile is achieved in the GA based approach. A nine level cascaded multi-level inverter is simulated in MATLAB Simulink and a prototype model has been fabricated to validate the simulation results.

Avik Bhattacharya and Chandan Chakraborty (2011) derived an integration of predictive and adaptive control techniques for fast convergence and reduced computations. Two ANN-based controllers are used for such purpose. The predictive controller generates the first estimate of the compensating current quickly after the change in load is detected. The change in voltage across the capacitor is used for this purpose. This is followed by an adaline-based controller to fast converge to the steady value.

Also, Venkatramanan et al (2012) have proposed SHE-PWM control for cascaded voltage source multilevel inverter based on GA optimization. There was no absolute assurance that the GA will find the global optimum solution.

2.7 HYBRID CONTROL SCHEMES

If a system requires, two or more different control methods should be combined according to its dynamic characteristics or the inner process involved, this concept is widely known as hybrid control. In power systems, there are many applications considered by some authors like voltage
regulators or reactive power controllers where hybrid control shows good results and operation (Chamorro et al 2010). Hybrid systems are those which combine other intelligent methods such as neural networks and genetic algorithms with the fuzzy logic. Hybrid controllers get the benefit of neural network as well as fuzzy logic systems and it removes the individual disadvantages by combining them on the common features.

The evaluation of active power filter which is controlled by fuzzy logic and neural network based controller for harmonic mitigation and power factor enhancement was proposed by Suresh Kumar et al (2008). The APF consists of a variable DC voltage source and a DC/AC inverter. The task of an APF is to make the line current waveform as close as possible to a sinusoid in phase with the line voltage by injecting the compensation current. The compensation current is estimated using adaptive neural network. Using the estimated current, the proposed APF is controlled using neural network and fuzzy logic. Computer simulations of the proposed APF are performed using MATLAB. The results show that the proposed techniques for the evaluation of APF can reduce the total harmonic distortion less than 3% and improve the power factor of the system to almost unity.

Bhoopal et al (2009) have proposed a neural and neuro-fuzzy controller for improving the transient response and adaptableness of the inverters of Uninterruptible Power Supplies (UPS) to a range of loads. Example patterns for training the networks have been obtained by constructing idealized load-current feedback controller. The off-line training of the selected neural and neuro-fuzzy networks has been made as simple as possible to decrease the calculation time by using example patterns under diverse loading conditions. Each time, the mean square error between the desired output and actual output has been made less than the predefined value by updating the weights and biases of neural network (NN) parameters of
adaptive node in Adaptive neuro-fuzzy inference system (ANFIS), using the back propagation algorithm. The UPS inverter online has been regulated online using the neural and neuro-fuzzy controllers, once the training has been completed.

KaruppananPitchaiVijaya and KamalaKantaMahapatra (2011) presented a novel Fuzzy Logic Controller (FLC) in conjunction with Phase Locked Loop (PLL) based shunt active filter for Power Line Conditioners (PLCs) to improve the power quality in the distribution system. The active filter is implemented with current controlled Voltage Source Inverter (VSI) for compensating current harmonics and reactive power at the point of common coupling. The VSI gate control switching pulses are derived from proposed Adaptive-Fuzzy-Hysteresis Current Controller (HCC) and this method calculates the hysteresis bandwidth effectively using fuzzy logic.

Fuzzy logic and artificial neural network current controllers are proposed by Chennai Salim et al (2011) to control the three-phase three-wire shunt active filter with two different control strategies: synchronous reference frame detection algorithm based on fuzzy controller and synchronous current reference detection method based on ANN controller. Fuzzy Logic and PI controller for inverter is proposed by Ismail Atacak (2011).

Mridul Jha et al (2011) describes the application of a novel neuro-fuzzy based control strategy which is used in order to improve the Active Power Filter (APF) dynamics to minimize the harmonics for wide range of variations of load current under various conditions. To improve dynamic behavior of a three phase four-wire shunt active power filter and its robustness under range of load variations, adaptive hysteresis band with instantaneous p-q theory is used with the inclusion of neural network filter for reference current generation and fuzzy logic controller for DC voltage control.
2.8 CONCLUSION

A Detailed literature survey has been made in the areas of UPS Systems, Different Control Schemes for Harmonics Elimination which include Conventional (General) Control Schemes, High Performance feedback Control Schemes, Intelligent Control Schemes and Hybrid Control Schemes. It is clear from the literature survey that High Performance feedback Control Schemes such as deadbeat control approach, Repetitive control scheme, Predictive control scheme, Sliding mode control scheme, SHEPWM along with Intelligent controllers such as fuzzy logic, neural network, neuro-fuzzy controllers etc. provide a good performance for the mitigation of harmonics in UPS application with non-linear loads. High Performance feedback Control Schemes with Hybrid controllers is an emerging technology today and lesser works have been reported in the literature survey.