# Investigations on Dynamic Performance of Hybrid Shunt Active Power Filter Strategy for Power Quality Enhancement Using PI Controller and Neural Learning Algorithm for Three Phase Three Wire Distribution System

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***Abstract:*** *this paper investigates the dynamic behaviour of the hybrid shunt active power filter strategy for mitigating the voltage harmonics and the current imperfections for three phase three wire distribution system. The unit vector template generation control technique is designed as a DC link voltage controller for the hybrid shunt active power filter strategy. The PI controller is designed to estimate the rated source current magnitude from the error between the actual and reference DC link voltage. The transient period and peak overshoot of DC link voltage using PI controller is observed to be high in initial and load change conditions. This paper explores the application of artificial intelligence on reducing the transient period and peak overshoot of DC link voltage. In this paper, a neural learning algorithm is proposed for the DC link voltage of the shunt active power filter strategy. To validate the efficiency and reliability of the proposed system is designed and tested in the MATLAB / Simulink environment.*

***Keywords:*** *Power Quality, Power Factor, Total Harmonic Distortion, Neural Learning Algorithm, Real Power, Reactive Power, True Power.*

## 1. Introduction

The innovation of power electronics technology has brought great awareness on power quality of the power system in the recent years. The sophisticated usage of power electronic devices has incorporated with the electrical loads, power converters, measuring instruments, electronic controller has increased the pollutions in the power transmission and distribution system. These power electronics based loads have behaved as non linear loads and generate the unwanted current and voltage harmonics in the power system network [1-3]. These unwanted current and voltage harmonics have caused over heating, reduced life time, acoustic noise emission, pulsating torque in the electrical machines, malfunction of equipments and radio interference. These effects are very expensive for the customer, ranging from minor quality variations to production downtime. All this interest has resulted in a variety of devices have introduced to mitigate power disturbance like voltage and current harmonics [4-6].

Traditionally, the passive filters have used to compensate the current harmonics and to improve the power factor of the system. But these conventional methods have a lot of disadvantages such as tunning problem, creates series and parallel resonance [7]&[8]. To overcome these problems series and shunt active power filter topologies have been introduced [9-11]. However, these active power filter topology suffered from the high volt-ampere rating of the system. The hybrid active power filter topology is the combination of the passive filter and active power which gave a suitable solution for the above mentioned problems [12] and [13]. On the other hand, the hybrid active power filter topology is a cost effective way of the harmonic mitigation for the nonlinear loads.

A number of control techniques for the shunt active power filter strategy have presented in the literature [14-17]. The unit vector template generation (UVTG) is a familiar time domain based control techniques designed and analyzed in this paper. The advantage of the unit vector control technique is that is simple to implement, easy to analyze and it has high reliability on the compensation of the power quality problems. In this control technique, the proportional and integral PI controller is tuned to extract the rated magnitude of the source current. However, the drawbacks of this method are the peak overshoot and the settling time of the DC link voltage is observed to be high which leads to poor compensation on the power quality problem. In order to solve this problem, a neural learning algorithm is proposed in this paper.

This paper investigates the performance of a hybrid shunt active power filter strategy on compensating power quality issues. The power quality for before and after connecting the hybrid shunt active power filter is carried out. The neural learning algorithm is proposed to regulate the DC link voltage of hybrid shunt active power filter strategy. The performance of a hybrid shunt active power filter strategy with PI controller and neural learning algorithm is investigated for different operating conditions.

A general introduction to the problem of power quality is presented the in introduction, the configuration of three phase three wire hybrid shunt active power filter strategy is represented in section 2, the control technique for the DC link voltage controller using a PI controller and the neural learning algorithm is discussed in the section 3 and 4 respectively, a mathematical approach to quantity the technique benefits of power quality is proposed elaborated in the section 5, the simulation results for quantifying the proposed system is brought out in section 6, finally the conclusions of this paper finds a place in section 7.

## 2. The Shunt Active Filter

The topology for the hybrid shunt active power Filter connected to the nonlinear system is highlighted in Fig. 1. The hybrid shunt active power filter topology is used to compensate the current related problems like current harmonics, power factor improvement, reactive power compensation and voltage harmonics. It consists of a voltage source converter with a DC link capacitor and it is connected in parallel at the point of common coupling (PCC) acts as a current source inverter. The point of common coupling is present in between the source and the critical load. The hybrid shunt active filter topology detects the harmonics produced by the load and injects the harmonics in the opposite direction at the PCC. The injected harmonics cancel the harmonics present in the system and thereby THD% is considerably reduced, the power factor is improved and the reactive power consumption by both the linear and nonlinear load is minimized thereby improving the power quality of the entire system. The control technique for the hybrid shunt active power filter topology is discussed in the following sections.

## 3. Control Technique used in Active Shunt Filter

The control technique used to regulate the DC link voltage at rated voltage for the hybrid shunt active power filter strategy is the unit vector template generation technique (UVGT) [2]. The voltage across the DC link capacitor is sensed by voltage sensor and compared with the reference DC voltage value. The error is computed by this comparison. The PI controller or neural learning algorithm estimates the input current magnitude from the computed error. The reference current is the product of an estimated current magnitude and unit vector calculated from the source voltage by the phase lock loop. The harmonics produced by the nonlinear load is extracted by subtracting the source current from the reference current and it is fed to the hysteresis current controller. The pulses produced from the hysteresis current controller are fed to the converter. Then the converter injects the harmonics to the system at PCC and thereby reduces the harmonics presented in the system and improves the power quality of the system. The block diagram for a control technique used in the current controller is represented in Fig. 2. The following section deals with the neural learning algorithm.

## 4. NEURAL LEARNING ALGORITHM

The compensation of total harmonic distortion purely depends on the generation of reference current. The adaptive property of the artificial neural - network (ANN) is the abilities of real-time learning, flexibility, parallel computation and is used to generate fast reference current for the current controller of shunt active power filter strategy. The two layer ANN is trained on line by using the proposed learning algorithm in order to generate reference current. The neural network for the proposed learning algorithm is highlighted in Fig. 3.The inputs of the network are error, integral of error and feedback output signal. In general, each on-line training epoch consists of propagating the ANN input vector to compute its output, comparing this output with a reference voltage to compute the training error, and finally modifying the ANN weights in such

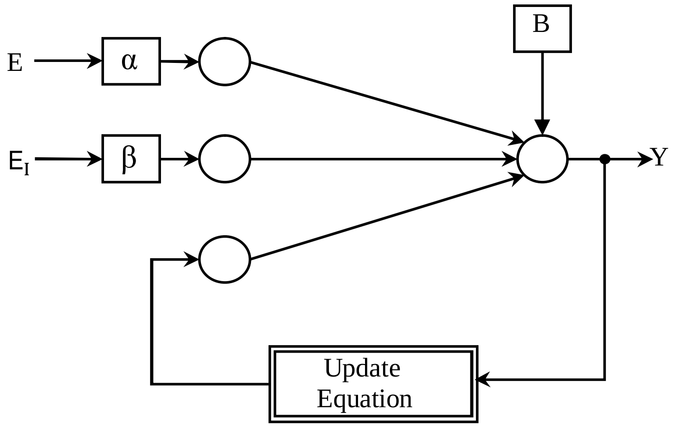

Fig. 3. Neural Learning Network

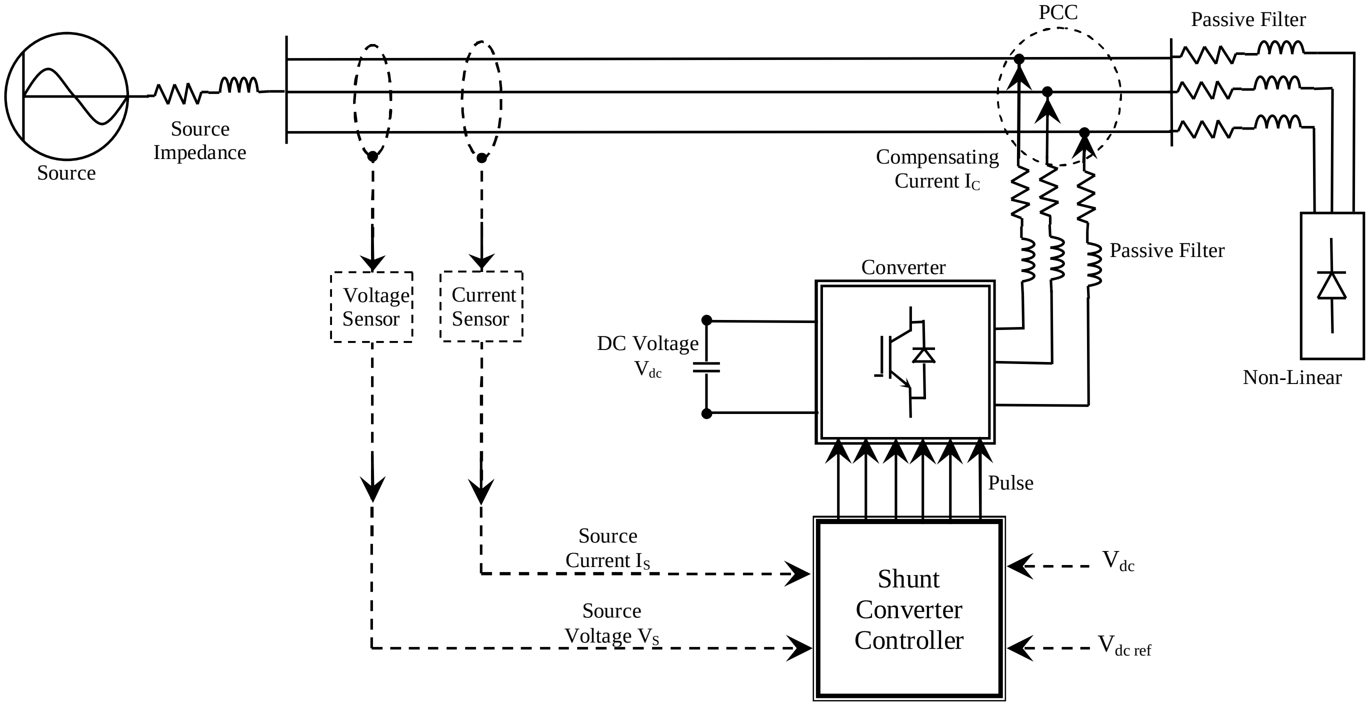

Fig 1. Topology for hybrid Shunt Active power Filter

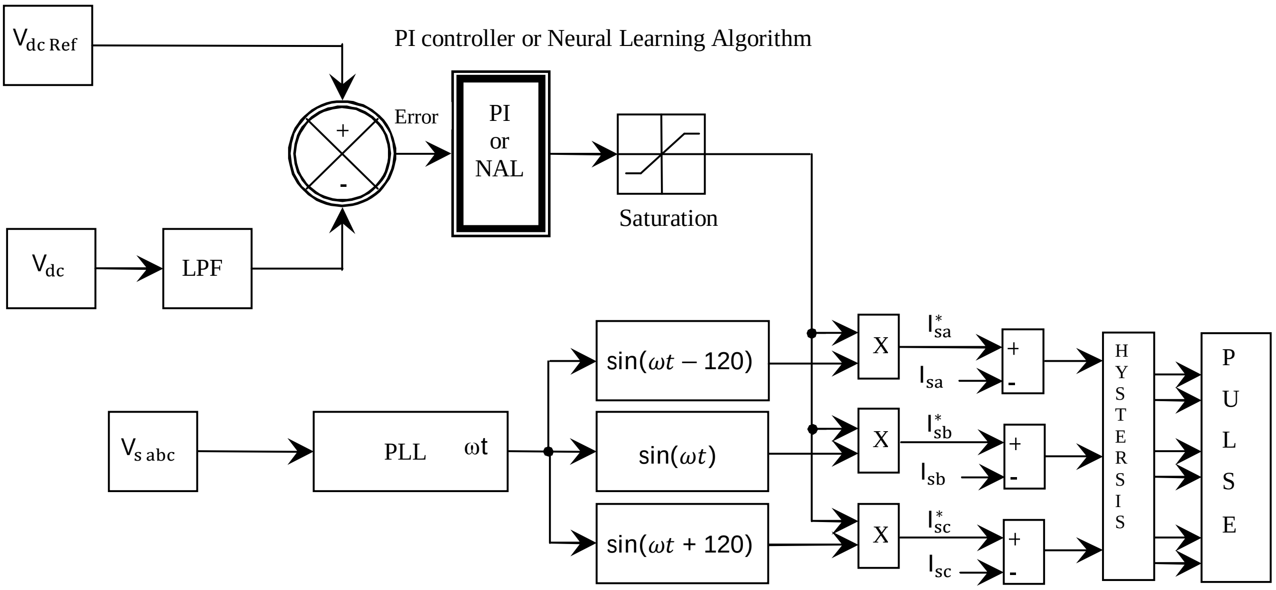

Fig 2. Block Diagram for Unit Vector Template Generation technique

a way as to reduce the error magnitude to obtain optimum value. Likewise, difference of actual DC voltage and reference DC voltage is compared with error tolerant. The weight of the each input neuron is trained in order to minimize the error and generate the optimum reference current magnitude with minimum oscillation.

## 5. MATHEMATICAL MODELLING OF THE NONLINEAR SYSTEM

The three phase source voltage of the system has been formulated as follows

$$V_a(t) = V_m \sin(\omega t) \quad (1)$$

$$V_b(t) = V_m \sin(\omega t + 120) \quad (2)$$

$$V_c(t) = V_m \sin(\omega t - 120) \quad (3)$$

Before compensation, the source current is equal to the load current and it contains both the fundamental and the harmonic current component.

$$I_s(t) = I_l(t)$$

$$I_s(t) = I_1 \sin(\omega t + \phi_1) + \sum_{n=1,3}^{\infty} I_n \sin(n\omega t + \phi_n) \quad (4)$$

$I_1 \sin(\omega t + \phi_1)$ = fundamental component

$\sum_{n=1,3}^{\infty} I_n \sin(n\omega t + \phi_n)$ = harmonics component

Before compensation, the source current contains harmonics produced by the nonlinear load which increases the power loss of the system and also affects the electrical equipment and loads connected to this system. The main purpose of using the hybrid shunt active power topology is to mitigate the harmonics produced by the nonlinear load. In order to mitigate the harmonics, the control technique used in the hybrid shunt active power filter strategy is forced to generate the harmonics present in the system in opposite direction at the point of common coupling. This injected harmonics cancel the harmonics produced by the nonlinear load and keep the source current normal harmonic distortion limit. This analysis is carried out based on the following mathematical modelling.

The source current of the nonlinear system after connecting hybrid shunt active power filter strategy is derived to be

$$I_s(t) = I_{sh}(t) + I_l(t) \quad (5)$$

In order to keep the source current free from the harmonic mean the shunt active power filter current or compensating current is the harmonic current in opposite direction given as

$$I_{sh}(t) = -I_h(t) = -\sum_{n=1,3}^{\infty} I_n \sin(n\omega t + \phi_n)$$

After injecting the compensating current, the source current is observed to be

$$I_s(t) = -\sum_{n=1,3}^{\infty} I_n \sin(n\omega t + \phi_n) + I_l(t)$$

$$I_s(t) = -\sum_{n=1,3}^{\infty} I_n \sin(n\omega t + \phi_n) + I_1 \sin(\omega t + \phi_1) + \sum_{n=1,3}^{\infty} I_n \sin(n\omega t + \phi_n)$$

$$I_s(t) = I_1 \sin(\omega t + \phi_1)$$

After mitigating harmonics, the voltage and current observed to be in phase with each other. Hence the angle between voltage and current is found to be zero, then the source current became

$$I_a(t) = I_m \sin(\omega t) \quad (6)$$

$$I_b(t) = I_m \sin(\omega t + 120) \quad (7)$$

$$I_c(t) = I_m \sin(\omega t - 120) \quad (8)$$

### 5.1 Modelling for reference current extraction using PI controller

In general, the control technique designed in the hybrid shunt active power filter strategy is used to extract the reference signal for compensating current harmonics which are given as

Reference signal = DC voltage Error* controller*Unit Sine signal

$$I_{sref}(t) = (V_{dcref} - V_{dc}) * (K_p + \frac{K_I}{s}) * \sin(\omega t) \qquad (9)$$

where

$(K_p + \frac{K_I}{s})$ is PI Controller

$(V_{dcref} - V_{dc})$ is error

$\sin(\omega t)$ is unit vector

So the reference signal for three phase signal is obtained as following equations

$$I_{sref\_a}(t) = (K_p + \frac{K_I}{s}) * (V_{dcref} - V_{dc}) * \sin(\omega t) \qquad (10)$$

$$I_{sref\_b}(t) = (K_p + \frac{K_I}{s}) * (V_{dcref} - V_{dc}) * \sin(\omega t + 120) \qquad (11)$$

$$I_{sref\_c}(t) = (K_p + \frac{K_I}{s}) * (V_{dcref} - V_{dc}) * \sin(\omega t - 120) \qquad (12)$$

### 5.2 Modelling for reference current extraction using the neural learning algorithm

The reference current extraction using a neural learning algorithm is derived as follows

Let $E = V_{dc\,Ref} - V_{dc}$ be error (13)

EI be Integral of error

$a_{1\ to\ 5}$ be constants used to train the neural network

Y(K) be the output of artificial neural network

W(K) and CW(K) be the weight and change in weight of the learning algorithm

The output and update equation of the artificial neural network is represented in the following equations

$$Y(k) = a_1 * W(k-1) + \alpha * CW(k-1) + a_2 * CW(k) + a_3$$

$$CW(k) = \gamma * (a_4 * E(K) + a_5 * EI(K)) \qquad (14)$$

The Reference current extraction using a neural learning algorithm for three phase can be given as

$$I_{sref\_nn\_a}(t) = Y(k) * \sin(\omega t) \qquad (15)$$

$$I_{sref\_nn\_b}(t) = Y(k) * \sin(\omega t + 120) \qquad (16)$$

$$I_{sref\_nn\_a}(t) = Y(k) * \sin(\omega t - 120) \qquad (17)$$

Hence the harmonic current fed to the hysteresis current controller for generating pulse to the inverter is given as

$$I_{ha}(t) = I_{sref\_a}(t) - I_{sa}(t)$$

$$I_{hb}(t) = I_{sref\_b}(t) - I_{sb}(t)$$

$$I_{hc}(t) = I_{sref\_c}(t) - I_{sc}(t)$$

Design of DC capacitor

The DC link capacitor has used to maintain a DC voltage with minimum ripple in both steady and dynamic state and also an energy storage element has used to supply real power difference between load and source. The real and reactive power injection may result in the ripple voltage of DC capacitor. The selection of DC link capacitor can be governed by reducing the voltage ripple content. The energy stored in a DC link capacitor can be represented by

$$E = \frac{1}{2} C (V_{dc})^2 \qquad (18)$$

$$C_{dc} = \frac{\pi * I_{c,rated}}{\sqrt{3} * \omega * V_{dc},} \qquad (19)$$

## 6. SIMULATION RESULTS AND DISCUSSION

A. System data and analysis

1. Supply Voltage = 230Vrms
2. Supply Frequency = 50 Hz
3. Source Impedance = 1 Ohms and 0.1mH

**4.** Load –Rectifier RL Load, R=7Ohms and

5. Operating Condition

1- Before and After connected SAPF- at 0.5sec SAPF connected

2- Load change Condition - Performance Comparison between PI and NLA based SAPF –0.3 to 0.5sec –another R=7Ohms and L=20mH load is added on DC side Rectifier Load.

### 6.1 Analysis of compensation of power quality problems for before and after connecting shunt active power filter strategy

This analysis is carried out to ensure the aptitude of shunt active power filter strategy on mitigating current harmonics, the power quality for non linear load has investigated for before and after connecting the shunt active power filter strategy. The simulation results for before and after connecting shunt active power filter strategy is shown in the Fig. 4. The hybrid shunt active power filter (HSAPF) is turned on at time 0.5 sec such that the DC link voltage is started to tack the reference DC link voltage. The compensation of power quality problems for before and after 0.5 second is briefly discussed below.

The source voltage and current is distorted for before connecting HSAPF strategy and its correspond THD is observed to be 8.14% and 30.92% respectively. After 0.5 sec, the hybrid shunt active power filter is started to inject the compensation current is shown in Fig.4. An interesting point is to observe that the THD of source voltage and current is observed to be mitigated while after DC link Voltage is maintained at rated value. This investigation has proven that the settling time DC link voltage is the time required for mitigating the power quality problems. After compensation, the THD of source voltage and current is found to be 0.88% and 3.42% respectively. From this analysis, after connecting the HSAPF 89.18% of source voltage THD and 89.93% of source current THD are minimized. The THD of source voltage and current comparison of three phase system for before and after compensation is tabulated in Table 1 and 2.

### 6.2 Performance comparison of hybrid shunt active filter strategy using the PI controller and Neural Learning Algorithm

In this section, the performance of the hybrid shunt active filter strategy is evaluated using the PI controller and Neural Learning Algorithm. The performance of the hybrid shunt active filter strategy has depended on regulation of the DC link voltage. The settling time of DC link voltage determines the time required for compensation of the current harmonics and other power quality problem. So the settling time and peak overshoot of the DC link voltage using PI and neural learning algorithm are analysed and compared.

#### 6.2.1 Analysis of DC link voltage using a PI controller and the neural learning algorithm

The parameter of the DC link voltage has played a vital role in improving the filtering performance of

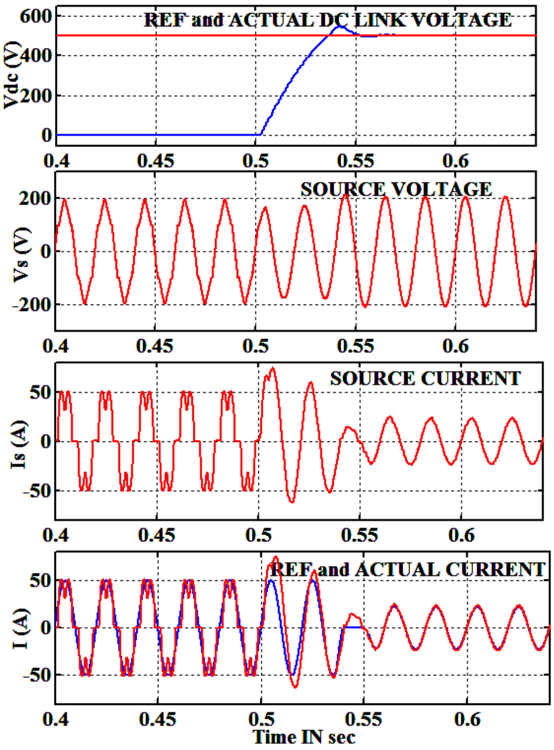

Fig. 4. Simulation results for power quality analysis for before and after connecting HSAPF

passive filter and compensating the power quality problems. The settling time and peak overshoot of the DC link voltage have determined the time required for the compensation of current harmonics and to maintain the unit power factor. And also the magnitude of the DC link voltage is the important parameter in determining the quality of the compensation of current and voltage harmonics. The dynamic performance of DC link voltage using PI and NLA for initial and step load change conditions are illustrated in the Fig. 5. The peak overshoot and settling time of DC link voltage using a PI controller is observed to be 25.1% and 170 msec respectively for initial condition. This result demonstrates the time required for the compensation of current harmonics is after 170 msec. This time is sufficient to affect the performance of the load and power quality of the grid. To reduce the settling time of the DC link voltage, a neural learning algorithm is proposed. From the obtained result, the peak overshoot of the DC link voltage using a neural learning algorithm is found to be 0.5% and settling time is observed to be 50 msec. From this analysis, using a neural learning algorithm the peak overshoot of DC link voltage is reduced to 98% and 120 msec faster settling compared to PI controller. The performance of DC link voltage during load change conditions are compared in table 4 and 5.

### 6.2.2 Analysis the relation between total harmonic distortion and DC link voltage using a PI controller and the neural learning algorithm

The relation between THD of source current and DC link voltage is analyzed using the both PI and neural learning algorithm and represented in the Fig. 6. The value of the DC voltage determines the performance of filter on compensating the harmonics. The characteristic between THD and DC voltage helps to determine the optimal value of DC link voltage. From the characteristic it is observed that the THD of current is reduced with increase of DC voltage. The minimum value of THD of the source current voltage is observed at the point of 500 DC voltages. The parameter of DC voltage has greatly affected the power rating of the system.

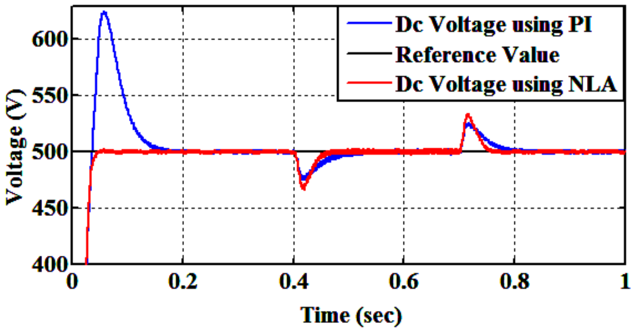

Fig. 5. Dynamic response of DC link voltage using PI and NLA

This analysis demonstrates the time required for reducing the current harmonics by using a PI controller and a neural leasing algorithm. From the obtained result, the time required to reduce the current harmonic distortion using a PI controller is observed to be 170 msec whereas the time required to reduce the current harmonic distortion using the neural learning algorithm is noticed to be 70msec. This investigation proves that the compensation of current harmonic using neural learning algorithm is found to be 100 msec faster than PI controller.

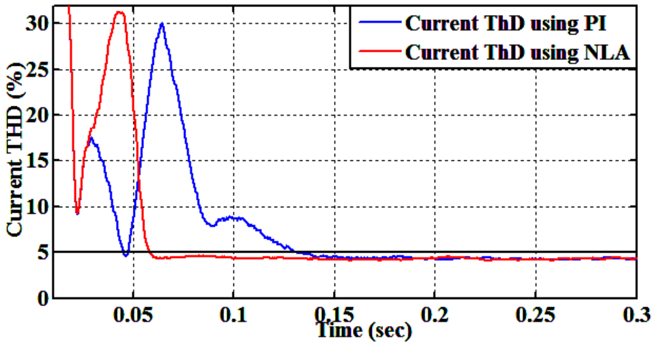

Fig. 6. Waveform for Characterstics between source current ThD using PI and NLA

### 6.2.3 Analysis of compensation of source voltage and current harmonic distortion by SHAPF using a PI controller and the neural learning algorithm

The dynamic response of the source voltage waveform with shunt active power filter strategy using a PI controller and a neural learning algorithm for normal and load change condition is highlighted in the Fig. 7- A and B. From the obtained results, settling time and ThD of source voltage using a PI controller are observed to be 130 msec and 0.86% respectively whereas source voltage using neural learning algorithm settling time and ThD of are found to be 70 msec and 0.87% respectively. From this analysis, settling time of source voltage using NLA is 60 msec faster than PI controller.

The dynamic waveform of the source current for shunt active power filter using a PI controller and neural learning algorithm for normal and load change condition is highlighted in the Fig. 7-C and D. From the obtained results, settling time and THD of the source voltage using a PI controller is noticed to be 180 msec and 0.86% repectively whereas source voltage using a neural learning algorithm settling time and THD of is found to be 60 msec and 0.87% respectively. From this analysis, settling time of the source current using NLA is 120 msec faster than PI controller.

### 6.2.4 Analysis of tracking of actual current and reference current of SHAPF using PI and NLA

The performance of tracking of actual current and reference current of shunt active power filter strategy using a PI controller and a neural learning algorithm is highlighted in Fig. 8. For best performance of the control technique is that the actual signal must track reference signal and this analysis is demonstrated in this section. The reference current signal has fundamental component of source current and the actual source current contains both fundamental and harmonic components. The difference of reference current and actual current gives the harmonic current. The detected harmonics are fed to the hysteresis current controller. The performance compensation of current harmonics and to regulate the DC link voltage is depended on the tracking of actual and reference current of the hybrid shunt active power filter strategy. The actual and reference current of shunt active power filter strategy using a PI controller is observed to be tracked after two cycles and both currents are found to be settled at 150 msec. While using a neural learning algorithm the actual current is tracked the reference current within two cycles and both currents are settled at 60 msec. This analysis demonstrates the hybrid shunt active power filter strategy has better performance using a neural learning algorithm compared to PI controller.

### 6.2.5 Analysis of power consumption of a nonlinear load using HSAPF strategy

In this section, the power consumption by the load for before and after compensation is analyzed and also the performance analysis of shunt active power filter strategy on compensation of power consumption using the PI controller and a neural learning algorithm is carried out. Normally, power consumed by the load is measured from the product of voltage and current. However, before compensation the source current contains both the fundamental and harmonic component and the power consumption of the nonlinear load is given as

$$P(t)=V_m \sin(\omega t)*\left(I_1 \sin(\omega t+\phi_1)+\sum_{n=1,3}^{\infty} I_n \sin(\omega t+\phi_n)\right) \qquad (20)$$

Power Consumed= Real power + Reactive Power + Harmonic Power

Due to the presence of harmonic and reactive power, the power consumption of the load is found to be high for before compensation. While after connecting the hybrid shunt active power filter strategy, the harmonic current and reactive current are mitigated from the system so that source current is contained only fundamental component and harmonic components are brought to zero. The power consumption of the load after compensation is measured from the following equation.

$$P(t)=V_m \sin(\omega t)*(I_1 \sin(\omega t+\phi_1))$$

However after compensation, the voltage and current are found to be in phase with each other. The angle between voltage and current is observed to be approximately zero, then the power equation became

$$P(t)=V_m * I_1 * \sin^2(\omega t) * \cos(\phi_1) \qquad (21)$$

The simulation results for power consumption by the load for before and after connecting hybrid shunt active power filter strategy is highlighted in the Fig. 9-A. The comparison of power consumption for before and after compensation is tabulated in table3. Also the power consumption of the load using the hybrid shunt active power filter strategy for PI and

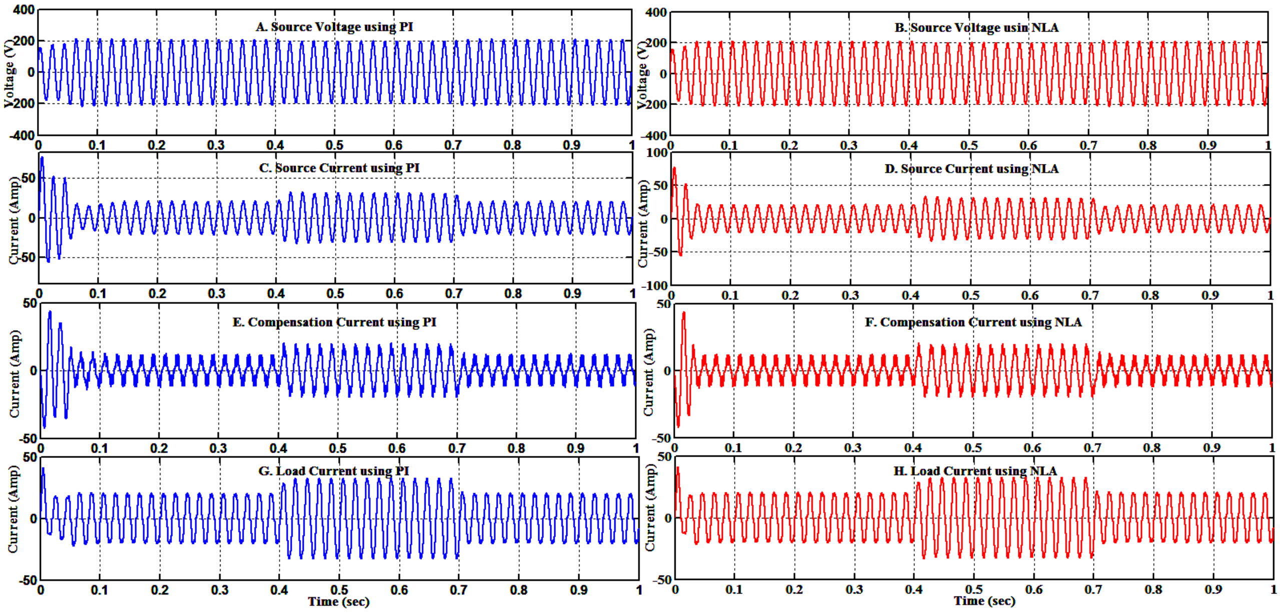

Fig.7. Waveform for the source voltage and current, compensation current and load current for SAPF using PI and NLA

Table 1 THD % comparison of voltage for before and after connected HSAPF

| Phases | Voltage THD | | |
|---|---|---|---|
| | Before compensation (%) | After compensation (%) | Reduced in (%) |
| Phase A | 8.14 | 0.88 | 89.18 |
| Phase B | 8.10 | 0.89 | 88.57 |
| Phase C | 8.14 | 0.80 | 90.17 |

Table 1 THD % comparison of voltage for before and after connected HSAPF

| Phases | Current THD | | |
|---|---|---|---|
| | Before compensation (%) | After compensation (%) | Reduced in (%) |
| Phase A | 30.92 | Phase A | 30.92 |
| Phase B | 30.94 | Phase B | 30.94 |
| Phase C | 30.84 | Phase C | 30.84 |

Table 1 THD % comparison of voltage for before and after connected HSAPF

| Power | Power consumption by load | | |
|---|---|---|---|
| | Before compensation (%) | After compensation (%) | Reduced in (%) |
| Real | 8390 | Real | 8390 |
| Reactive | 146 | Reactive | 146 |
| True | 8391 | True | 8391 |

Table 4 comparison of settling time of DC voltage for HSAPF using PI and NLA

| Operation condition | Settling Time | | |
|---|---|---|---|
| | PI (sec) | NLA (sec) | Quick response (sec) |
| I | 0.16 | 0.06 | 0.1 |
| II | 0.1 | 0.06 | 0.04 |

Table 5 comparison of peak overshoot of DC voltage for HSAPF using PI and NLA

| Operation condition | peak overshoot | | |
|---|---|---|---|
| | PI (%) | NLA (%) | Reduced (%) |
| I | 29.65 | 0.25 | 99.15 |
| II | 7 | 6.9 | 1.43 |

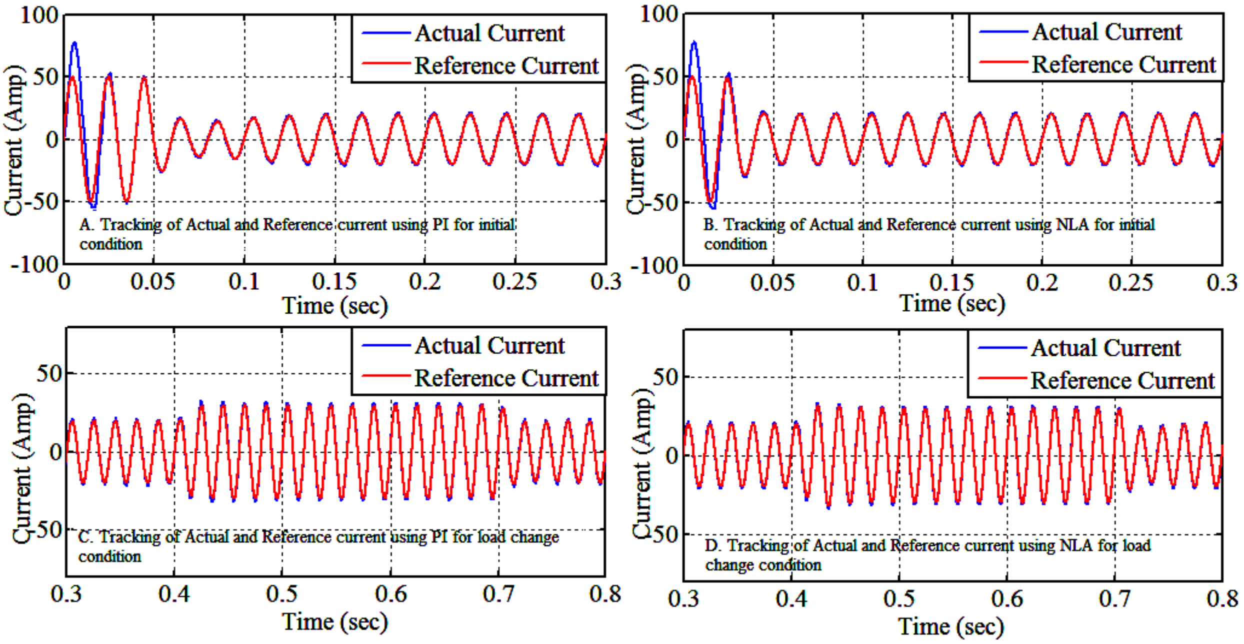

Fig.8. waveform for tracking of actual and reference current for normal and load change condition using PI and NLA

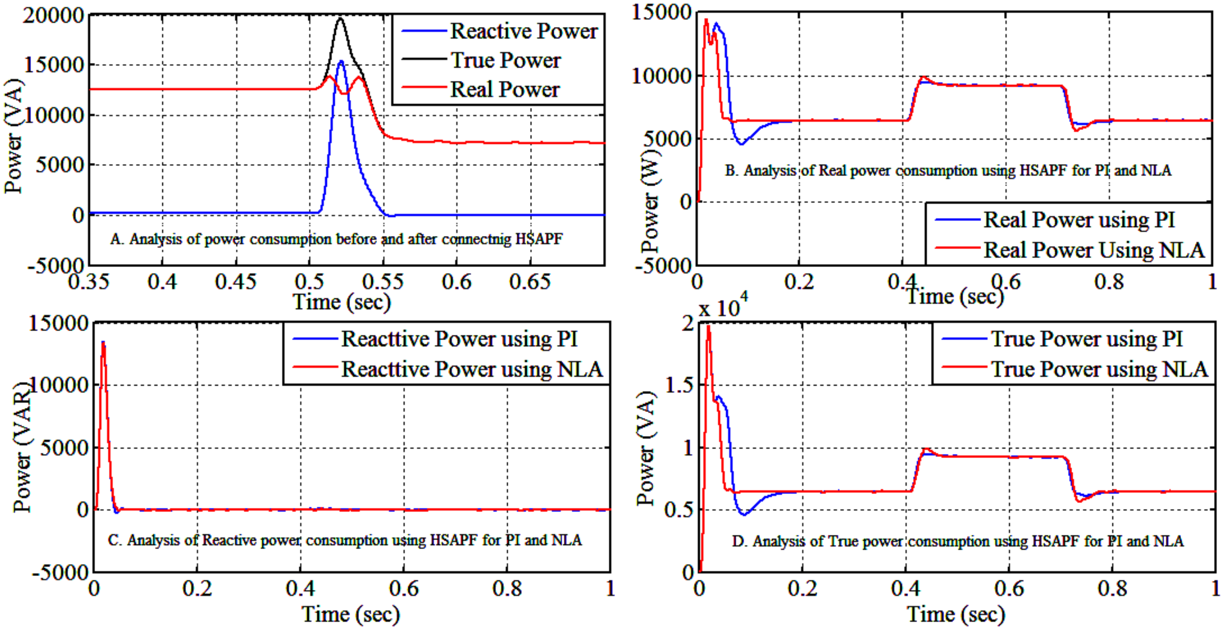

Fig.9. Waveform for the real, reactive and true power consumption by load using SAPF for PI and NLA

the neural learning algorithm is analyzed. From this analysis, the magnitude of power consumption for both PI and NLA is found to be same whereas settling time of power using a PI controller is found to be 180 msec but using NLA, the settling time of power is observed to be 60 msec. This analysis demonstrates that the power consumption by load using NLA is quickly settled compared to PI controller. The simulation result for analysis of real, reactive and true power consumption by load using PI and NLA is shown in Fig. 9 –B,C,D respectively.

## 7. CONCLUSION

This paper investigates the dynamic behaviour of the hybrid shunt active power filter strategy for the management of inherent issues of power quality of three phase three wire distribution system has been investigated in this paper. The proposed hybrid shunt active power filter strategy has reduced the power consumed by the non linear load and also power factor of the system has maintained in unity. The unit vector template generation technique is designed as DC link voltage controller for the hybrid shunt active power filter strategy. The settling time and peak overshoot of the DC link voltage using a PI controller is noticed to be high in initial and load change condition. The proposed neural learning algorithm has reduced the settling time and peak overshoot and also improved the performance of the hybrid shunt active power filter strategy. To verify the effectiveness of the proposed neural learning algorithm based hybrid shunt active power filter strategy is tested for different operating conditions. The better computation efficiency of the proposed approach has shown that it can be applied to a wide range of power quality problems. The test results have bought out the advantage of the hybrid shunt active power filter for power quality enhancement.

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