

POWER QUALITY IMPROVEMENT USING SHUNT ACTIVE POWER FILTER WITH HYBRID NON-LINEAR CONTROLLER IN THREE PHASE FOUR WIRE FOR DIODE LOAD

¹K. R. SUGAVANAM

¹Research Scholar, Anna University, Chennai

¹sugavanamkr@gmail.com.

²Dr. K. MOHANASUNDARAM

²Professor, Vel Tech MultiTech Dr. Rangarajan Dr.

Sakunthala Engineering College. ,

²kumohanasundaram@gmail.com.

³Dr. N.R Shanker

³Professor,

Aalim Muhammed Salegh College of Engineering, ³nr_phd@yahoo.co.in

Abstract: This paper describes the reactive power compensation and harmonic reduction in non-linear load with help of Hybrid Non-Linear Controlled (HNLC) Shunt Active Power Filter (SAPF) in three phase four wire system. The diode load is tested with hybrid controller for harmonic reduction in 3 Φ , 4wire system. The SAPF contains control loop namely hysteresis current loop for current shaping inner loop and the voltage regulation of DC link controlled by outer loop. The outer loop is selected as HNLC such Sliding Mode Control (SMC) plus Proportional Integral Controller (PIC) and Fuzzy Logic Controller (FLC) plus Proportional Integral Controller (PIC). HNLC and synchronous reference frame theory receive the reference current for inner current loop indirectly. The performance of HNLC is validated at various load operating conditions by creating the Matrix Laboratory (MATLAB)/ Simulink.

Key words: 3 phase 4 four systems, hybrid controller, active filter, power quality, MATLAB/Simulink.

1. Introduction

In power system the Total Harmonic Distortion (THD) is plays vital role. The non-linear loads produce harmonics and injected to power system such as diode and power electronics devices. Overheating, malfunction in sensitive devices, power losses and damage the equipments due the harmonic infection in power system. As per the IEEE 519-1992 harmonic standard THD elimination should be smaller than 5%. In order to

minimize these problems, many of the methods were surveyed [1-2]. From this reports, disadvantages of passive filter are complex in filter size, resonance and instability via. load conditions. Shunt and series Active Power Filter (APF) overcomes the drawbacks of passive filters. A series APF compensate the voltage harmonics and fed to load. But this approach could not compensate the current harmonics in the load. The second method shunt APF is compensate reactive power and current harmonics of fundamental component [3]. Therefore, in this document is selected shunt APF for 3 phase four wire power system for study. Many current controller and voltage controller used in shunt APF to overcome the problems in design and control methodology [3-8]. However, from literature survey of these articles, hybrid controller techniques with 3 Φ , 4wire system has not been designed. The repetitive control method for shunt APF is well produced [9]. Synchronous rotating reference frame theory and shunt compensator based control techniques taken for experimental analysis [10]. However this article tells about hysteresis current controller uses to shaping the current and compensation and also the PI controller which improves the regulation of the DC link capacitor voltage. Various analyses of current injection techniques for shunt APF is well presented for shunt APF [11-12]. The FLC with shunt APF has been given [13-14]. From the literature survey, in FLC the reference current generation calculations has been more obscure and more transcends in D.C link voltage of VSI. The

drawbacks are resolved by proposed Hybrid Non-Linear Controlled (HNLC) for shunt APF. Therefore, in proposed method the HNLC shunt APF for power quality enhancement in 3Ø four wire power system. Here, Sliding Mode Controller (SMC) plus PIC and FLC plus PIC is used as HNLC for designed system. The designed model is verified by making MATLAB/Simulink at various operating conditions as well as load.

2 Design of Hybrid Non-Linear Controlled Shunt APF

The shunt APF is controlled the source current compensation from/to the utility. A shunt APF eliminates a current harmonic on the grid side and builds in phase between source current and voltage. A shunt APF is contains filter inductances and controlled feedback current source converter which is depicted in fig 1. The VSI output voltage from D.C link capacitors voltage is regulated with help HNLC.

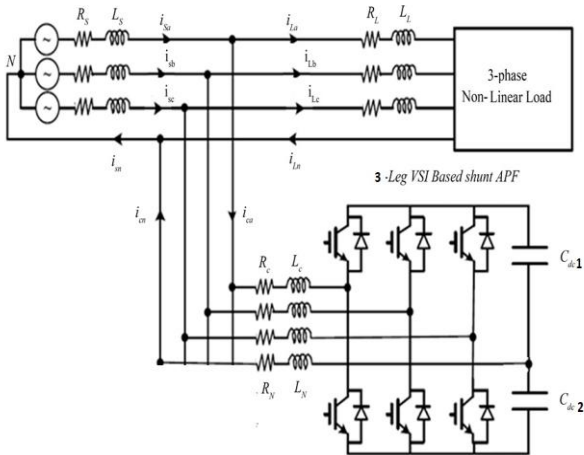


Fig. 1. 3 phase, 4 wire, Shunt APF with Traction Non-linear load

Shunt APF reference current generated from synchronous reference frame theory called as direct-quadrature-zero transformation. In this view, the direct-quadrature-zero transformation (d-q axis) is computed by the angle θ used in the d-q theory. One of the merits in this technique is the angle θ is computed instantly from the supply voltages and making this method frequency individualistic.

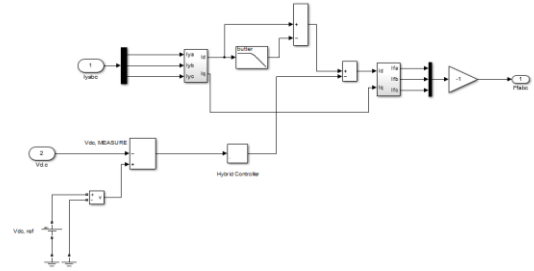


Fig. 2. Synchronous reference frame theory for generation of reference current

HNLC eliminate the synchronizing problems with distorted, imbalanced main voltage. Thus with frame theory a wide frequency range can be attained for operation. After, from the park transformation the load currents i_d-i_q are evaluated, the i_d-i_q pass through a high pass filter which eliminates the DC components presented in nonlinear load currents shown in Fig.2.

3. Design of HNLC shunt APF

The improvements of power quality parameters by the HNLC shunt APF. HNLC is selected as a compound of PI plus FLC and PI plus SMC which regulates the D.C link voltage of shunt APF. Inner hysteresis current controller (HCC) loop is generating PWM pulses to shape the source current and reduce the harmonics in source current. The reference current for HCC is obtained from d-q theory method.

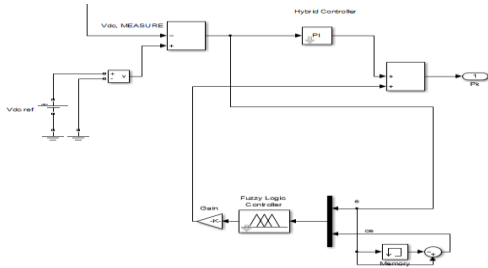
3.1. PI controller

A controller is generally provides a perfect D.C link capacitor voltage of shunt APF voltage regulation and steady state error suppressed form it. The controller parameters proportional gain (K_p) and integral times (T_i) are found using the Zeigler – Nichols tuning technique ($K_p=0.6$ and $K_i=500$).

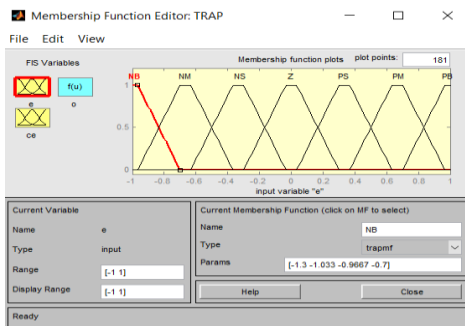
3.2. Design of fuzzy logic controller

The FLC introduced which has more benefits over linear controller are that it not requires any complex structure of mathematical models, which are always absolutely necessary for favorably complex non-linear models. The FLC use to learning the reasoning ability based on the error and human experience of the model [13].The

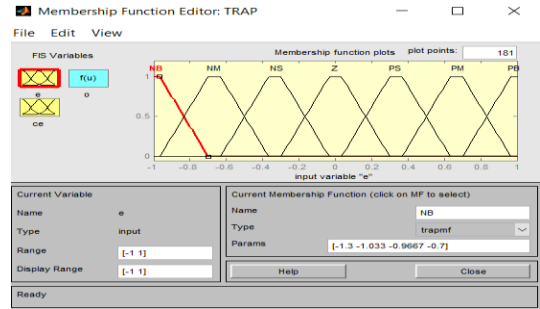
pictorial representation of the FLC for shunt APF is shown in Fig. 3. In this article, the sugeno-type FLC is applied as an outer voltage circuit to modulate the switches of the VSI. The applied inputs and output of the FLC for the shunt APF is depicting in Fig. 3(a) to 3(c). The voltage error (e) and its change in error (ce) of this converter is applied as a input the FLC and the output is o (mark the control signal for the power switches of the converter). For convenience, the arithmetic values of the inputs as well as the output of the FLC may be standardized and showed in Figs.3b, 3c and 3d ($o = [-0.5 -0.4 -0.3033 0 0.4 0.3033 0.5]$) and its equivalent fuzzy rule sets are [NB, NM, NS, Z, PS, PM, PB] where, NB (negative big), NS (negative small), Z (zero), PS (positive small), PM (positive medium), PB (positive big), respectively. The trapezoidal membership functions of the e , ce , and o are illustrated in Fig. 3. The assortment of FLC sets is totally depends on dynamic characteristics of the proposed shunt APF. In the proposed method 49 fuzzy rules are framed (Table 1). The most efficient defuzzification method is weighted average method. This method applied to close the FLC design.



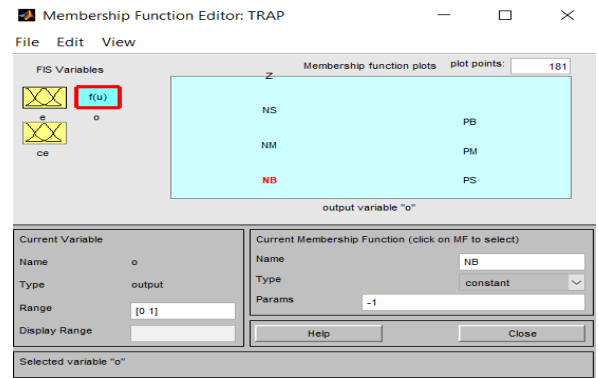
(a) Simulink model of HNLC for shunt APF



(b) error membership function



(c) change in error membership function



(d) output memberships function

Fig.3 of HNLC for shunt APF

TABLE. I FUZZY RULE BASE TABLE OF SHUNT APF

$e \backslash ce$	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	PM	PM	NB	NS	NM	NB
NS	NB	NB	NB	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	NB
PS	NM	NS	NM	PS	PS	PM	PB
PM	NS	Z	PS	PM	PM	NB	PB
PB	Z	PS	PM	PB	NM	PB	PB

3.3. Sliding Mode Controller

SMC simulation introduces a signum function for the current with two values: $I_{d, \max}$ and $I_{d, \min}$. SMC algorithm is given in equation (1).

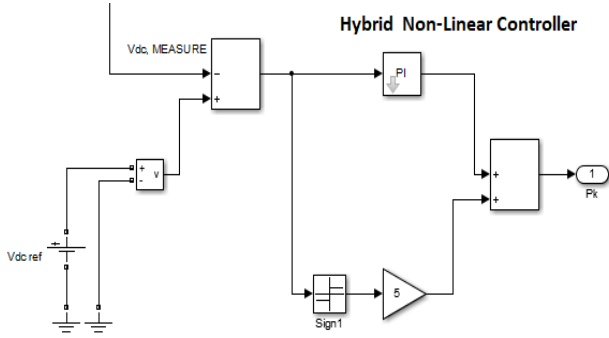


Fig. 4. Simulink model SMC plus PI controller for shunt APF.

The simulation result for the D.C link voltage of shunt APF is given in the Fig. 4.

$$i_d = \begin{cases} i_{d,min} & \Delta V_{dc} > 0 \\ i_{d,max} & \Delta V_{dc} < 0 \end{cases} \quad (1)$$

Where,

$$\Delta V_{dc} = V_{dc} - V_{dc,ref}$$

4. Simulation Study and Discussions

The simulation study and analysis of HNLC shunt APF at different operating conditions and its specifications are listed in Table 2. Fig. 5 and 6 show the MATLAB/Simulink model of the designed model.

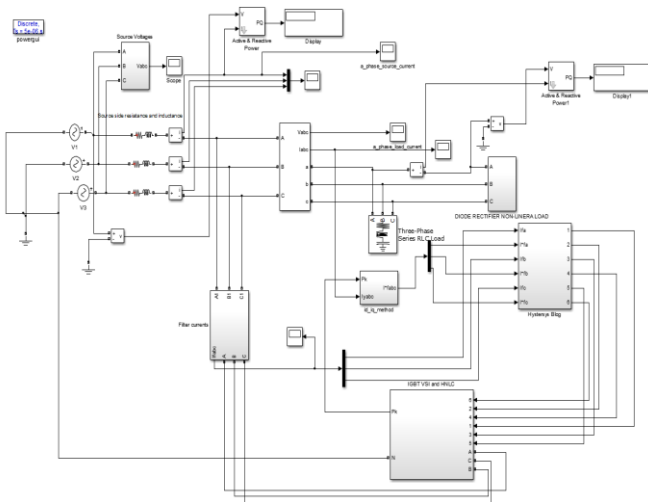


Fig.5. Simulink model HNLC for shunt APF.

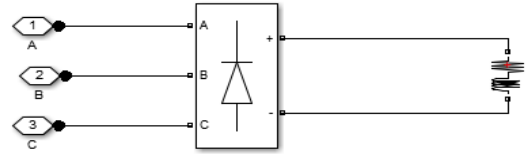


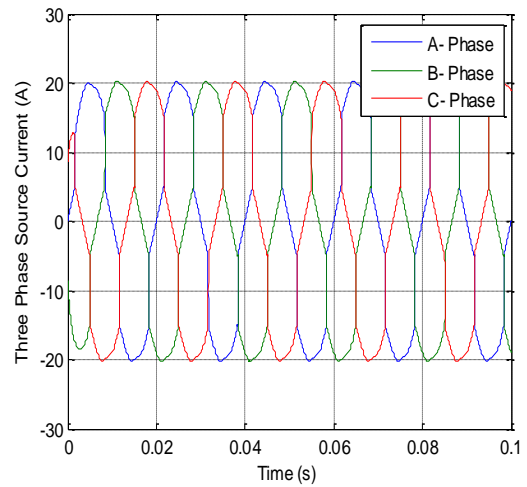
Fig.6.Simulink model of Diode rectifier non-linear load.

Table.2. Circuit parameters of designed shunt APF

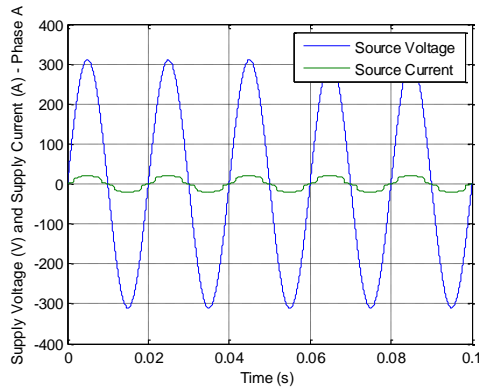
Parameters name	Numerical value
Voltage/Ø	220V, 50 Hz
Capacitor V_{ref} & $C1=C2$	3000µF, 800V
Source Resistance (R_s) & Inductance(L_s)	0.01 Ω, 0.1e-3H
Diode Rectifier load with R and L	50Ω, 60 mH
Filter values(L_F), (C_F)	0.1 ohm, 1mH
Switching frequency	1KHZ

4.1. Diode load without Shunt APF

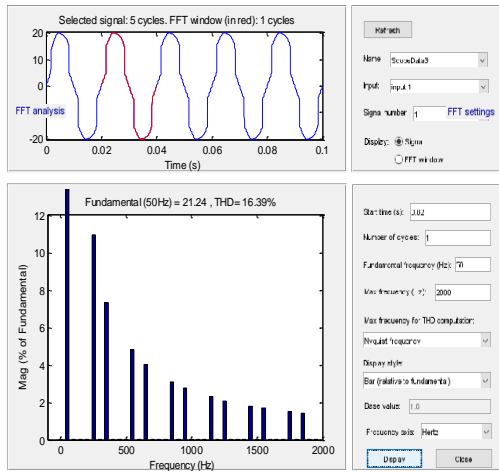
The fig. 7 show the simulation responses of current, voltage, THD analysis and load current of 3 phase, 4 wire system without shunt APF for non-linear uncontrolled diode rectifier inductive reactance load. The simulation result proves the THD of the power system without filter has been 16.39% for diode rectifier load.



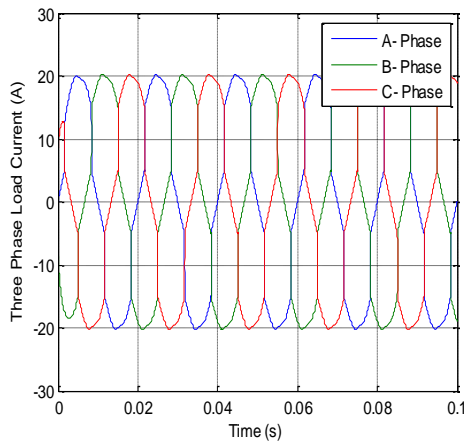
(a) Source current



(b) Source voltage and current



(c) THD analysis



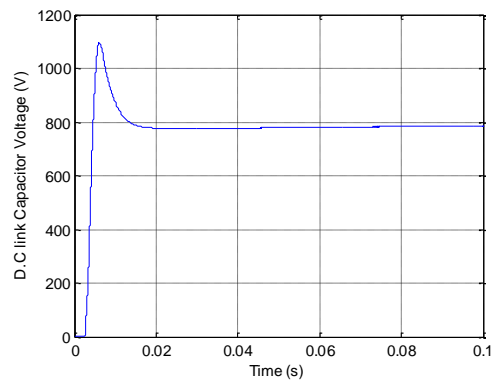
(d) Load current

Fig. 7. Simulation results of 3 phase, 4 wire power system without shunt APF for non-linear diode rectifier R-L load

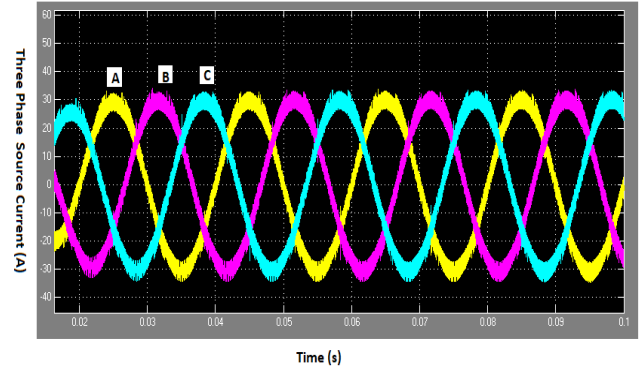
4.2. Shunt APF for diode rectifier load using PI controller plus HCC

The fig 8. show the simulated responses of source current, source voltage, THD analysis, compensated filter current, D.C link capacitor

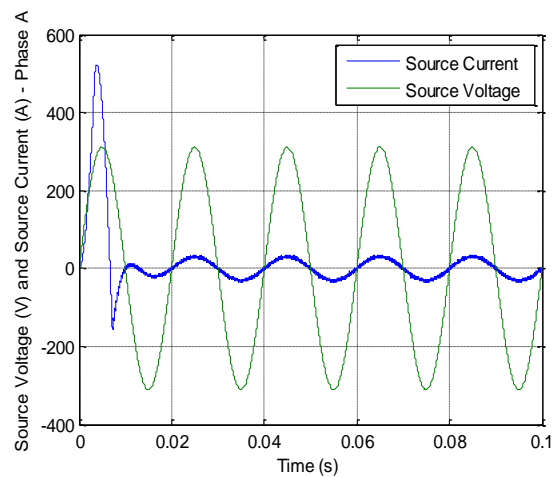
voltage and load current of 3 phase, 4 wire power system using shunt APF for non-linear diode rectifier R-L load with PI controller plus HCC. From these results, it is found that THD of the power system with filter has 5.28% for diode rectifier load. Also, the settling time of D.C link capacitor voltage is quick with small transient overshoots with this controller at the load conditions.



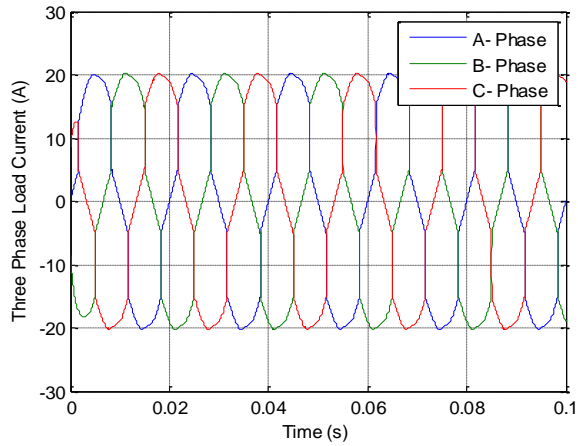
(a) D.C link capacitor voltage



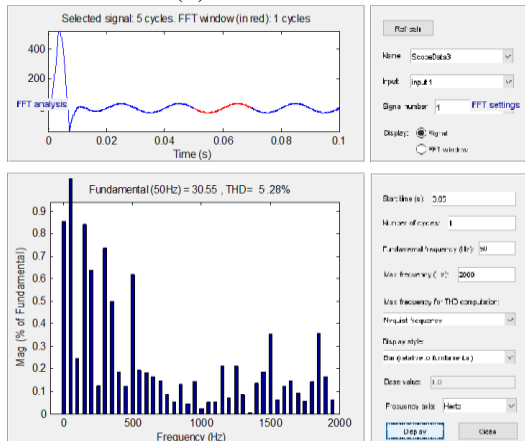
(b) Source current



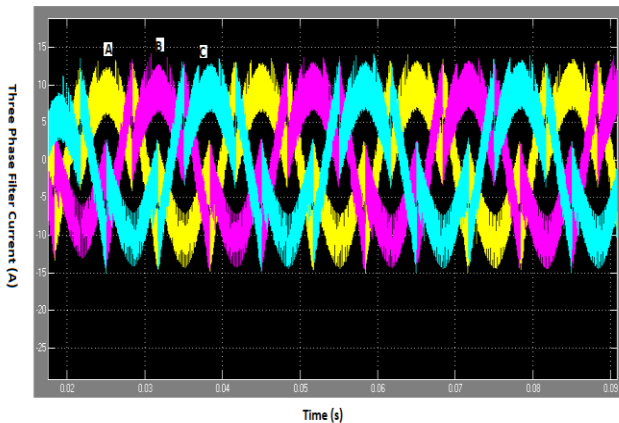
(c) Source current and voltage



(d) Load current



(e) THD analysis



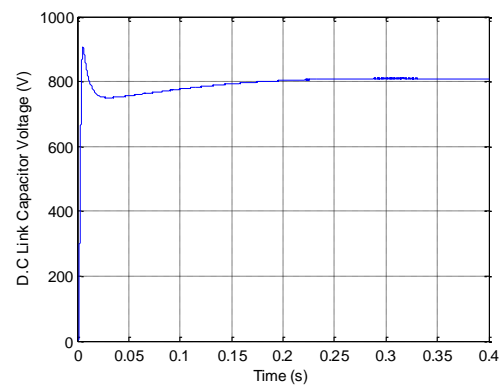
(f) Compensated filter current

Fig.8. Simulation results of 3 phase, 4 wire power system with shunt APF for diode rectifier load using PI controller plus HCC

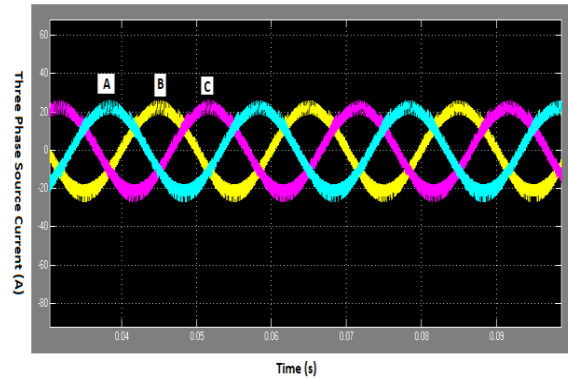
4.3. Shunt APF with FLC plus PI controller (HNLC) and HCC

The fig.9.shows the simulated responses of source current, source voltage, THD analysis, compensated filter current, D.C link capacitor

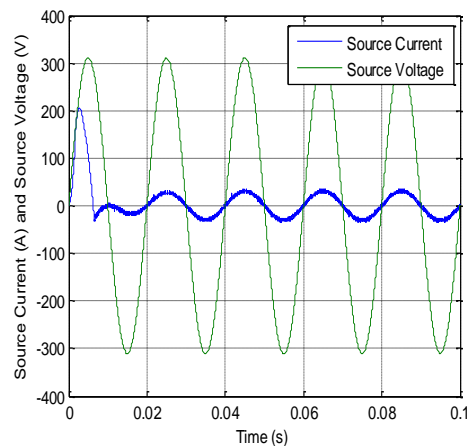
voltage and load current of 3 phase, 4 wire power system using shunt APF for non-linear diode rectifier R-L load with FLC plus PI controller (HNLC) and HCC. From these results, it is found that THD of the power system with filter has 3.28% for diode rectifier load. Also, the settling time of D.C link capacitor voltage is rapid with low transient overshoots with this controller at both load conditions.



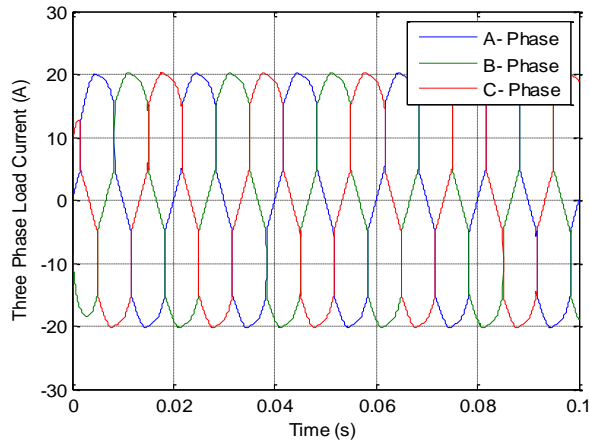
(a) DC link voltage



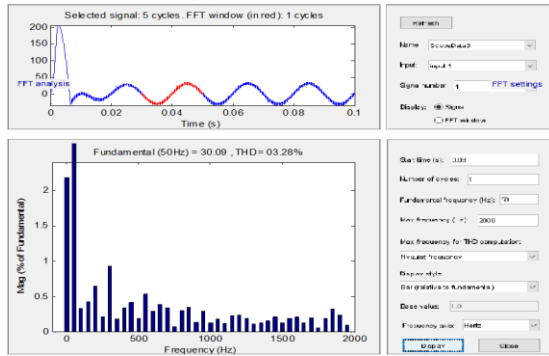
(b) Source current



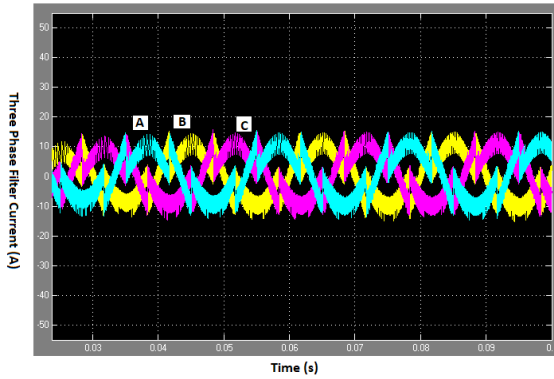
(c) Source current and voltage



(d) Load current



(e) THD analysis



(f) Compensated filter current

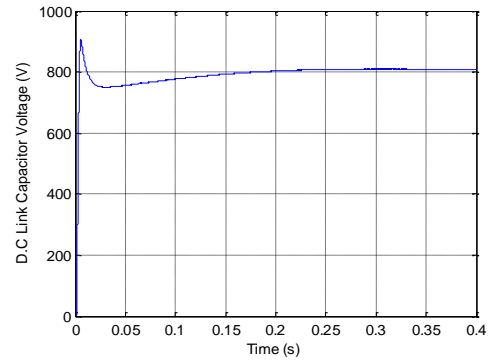
Fig.9. Simulation results of 3 phase, 4 wire diode rectifier load with shunt APF using FLC plus PI (HNLC) and HCC

4.4 Shunt APF using SMC plus PI and HCC

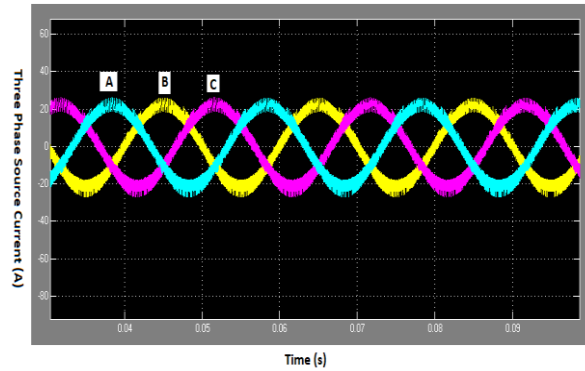
The simulation responses of current, voltage and THD analysis, compensated filter current, D.C link voltage and load current of 3 phase, 4 wire power system using shunt APF for diode rectifier inductive reactance load with SMC plus PI controller (HNLC) and inner loop HCC

are exhibit in fig 10. From these results, the THD of the power system with filter has 3.08% for diode rectifier load. Also, the settling time of D.C link voltage is very quick with minimal transient overshoots with this controller at the load conditions.

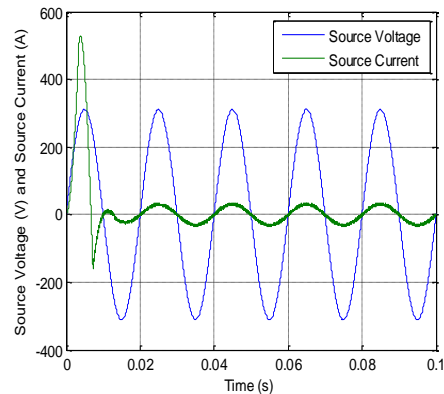
From these results, it is found that the designed shunt APF using designed controller has been produced excellent performance via. THD, power factor and time domain specifications at various load conditions.



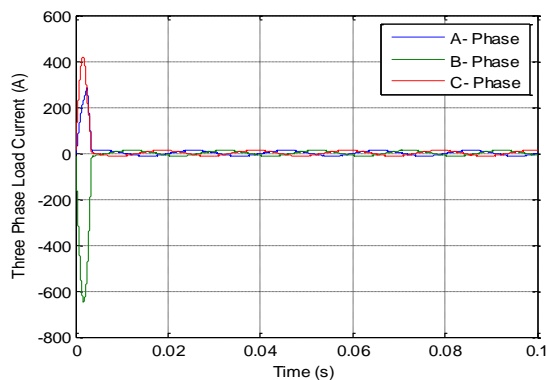
(a) D.C link capacitor voltage



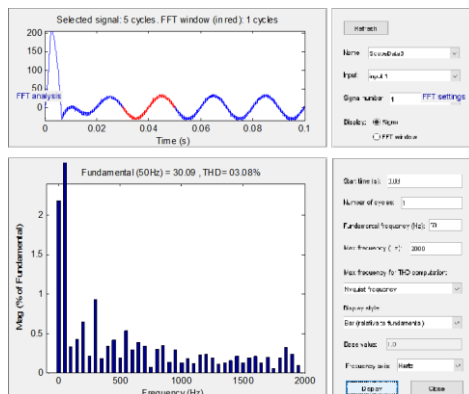
(b) Source current



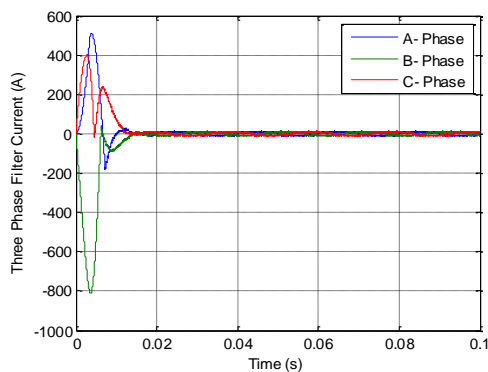
(c) Source current and voltage



(d) Load current



(e) THD analysis



(f) Compensated filter current

Fig.10. Simulated results of 3 phase, 4 wire power system with shunt APF for diode rectifier load using SMC plus PI and HCC.

5. Conclusions

The design and study of HNLC shunt APF achieve the high degree of the power quality in three phase four wire system through the reduction of harmonics and reactive power compensation has been successfully exhibited in MATLAB/Simulink software platform. Many results were denoted to show the proficient of the designed model in diode rectifier load through the

THD, power factor and time domain analysis. The SMC plus PI controller (HNLC) shunt APF has produced good D.C link voltage regulation, quick settling time and minimal steady state error in comparison with FLC plus PI controller and PI controller. The HCC is used to generate the PWM pulse for gate switches of shunt APF to produced quick response. Also, d-q theory is used to determine the reference current of designed system.

References

- [1] Bhim Singh, Kamal Al-Haddad, and Ambrish Chandra, "A Review of Active Filter for Power Quality Improvements" IEEE Trans on Indus. Electronics, Vol.46, No.5, pp 960-970, Oct-1999.
- [2] K. Mohanadasse, C. Sharmela, T.D. Sudhakar, "Filters for Power Quality Improvement – A Survey," Australian Journal of Basic and Applied Sciences, Vol.9, No. 2, February 2015, pp. 81-93.
- [3] Samir Gautam, Pei Yunqing, Muhammad Kashif, Yubaraj Kafle, Liu Yibo "DC Side voltage Control Consideration for Single Phase Shunt Active Power Filter for Harmonic and Reactive Power Compensation" Journal of Electrical Engineering, Vol. 15, Edition. 4, 2015, pp.290-297.
- [4] Z. Chelli, R. Toufouti, A. Omeiri, and S. Saad, "Hysteresis Control for Shunt Active Power Filter under Unbalanced Three-Phase Load Conditions" Journal of Electrical and Computer Engineering, Vol. 2015, Article ID 391040, pp.1-9.
- [5] Anzari M, Rejil Chandran and ArunKumar R "Single-Phase Shunt Active Power Filter Using Indirect Control Method" Advance in Electronic and Electric Engineering, Vol. 3, No. 1, 2013, pp. 81-90.
- [6] Ashraf A. ,Hagras Sherif A., Zaid Ahmed A. ,Elkousyshokkry M. Saad "Sensorless DC Voltage Control with Backstepping Design Scheme for Shunt Active Power Filter" Journal of Electrical Engineering, Vol. 15, Edition. 1, 2015, pp.294-303.
- [7] R. Belaidi, A. Haddouche, H. Guendouz, "Fuzzy Logic Controller Based Three-Phase Shunt Active Power Filter for Compensating Harmonics and Reactive Power under Unbalanced Mains Voltages" Energy Procedia, Vol.18, 2012, pp. 560 – 570.
- [8] P. K. Mani and K. Siddappa Naidu, "Fuzzy Logic Control Based Three Phase Shunt Active Filter for Power Quality Improvement in Distributions System" ARPN Journal of

Engineering and Applied Sciences, Vol. 11, No. 2, January 2016, pp.1127-1132.

- [9] Dongdong Chen, Hao Chen, Yaowei Hu, Guozhu Chen, "*A novel serial structure repetitive control strategy for shunt active power filter*" COMPEL - The international journal for computation and mathematics in electrical and electronic engineering, <https://doi.org/10.1108/COMPEL-02-2018-0079>, 2018.
- [10] R. Balasubramanian, K. Parkavikathirvelu, R. Sankaran and Rengarajan Amirtharajan, "*Design, Simulation and Hardware Implementation of Shunt Hybrid Compensator Using Synchronous Rotating Reference Frame (SRRF)-Based Control Technique*," Electronics, 2019, 8, 42; doi:10.3390/electronics8010042.
- [11] Goudarzian A, Adel Khosravi, Navid Reza Abjadi, "*Sliding mode current control of a NOCULL converter based on hysteresis modulation method in a wide range of operating conditions*" ISA Transactions, (2018), <https://doi.org/10.1016/j.isatra.2018.10.007>.
- [12] Ikramullah, Muhammad Ashraf, Abdur Rehman, "*Performance Analysis of Current Injection Techniques for Shunt Active Power Filter*" IOP Conf. Series: Earth and Environmental Science 168 (2018) 012014 doi: 10.1088/1755-1315/168/1/012014.
- [13] Musa Yusup Lada, Ismadi Bugis and Md Hairul Nizam Talib, "*Simulation a Shunt Active Power Filter using MATLAB/Simulink*," The 4th International Power Engineering and Optimization Conf. (PEOCO2010), Shah Alam, Selangor, MALAYSIA: 23-24 June 2010.
- [14] Sagar S.Patil, R.A.Metri, "*Power Quality Improvement Using Shunt Active Power Filter*" 2017 International Conference on Data Management, Analytics and Innovation (ICDMAI) Zeal Education Society, Pune, India, Feb 24-26, 2017.