

Power Quality Improvement Using PI and Fuzzy Logic Controllers Based Shunt Active Filter

Dipen A. Mistry, Bhupelly Dheeraj, Ravit Gautam, Manmohan Singh Meena, Suresh Mikkili

Abstract—In recent years the large scale use of the power electronic equipment has led to an increase of harmonics in the power system. The harmonics results into a poor power quality and have great adverse economical impact on the utilities and customers. Current harmonics are one of the most common power quality problems and are usually resolved by using shunt active filter (SHAF). The main objective of this work is to develop PI and Fuzzy logic controllers (FLC) to analyze the performance of Shunt Active Filter for mitigating current harmonics under balanced and unbalanced sinusoidal source voltage conditions for normal load and increased load. When the supply voltages are ideal (balanced), both PI and FLC are converging to the same compensation characteristics. However, the supply voltages are non-ideal (unbalanced), FLC offers outstanding results. Simulation results validate the superiority of FLC with triangular membership function over the PI controller.

Keywords—DC link voltage, Fuzzy logic controller, Harmonics, PI controller, Shunt Active Filter.

I. INTRODUCTION

THE large scale use of the non-linear loads such as adjustable speed drives, traction drives, etc. [1], and power converters has contributed for the deterioration of the power quality and this has resulted in to a great economic loss. Thus it is important to develop the equipment that can mitigate the problem of poor power quality.

Power Quality (PQ) [2], is defined as “Any power problem established in voltage, current or frequency deviation which leads to damage, malfunctioning, mis-operation of the consumer equipment”. Poor power quality causes many damages to the system, and has a contrary economical impact on the utilities and customers. Highly automatic electric equipment, in particular, causes enormous economic loss every year. The problems of harmonics can be reduced or mitigated by the use of power filters. The Active power filters have been proven very effective in the reduction of the system harmonics. One of the most severe and common power quality

problem is current harmonics. Particularly, voltage harmonics [1] and power distribution equipment problems result from current harmonics.

The voltage generated at the generating station is not purely Sinusoidal. Due to the non-uniformity of the magnetic field and the winding distribution in a working AC machine, voltage waveform distortions are created, and thus the voltage obtained is not purely sinusoidal. The distortion at the point of generation is very small (about 1% to 2%), but still it exists. Due to this deviation from the pure sine wave, voltage harmonics occurs.

When a pure sinusoidal voltage is applied to a certain type of load, the current drawn by the load is proportional to the voltage and impedance and follows the envelope of the voltage waveform. These loads are referred to as linear loads (loads where the voltage and current follow one another without any distortion to their pure sine waves) [3]. Examples of linear loads are resistive heaters, incandescent lamps and constant speed induction motors. In contrast, some loads cause the current to vary disproportionately with the voltage during each half cycle. These loads are defined as non-linear loads. The current harmonics and the voltage harmonics are generated because of these non-linear loads. It is noted that non-sinusoidal current results in many problems for the utility of power supply company, such as: low-power factor, low-energy efficiency, electro-magnetic interference (EMI), power system voltage fluctuations and so on. Thus, a perfect compensator is necessary to avoid the negative consequences of harmonics. The THD [4] obtained without using the shunt active filter is much more than described in the IEEE standard-519. According to this standard the THD value should be less than 5%. The THD equation for voltage harmonics is given by

$$\% THD (V) = \frac{\sqrt{V_2^2 + V_3^2 + \dots + V_n^2}}{V_1} \times 100 \quad (1)$$

and the THD equation for current harmonics is given by

$$\% THD (I) = \frac{\sqrt{I_2^2 + I_3^2 + \dots + I_n^2}}{I_1} \times 100 \quad (2)$$

Fig. 1 shows the schematic diagram of Shunt active filter (SHAF) [5]-[9], feeding a three-phase, three-wire system along with the three phase non-linear load. These non-linear loads affect source voltage and source current, so unity power factor is not maintained at source. Thus shunt active filters are required to maintain unity power factor in the power system.

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The SHAF will inject the compensating current in such a way that source current is pure sinusoidal and the power factor is maintained at unity. The shunt active filter consists of a three-leg IGBT based voltage source inverter (VSI), interface inductor and a dc bus capacitor. The shunt active filter needs to be controlled to obtain the best performance and thus PI controller as well as FLC [10], [11] are used. The performance of shunt active filter here is studied under balanced and unbalanced source voltage condition for normal load and increase load. The results show that the controlling of the shunt active filter offered by the FLC is much better than the controlling offered by the PI controller. When the source voltage is balanced, both the controller offers the same amount of compensation, a minimal change is observed, but when the source voltages are unbalanced, the fuzzy logic controller offers an outstanding compensation as compared to the PI controller.

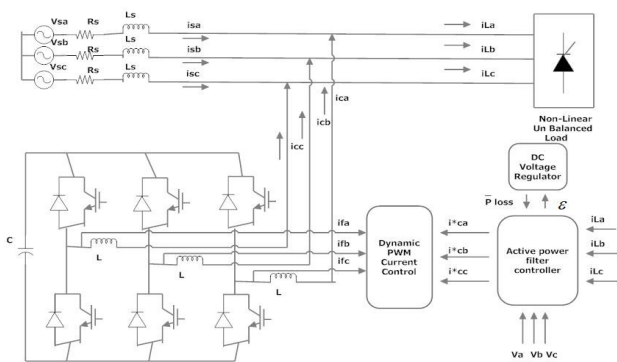


Fig. 1 SHAF for three-phase, three-wire system

In this work, controlling of the shunt active filter using the PI controller and FLC with triangular membership function is analyzed and studied. In Section II, the types of the power filters and the compensation principle of the shunt active filter are explained. Section III focuses on the importance of the DC link voltage in the shunt active filter as well as its influence in the system and why to maintain it equal to the reference value. Section IV includes the simulation part and followed by Section V which deals with the results and its analysis. Section VI gives the final conclusion of this paper followed by references.

II. SHUNT ACTIVE FILTERS

A. Active Power Filters

The power filters are used to mitigate the harmonics present in the electrical systems. Harmonics are considered as pollutants present in the power system. Traditionally a bank of capacitors or LC filters were used to filter out the system harmonics, as they have simple structure, easy to design, low cost and high efficiency. These are some examples of the passive power filters [6]. Apart from this there are several drawbacks of the passive power filters such as resonance, bulky in nature, tuning frequency is not accurate and it

requires lot of calculations. Thus to overcome these drawbacks of the passive power filters, Active power filters (APF) [7]-[9] are introduced. The Active power filters uses power-electronics devices to mitigate the harmonics content in the power system. The APF has been proven effective than the passive power filters in the mitigation of the harmonics. It overcomes the drawback of the passive power filters and has the advantages such as, smaller in size and accurate. Power filters are further divided into three categories, they are: series power filters, shunt power filters and hybrid power filters. The series active filters are used to mitigate the problems of the voltage harmonics and are placed in series with the power system. The shunt active filter is used to mitigate the current harmonics present in the system and they are placed in the system at a point of common coupling (PCC). The hybrid filters are used to mitigate the current as well as the voltage harmonics present in the power system. Here we are dealing with the mitigation of current harmonics and thus we consider the use of shunt active filter to perform the job.

B. APF Compensation Principle

The Active power filter is controlled by using PI controller and Fuzzy logic controller (FLC), to draw/supply the compensating current from/to the load to cancel out the current harmonics on AC side, to maintain the DC link voltage constant by maintaining the real power flow in the system and reactive power flow from/to the source, thereby making the source current in phase with source voltage.

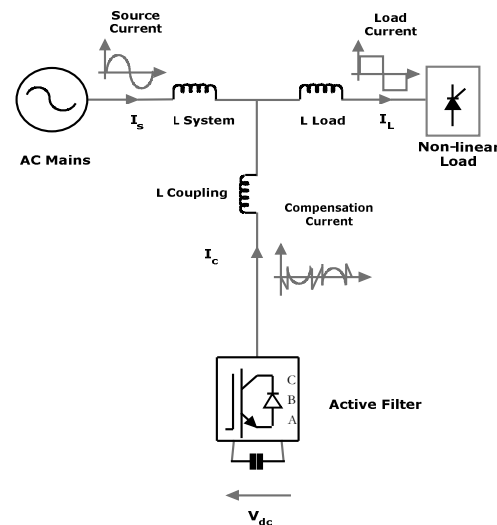


Fig. 2 Compensation Principle of a SHAF

Fig. 2 shows the basic compensation principle of the active power filter and it serves as an energy storage element to supply the real power difference between load and source during the transient period. When the load condition changes, the real power in the system i.e. between the mains and the load also changes. Due to this unbalance of the real power in the system the improper functioning of the system happens and thus the real power disturbance is cleared by the DC link

capacitor and in doing so the voltage across the DC link capacitor changes away from the reference voltage.

To obtain the optimal performance of the system, the peak value of the reference source current must be adjusted to proportionally change the real power [12] drawn from the source. If the DC capacitor voltage is recovered and attains the reference voltage, the real power supplied by the source is supposed to be equal to that consumed by the load again. In this fashion, the peak value of the reference source current can be obtained by regulating the average voltage of the DC capacitor.

III. DC LINK VOLTAGE

A. DC Link Voltage Regulation

Whenever there is a sudden change in the load condition, the real power flowing in the system is disturbed and this needs to be settled down. The DC link voltage is used to balance the real power flow in the system and thus the voltage across the DC link capacitor changes. If the active power flowing into the filter can be controlled in such a way that it is equal to the losses inside the filter, the DC link voltage can be maintained at the desired value. Thus the main purpose of the active power filter is to maintain the DC link voltage and to give the compensating current to mitigate the current harmonics present in the system. This paper represents the control offered by two different controllers to control the shunt active filter (SHAF). PI controller which is a linear controller and fuzzy logic controller which is a non-linear controller, are used to control SHAF and the results are analyzed.

B. DC Link Voltage Regulation Using PI Controller

Fig. 3 shows the internal structure of the control circuit. The control scheme consists of PI controller, limiter and three phase sine wave generator for reference current generation and generation of switching signals [8]. It is known that the real power of the system changes and that is compensated by the DC link capacitor voltage. The new capacitor voltage is now compared with a reference voltage and a difference signal or error signal is given to the PI controller.

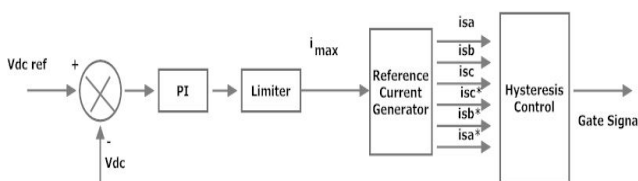


Fig. 3 Conventional PI controller

The error signal is then processed through a PI controller, which contributes to zero steady error in tracking the reference current signal. The output of the PI controller is considered as peak value of the supply current (I_{max}), which is composed of two components: (a) fundamental active power component of load current and (b) loss component of APF; to maintain the average capacitor voltage to a constant value. This peak value of the current (I_{max}) so obtained, is multiplied with the

respective source voltages to obtain the reference compensating currents. These estimated reference currents (I_{sa}^* , I_{sb}^* , I_{sc}^*) and sensed actual currents (I_{sa} , I_{sb} , I_{sc}) are compared at a hysteresis band, which gives the error signal. Fig. 4 shows how the error signal is generated by comparing the two currents. The output of this hysteresis band is used to give the gating signal, which controls the converter switches and using this gating signal the compensating current are generated. In this current control circuit configuration, the source/supply currents I_{sabc} are made to follow the sinusoidal reference current I_{abc} , within a fixed hysteretic band. The width of hysteresis window determines the source current pattern, its harmonic spectrum and the switching frequency of the devices.

In this scheme, each phase of the converter is controlled independently. To increase the current of a particular phase, the lower switch of the converter associated with that particular phase is turned on while to decrease the current the upper switch of the respective converter phase is turned on. With this, one can realize the potential and feasibility of PI controller [10], [11].

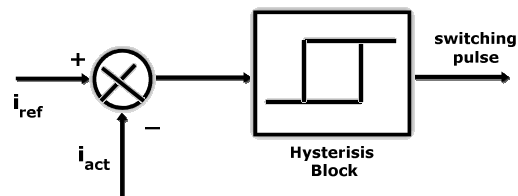


Fig. 4 (a) Details of current wave with hysteresis band current controller

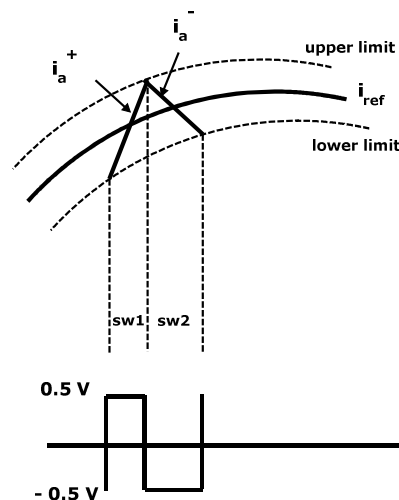


Fig. 4 (b) Details of hysteresis band current controller

C. DC Link Voltage Regulation Using Fuzzy Logic Controller

Fig. 5 shows the internal structure of the control circuit for fuzzy logic controller. The control scheme consists of FLC [13], limiter and three phase sine wave generator for reference current generation and generation of switching signals.

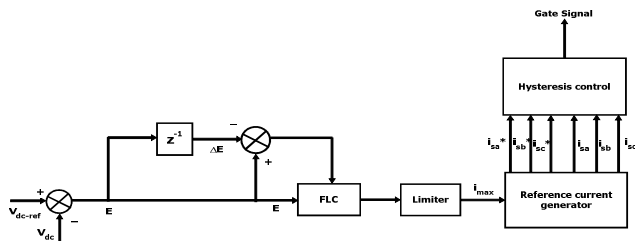


Fig. 5 Fuzzy logic controller

The peak value of reference currents is estimated regulating the DC link voltage. It is known that the real power of the system changes and that is compensated by the DC link capacitor voltage. The new capacitor voltage is now compared with a reference voltage and a difference signal or error signal is given to the FLC. The error signal is then processed through a FLC, which contributes to zero steady error in tracking the reference current signal. The output of the FLC is considered as peak value of the supply current (I_{max}) and using it the reference currents are generated and then through them the gating signals are generated.

The FLC is characterized as follows:

- 1) Five fuzzy sets for each input and output.
- 2) Fuzzification using continuous universe of discourse.
- 3) Implication using Mamdani's 'min' operator.
- 4) De-fuzzification using the 'centroid' method.

To convert these numerical variables into linguistic variables, the following five fuzzy levels or sets are chosen as: NB (negative big), NS (negative small), ZE (zero), PS (positive small) and PB (positive big).

IV. SIMULATIONS

The three-phase three-wire system with a non-linear load is equipped with shunt active filter for mitigating the current harmonics. PI controller and FLC are used to control the shunt active filter under balanced and unbalanced source voltage condition for normal load as well as increase load. Table I shows the system parameters of the Balance source voltage condition circuit that has been analyzed and Table II shows the system parameters of the Unbalance source voltage condition circuit that has been analyzed.

V. RESULT AND ANALYSIS

The results obtained from the simulation shows that the compensation offered by PI controller as well as by Fuzzy logic controller is same (negligible difference) when the source voltage is balanced (ideal). When the source voltage is unbalanced (non-ideal), it is observed that the compensation offered by the FLC is much better than the PI controller. The THD for normal load under balance condition using PI controller is 5.67% and using the FLC it is 3.16%. The THD for increased load under balance condition using PI controller is 6.61% and using the FLC it is 4.66%. The THD for normal load under unbalanced condition using PI controller is 6.80% and using FLC it is 5.86%. The THD for increased load under

unbalance condition using PI controller is 7.55% and using FLC it is 6.14%. The THD value should be less than 5% as per IEEE-519 standards. It is seen from the simulation results that THD value is less than 5% under balance condition and nearly 5% under unbalance source voltage condition, using the FLC. Thus it is clear that FLC gives an outstanding controlling of the shunt active filter.

TABLE I
SYSTEM PARAMETERS FOR BALANCE CONDITION

Specifications	Units
Source voltage of phase A	230 V
Source voltage of phase B	230 V
Source voltage of phase C	230 V
Smoothing resistance	0.1 Ω
Smoothing reactance	0.15 mH
DC link capacitor	2 mF
Sample interval	0.00001 S
Normal load resistance	6.7 Ω
Normal load reactance	20 mH
Increased load resistance	6.7 Ω
Increased load reactance	100 mH
Step input	0.3 S
FIS type for FLC	Mamdani
Membership function for FLC	5X5 Triangular
Implication for FLC	Min
Defuzzification	Centroid

V = voltage, Ω = ohm, H = henry, F = faraday, S = second.

TABLE II
SYSTEM PARAMETERS FOR UNBALANCE CONDITION

Specifications	Units
Source voltage of phase A	200 V
Source voltage of phase B	230 V
Source voltage of phase C	250V
Smoothing resistance	0.1 Ω
Smoothing reactance	0.15 mH
DC link capacitor	2 mF
Sample interval	0.00001 S
Normal load resistance	6.7 Ω
Normal load reactance	20 mH
Increased load resistance	6.7 Ω
Increased load reactance	100 mH
Step input	0.3 S
FIS type for FLC	Mamdani
Membership function for FLC	5X5 Triangular
Implication for FLC	Min
Defuzzification	Centroid

V = voltage, Ω = ohm, H = henry, F = faraday, S = second.

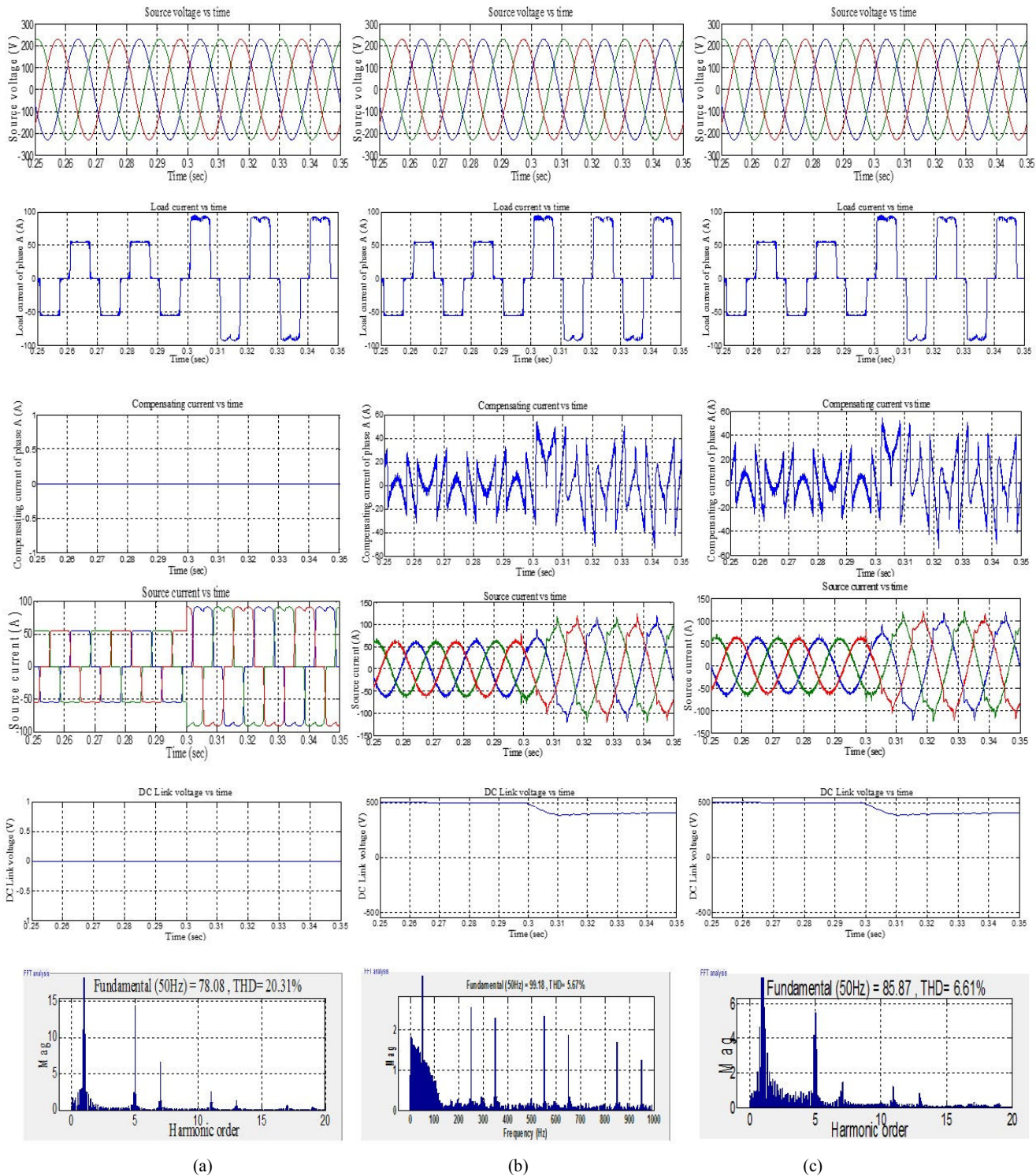


Fig. 6 SHAF response under (a) Balanced source voltage condition without controller, (b) Balanced source voltage condition using PI controller for normal load, (c) Balanced source voltage condition using PI controller for increased load.

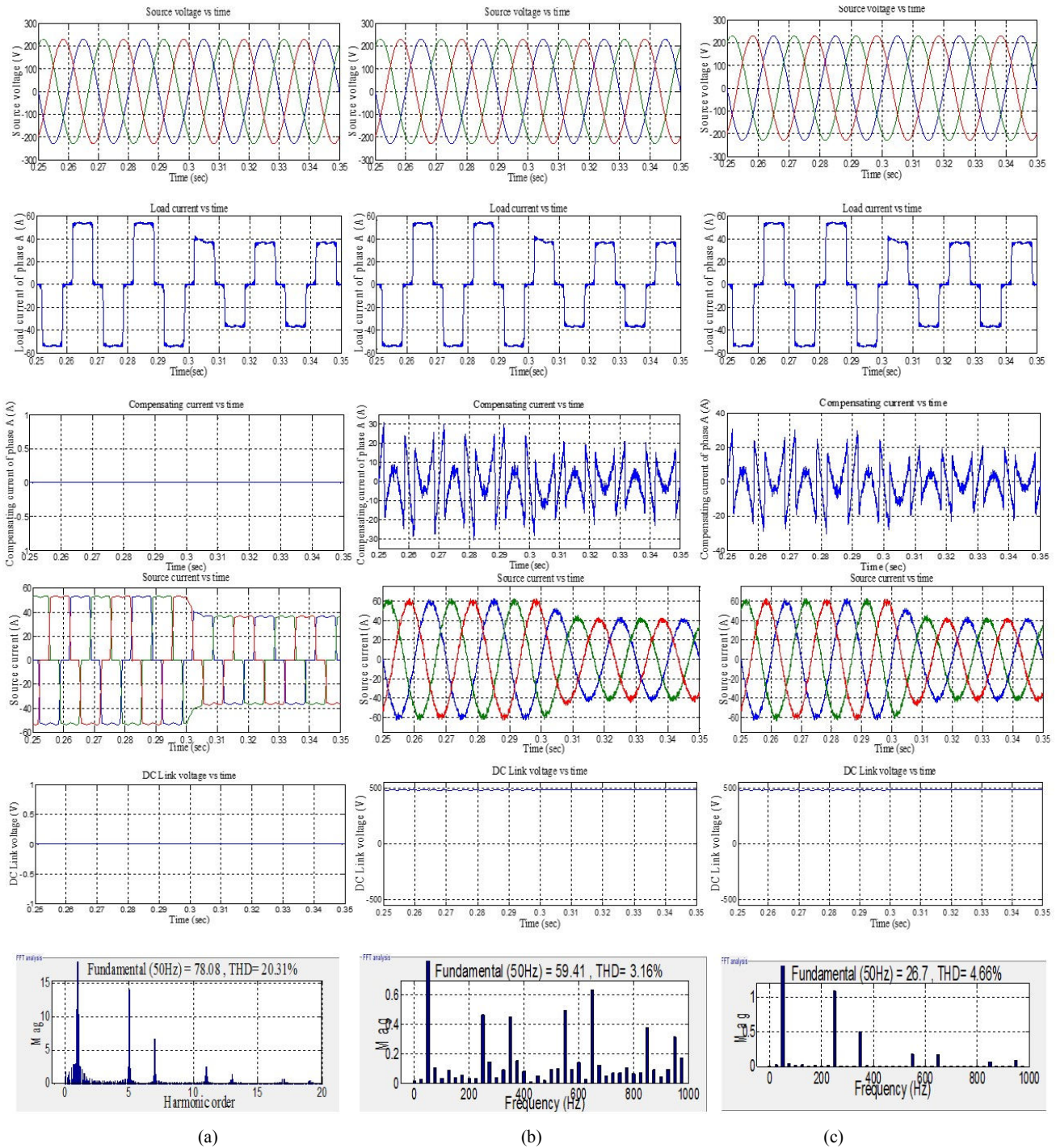


Fig. 7 SHAF response under (a) Balanced source voltage condition without controller, (b) Balanced source voltage condition using FLC for normal load, (c) Balanced source voltage condition using FLC for increased load

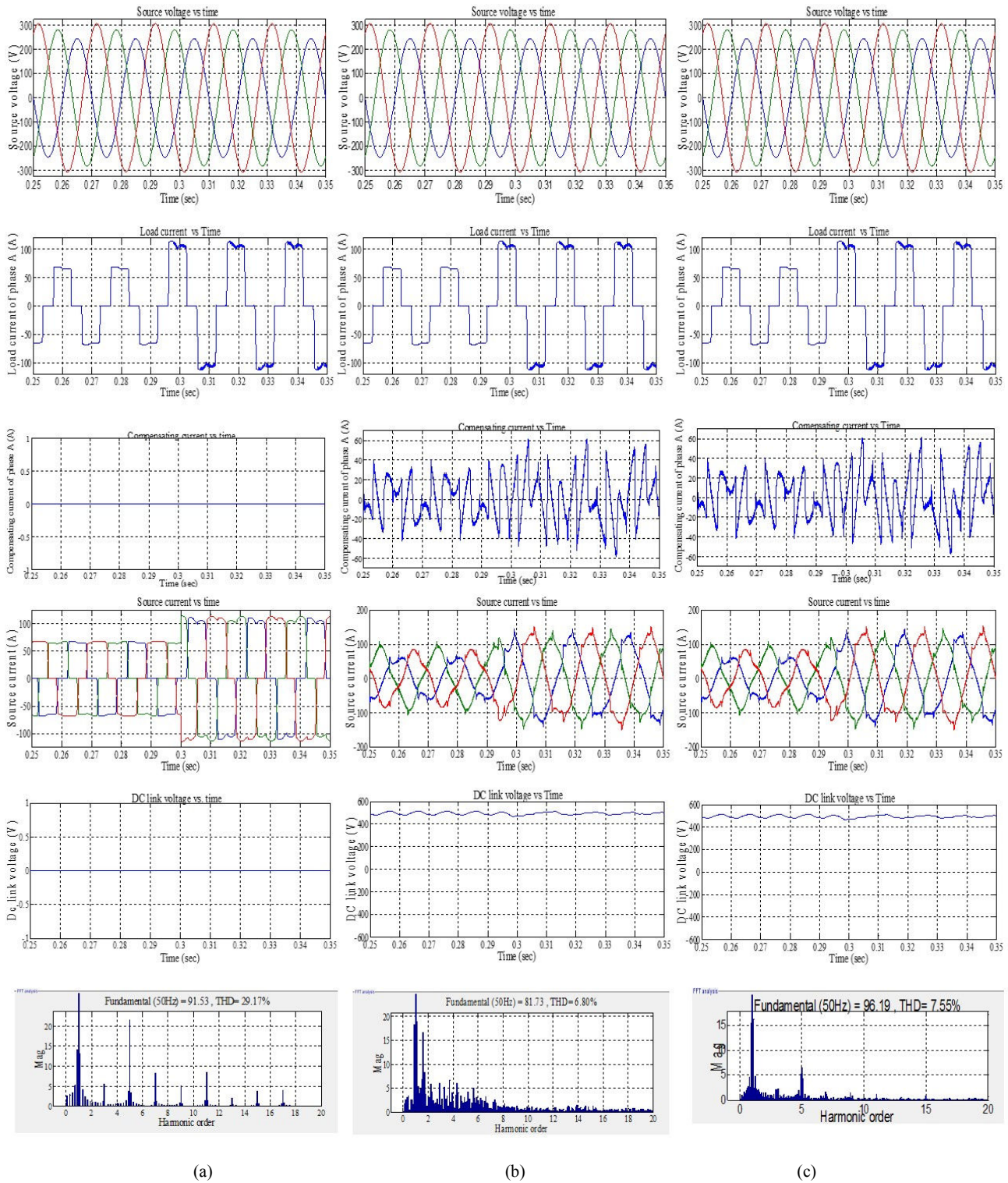


Fig. 8 SHAF response under (a) Unbalanced source voltage condition without controller, (b) Unbalanced source voltage condition using PI controller for normal load, (c) Unbalanced source voltage condition using PI controller for increased load.

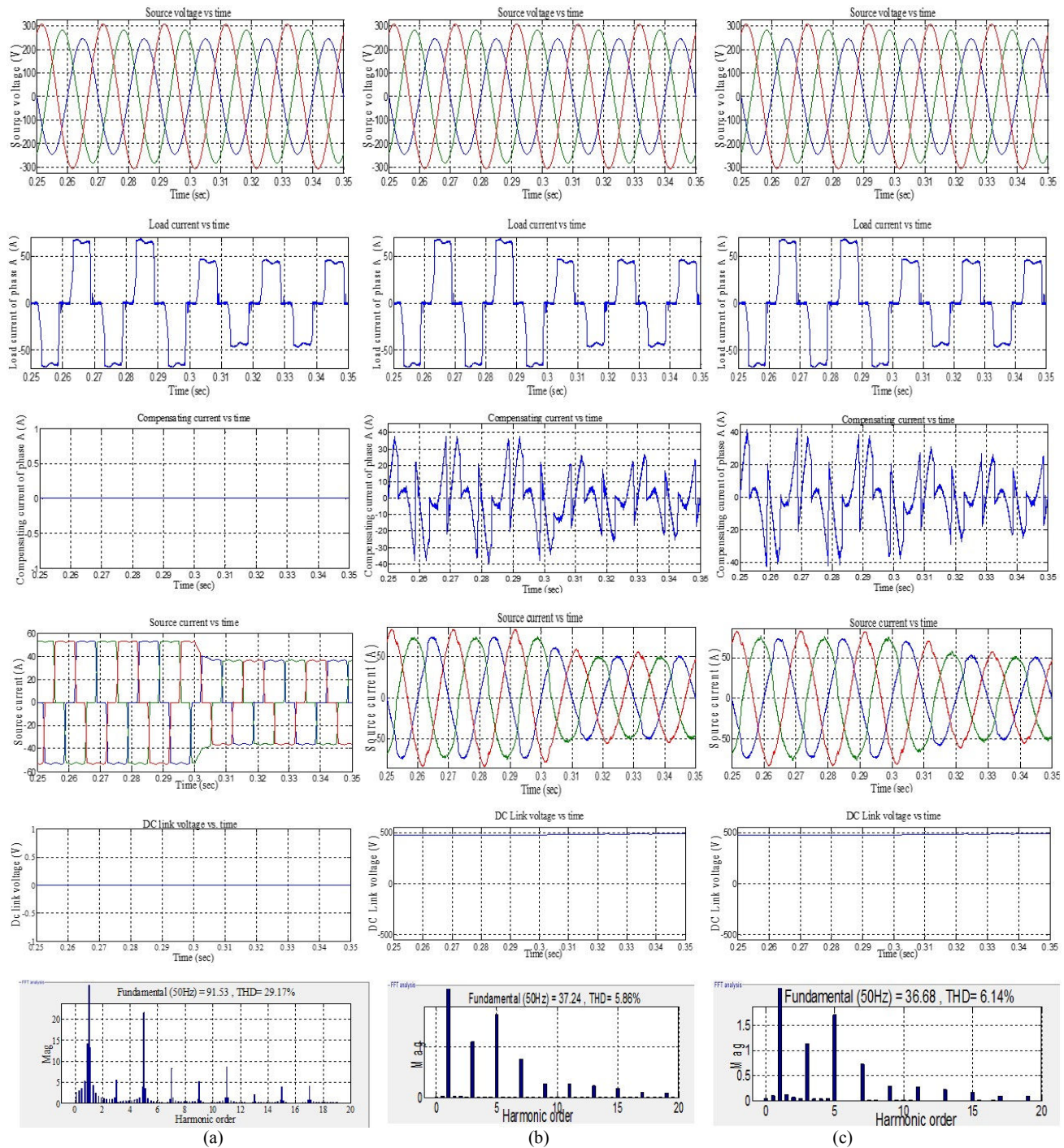


Fig. 9 SHAF response under (a) Unbalanced source voltage condition without controller, (b) Unbalanced source voltage condition using FLC for normal load, (c) Unbalanced source voltage condition using FLC for increased load.

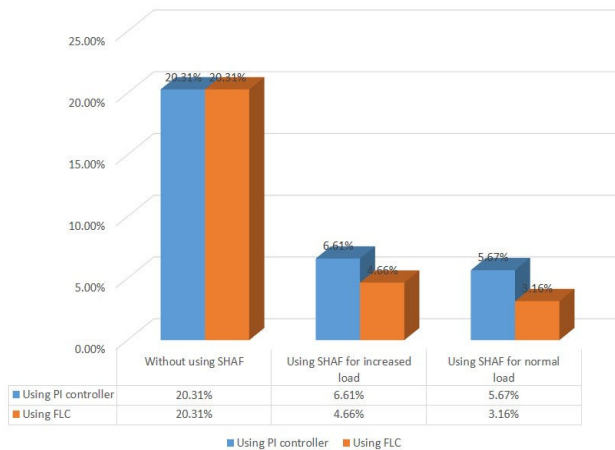


Fig. 10 THD chart and Table for Balance Source voltage condition

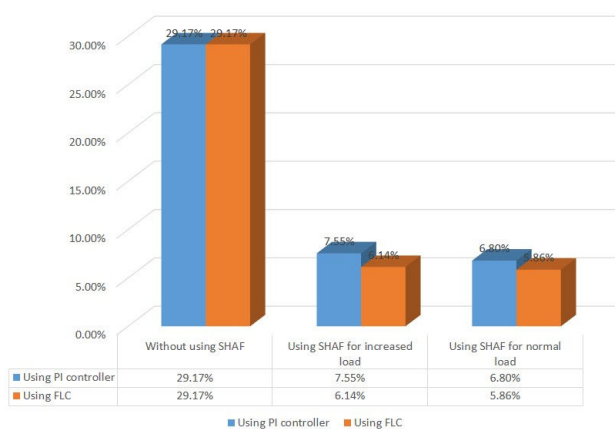


Fig. 11 THD chart and Table for Unbalance Source voltage condition

VI. CONCLUSION

In the present work two controllers, PI controller and Fuzzy logic controllers are used to control the shunt active filter, which is used to compensate the current harmonics. The simulation results showed that, even if the supply voltage is unbalanced (non-ideal) the performance of SHAF using FLC with triangular MF comfortably outperformed the results obtained using SHAF with PI controller. The THD value offered by the SHAF when controlled by FLC (with triangular MF) is much less as compared to the THD value obtained using PI controller. Thus it can be concluded that FLC offers a better controlling to the shunt active filter than the PI controller.

While considering the SHAF with FLC, the SHAF has been found to meet the IEEE 519-1992 standard recommendations on harmonic levels, making it easily adaptable to more severe constraints such as unbalanced supply voltage. The dc bus voltage of SHAF is almost maintained at the reference value under non-ideal conditions, which confirm the effectiveness of the Fuzzy logic controller.

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