Mitigation Unbalance Nonlinear Loads and Dissimilar Line Currents Using Shunt Active Power Filter SAPF

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Abstract— *Power quality has grown from obscurity to a major issue in last ten years. The new technologies lead to great demand of power electronic devices that leads to a distortion the quality of voltages and currents of power system in other hand many sensitive loads need a high degree of power quality thus it is important to have the suitable solutions. Several researches and studies regarding the power quality and tray to solve the problems of nonlinear loads regarding a union case of a balance three phase and similarity of line currents, while in fact the unbalance and dissimilar cases are the prevailing cases. This paper proposed a new controller method for compensating unbalance nonlinear loads and dissimilar in line currents as well as eliminate the negative and zero sequence components of line currents using SAPF. Also the proposed control method is compared with a will known method used for compensating nonlinear loads in many researches known as instantaneous power pq theory. Finally, fuzzy logic control is used to optimize the performance of the compensator.*

Keyword— SAPF, Unbalance Compensation, Power Quality. Hysteresis Control.

I. INTRODUCTION

The development of technology lead to the extensive use of power electronic for equipment and loads in presidential and industrial areas, the point of common coupling (PCC) could be highly distorted [1]. Power Quality problems are defined as any distortion in voltage and current waveforms or any voltage and frequency deviations that effect on the operation of customer loads [2]. Switching in power electronicconverters and unbalanced single phase loadscause toexist harmonics in current lines and to flow currentthrough null wire[3].performance of dq theory with PI controller is quite good over p-q theory with PIcontroller[4]. Harmonic distortion affects the power systems and equipment; therefore, harmonic problems become important to solve and improve the quality of the power industry. Non-linear loads such as converters for variable speed motor drives, HVDC systems, arc furnaces, static VAR compensators, switching power factor correction converter, switch mode power supplies, and other power electronic applications create harmonics in the power system [3]. In additions in modern power systems the harmonics not come from the load side but also they generated from the source side due to the presence of distribution generators [4]. There are several sensitive loads, such as computer or microprocessor based AC/DC drive controller, with good voltage profile requirement; can function improperly or sometime can lose valuable data or in certain cases get damaged due to these voltage sag and swell conditions[3]. One of the effective approaches is to use a shunt active power filter (SAPF) at PCC to protect the sensitive loads. Most of researchers deals with the problems of nonlinear loads by using the instantaneous power theory in the same time the researchers suppose that these loads are symmetric and balanced. In fact, the prevailing nonlinear loads are unbalanced in addition these loads are a hybrid of linear and nonlinear types. Some researches deals with the unbalance in nonlinear line currents due to the unbalanced in line voltages [3]. In this paper the unbalanced line currents are due to the asymmetrical in loads. A new control method to mitigate the distortion and asymmetry caused by nonlinear loads in distribution system is proposed. This method not only reduced the harmonics and disturbances in the point of common coupling but also may have a benefit of the negative sequence currents as well as the losses in all the equipment in the distribution system specially the power transformers.

II. SYSTEM CONFIGURATION

The shunt APF based on hysteresis PWMVSI, the most adopted type, is used to cancel load harmonics current due to nonlinear loads, compensate reactive-power and balancing of three phase currents. The operation system of the shunt APF is based on injecting harmonics current into the line system with the same magnitude as the harmonics generated by the nonlinear load with an opposite phase as shown in Fig. (1) [4]. Thus, the power distribution system sees the nonlinear load with the shunt APF as a dynamic resistor. If the harmonics current of the APF is injected to eliminate harmonics due to nonlinear loadapplications, the AC supply current will be sinusoidal. While, if the harmonics current of the APF is used to eliminate harmonics and correct power factor as the same time, the AC supply current will be sinusoidal and in-phase with its AC voltage.

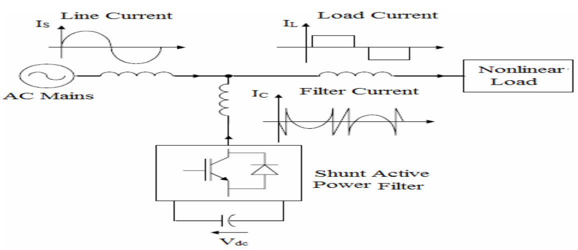


Fig.1: Block Diagram of SAPF

III. REFERENCE CURRENTS CALCULATION

First calculating the reference currents by using instantaneous power pq theory the desired injected reference current ($i_{abc\text{-}ref}$) is calculated [5] as:

$$i_{ab\_ref} = \frac{2/3}{v_a^2 + v_b^2}\begin{bmatrix} v_a & v_b \\ v_b & -v_a \end{bmatrix}\begin{bmatrix} \tilde{p} + p_{loss} \\ \tilde{q} \end{bmatrix} \quad (1)$$

Then

$$i_{abc\_ref} = \sqrt{\frac{2}{3}}\begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ 0 & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} 0 \\ a \\ b \end{bmatrix} \quad (2)$$

Where $\tilde{p}\ \tilde{q}$ are the ripple components of the active and reactive power, respectively p_{loss} is the required power for the regulation of capacitor voltage.

When the dq-pq theory is used the reference currents is calculated [6] as:

$$i_{ldqo\_ref} = \overline{i_{ldqo}} - i_{ldqo} \quad (3)$$

The first part of equation (1) represents the average values of the dq0 components of the load currents.

The alpha beta zero reference value [ ] are:

$$i_{abq} = \begin{bmatrix} 1 & 0 & 1 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & 1 \\ \frac{1}{2} & -\frac{\sqrt{3}}{2} & 1 \end{bmatrix}\begin{bmatrix} a \\ b \\ c \end{bmatrix} \quad (4)$$

Then

$$i_{dqo} = \begin{bmatrix} \cos wt & \sin wt & 0 \\ \sin wt & \cos wt & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} a \\ b \\ q \end{bmatrix} \quad (5)$$

The currents are injected to the system through the special transformer known as the injected transformer its turn ratio must be high enough to reduce the value of the inverter output current and to reduce the voltage induced at the primary windings. The transformer core and case dimensions are bigger than the regular transformer of the same MVA [7]. The interface filter or reactor is designed to prevent harmonic components from spreading into the power network and ensure the dynamic behaviour of the current. Most of the harmonics current components will flow into the power system if the interface reactor value L_f is low. On the other hand, a high value of the interface reactor blocks the harmonic currents from spreading into the supply system but reduces the quality of compensation [8]. Therefore, the main object of the coupling or interface reactor is to provide the isolation and filtering between the APF and the power system. Also during commutation, it limits the magnitude of the SAPF current spike and protects the switching device from a high rate of di/dt during switching transients [9].

IV. CONTROL SCHEMES FOR SAPF

As shown in figure 2 the measured currents are transformed to the dq0 components and the quadrate and zero q0 components are equated to zero. The in phase d component is filtered using a fifth order butter worth analogue filter then the ripple power value is retransformed to abc quantities. The dc voltage of the capacitor is regulated using PI controller to generate the P_{loss} with the ripple of real power to calculate the second reference currents using pq theory. These currents with the first reference currents represent the reference input to the inverter.

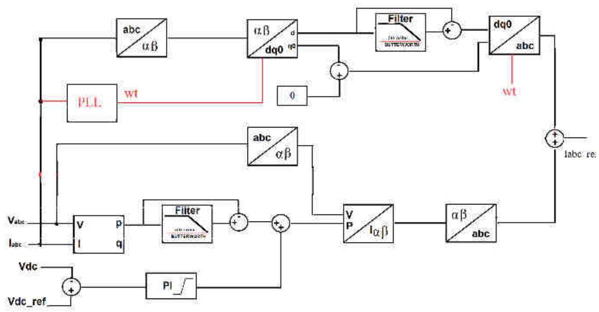


Fig. 2: Proposed Controller of SAPF for Unbalance Compensation

V. HYSTERESIS CURRENT CONTROL

Hysteresis band PWM HBPWM controller is simple implemented and fast [10] so that it used to control the compensating currents and determine switching signals for inverter switches. There are bands above and under the reference current. If the difference between the reference and inverter currents reaches to the upper (lower) limit, the currents is forced to decrease (increase) as shown in figure (3). In this method, the following relation is applied.

Where *HB* and *fc* are Hysteresis band and switching frequency, respectively.

$$T1 + T2 = Tc = 1/fc \qquad \ldots(6)$$

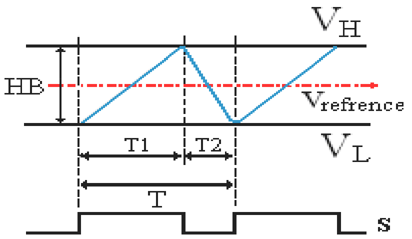


Fig. 3: Hysteresis Control

The HB that has inverse proportional relation with switching frequency is defined as the difference between VH and VL (HB=VH-VL) [7]. In bipolar switching scheme, as shown in Figure (4), there are two bands and the controller turns on and turns off the switch (S1and S2) at the same time to generate +Vdc or -Vdc at the output of inverter.

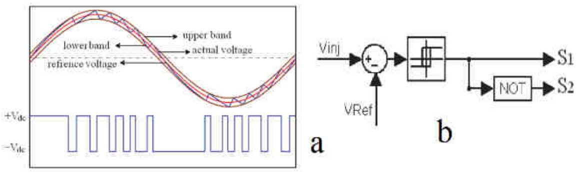


Fig.4: Bipolar hysteresis current control (a) output current with limiting bands (b) switching signals.

VI. FUZZY LOGIC BASED SAPF

Fuzzy logic is close in spirit to human thinking and natural language than other logical systems. It provides an effective means of capturing the approximate and inexact nature of systems. The fuzzy control is basically a nonlinear and adaptive in nature, giving the robust performance in the cases where in the effects ofparameter variation of controller is present. Fuzzy control is based on the principles of fuzzy logic. It is a non-linear control method, which attempts to apply the expert knowledge of an experienced user to the design of a controller. Fuzzy modelling provides the ability to linguistically specify approximate relationships between the input and desired output. The relationships are represented by a set of fuzzy If-then rules in which the antecedent is an approximate representation of the state of the system and the consequent provides a range of potential responses.

In Fuzzy Logic Control, basic control action is determined by a set of linguistic rules. These rules are determined by the system variables. Since the numerical variables are converted into linguistic variables, mathematical modelling of the system is not required in FLC. Fuzzy logic uses linguistic variables instead of numeric variables. The process of converting a numeric variable to a linguistic variable (fuzzy set) is called fuzzification. An arbitrary membership function is assigned to each linguistic label. The database stores the definition of the membership functions of the fuzzy system variables.

The fuzzy control algorithm consists of a set of fuzzy control rules which reflects the experience gained from the plant operation. The rules are combined by using the implication and the compositional inference.

The FLC comprises of three parts: Fuzzification, Interference engine and Defuzzification. The FLC is characterized as; i. seven fuzzy sets for each input and output. ii. Triangular membership functions for simplicity. iii. Fuzzification using continuous universe of discourse. iv. Implication using mamdani's 'min' operator. v. Defuzzification using the 'Takagi Surgeno' linear method. The knowledge bases are designed in order to obtain a good dynamic response under uncertainty in process parameters and external disturbances. DC voltage control using Fuzzy Logic is shown in Fig. (5). The membership functions are triangular shaped with 50% overlap for a soft and progressive control adjustment.In our application, the fuzzy controller is based on processing the voltage error and its derivation. Figure (6) show the membership functions of the input and the output linguistic variables. Triangle shaped membership function has the advantages of simplicity and easier implementation and is chosen in this application.

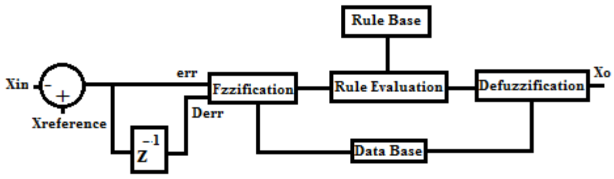


Fig. 5: DC voltage control using Fuzzy Logic

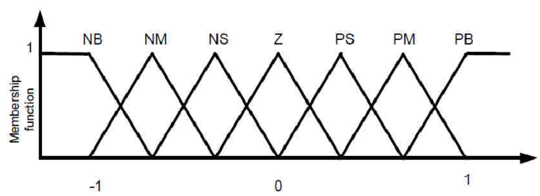


Fig. 6: Triangular membership function for input variables

In the fuzzification stage numerical values of the variables are converted into linguistic variables. Seven linguistic variables namely NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), and PB (positive big) are assigned for each of the input variables and output variable. Normalized values are used for fuzzy implementation. As there are seven variables for inputs and output there are 7 × 7 = 49 input output possibilities as tabulated in Table 1. A membership function value between zero and one will be assigned to each of the numerical values in the membership function graph [11].

Table.1: Rule-Base Linguistic for Fuzzy Like PI

e \ Δe	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

VII. SIMULATION RESULTS WITH DIFFERENT CONTROL SCHEMES

As shown in figure 7 the SAPF installed in substation side the transmission line is 10km long and the load consists of different single phase rectifier also one single phase RL load with various values of current levels.

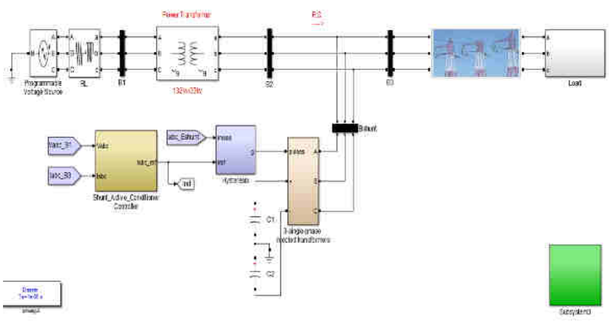


Fig. 7: Matlab simulation of SAPF

7.1 UNBALANCE COMPENSATION USING PQ THEORY

Most of the researches deals with the compensation of harmonics in three phase balance loads in spite of the most of loads are unsymmetrical. In this section the controller of the SAPF is developed in order to compensate unbalance three phase distortion currents in fact the instantaneous power pq theory generate a 3rd harmonics when used in unbalanced voltage system []. In this section we exam the pq theory to compensate unbalance nonlinear loads in balanced three phase voltage system, its clear that this method failed to compensate these types of loads as shown in figure (8) the unbalance in currents is remain as well as the THD is high so the new hybrid controller is developed and compensate nonlinear asymmetric loads based on using the dq and pq theories also the input of PLL is replaced by the line currents rather than the voltage as shown in figure (2) in section IV this is very effective and lead to perfect compensation of unbalance currents. It noted that the injected transformer consists of three single phase transformers and used in both controller methods this is also has a great effect for compensating unbalance currents.

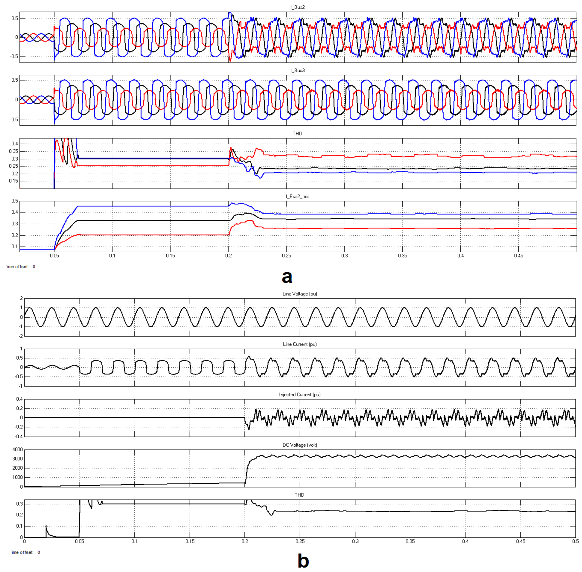
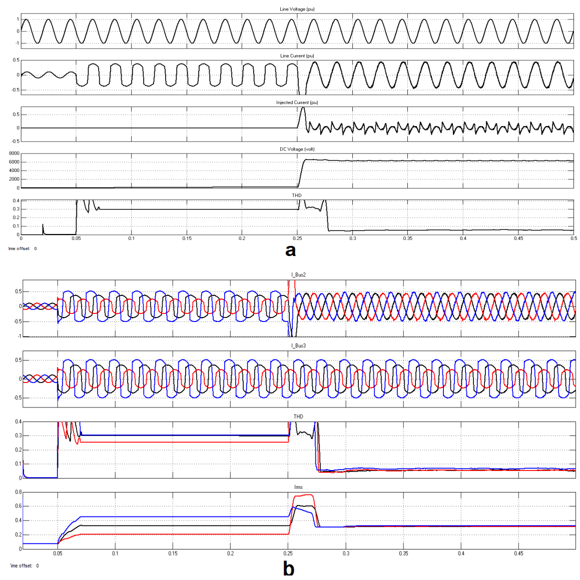
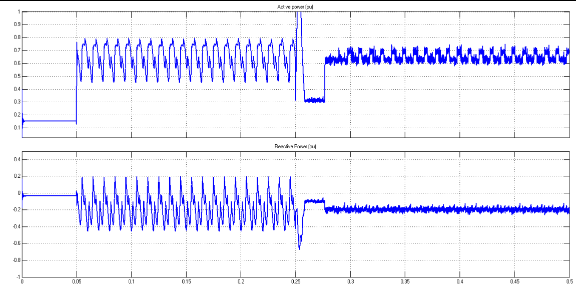


Fig. 8: Unbalance Compensation of nonlinear loads using pq theory

7.2 UNBALANCE COMPENSATION USING DQ WITH αβTHEORY

Asymmetric nonlinear loads are selected so that they generate highly unbalance and distorted line currents as shown in figure (9). After the compensation the rms values of the line currents are varies to a union average value and the THD is minimized from 29.8% to 4.1% also the ripple in power flow is reduced. The injected current has a high ripple in order to compensate the high ripple in power flow. Comparing figure (8-a) with figure (9-b) the proposed controller is very effective for compensating asymmetric nonlinear loads those may prevalent in distribution system.





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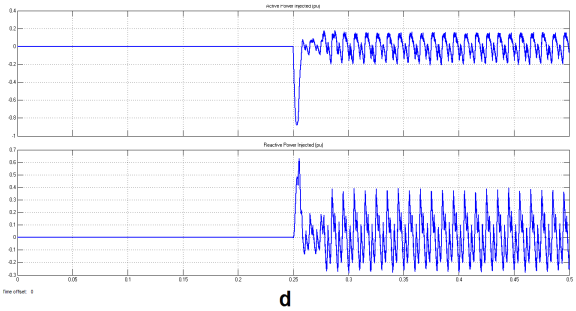

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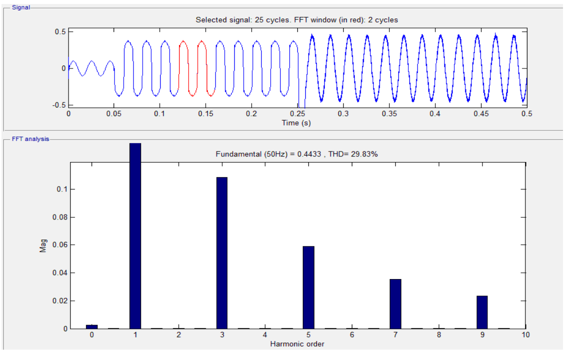

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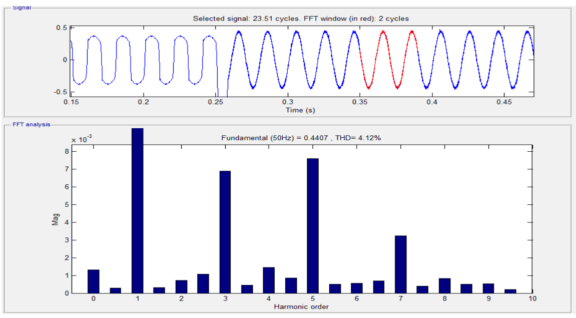

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Fig. 9: Asymmetric and dissimilar nonlinear loads compensation with a low single phase linear load (a) voltage, line current, injected current, dc voltage, and THD (b) three phase instantaneous and rms currents (c) power flow (d) injected power (e) THD of line currents before and (f) after compensation

As shown in Fig. 10 the negative sequence and zero sequence is completely eliminated after compensation this adding a new function of the compensator and leads to reduces the power loss and improve the capacity of the transmission line and increase the efficiency of the main power transformer of substation.

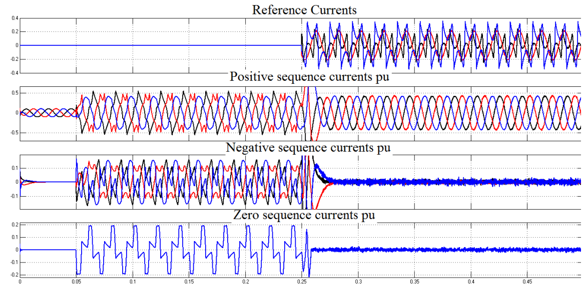
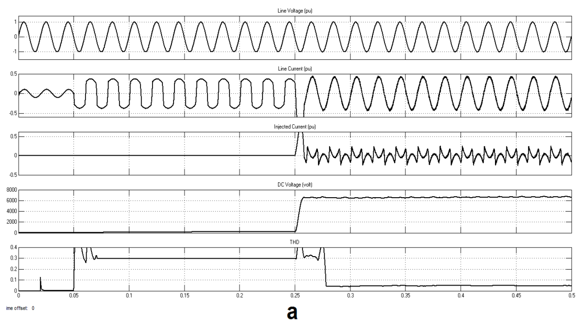


Fig.10: Reference currents and sequence line currents before and after compensation.

Another type of asymmetry and dissimilar in line current is tested using this controller. One of the three phase loads is linear (RL load) while the two others are nonlinear consists of the two single phase rectifiers and all of them have the different rms values as shown in figure (11).



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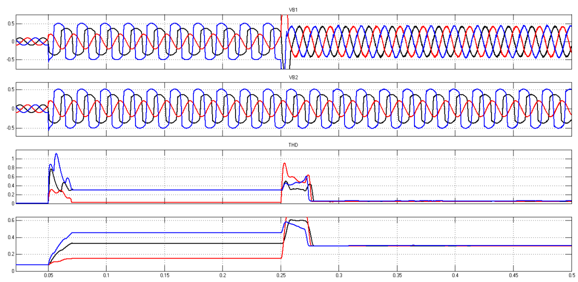

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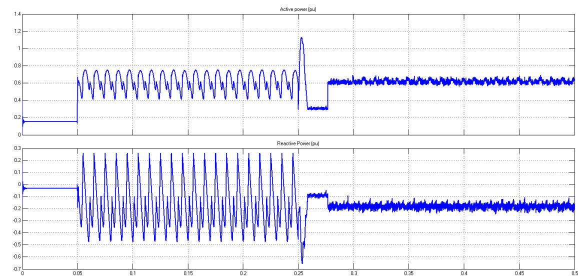

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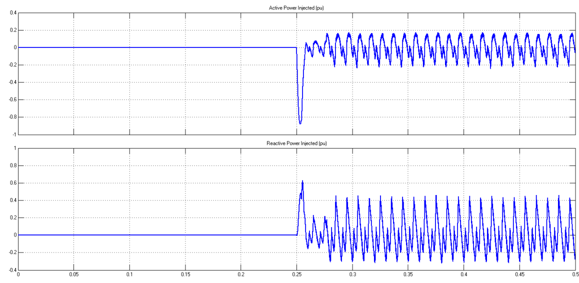

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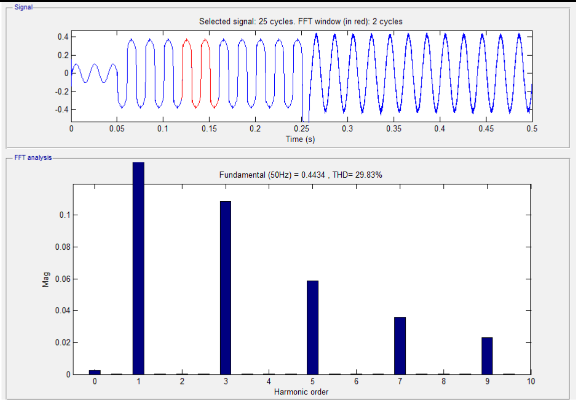

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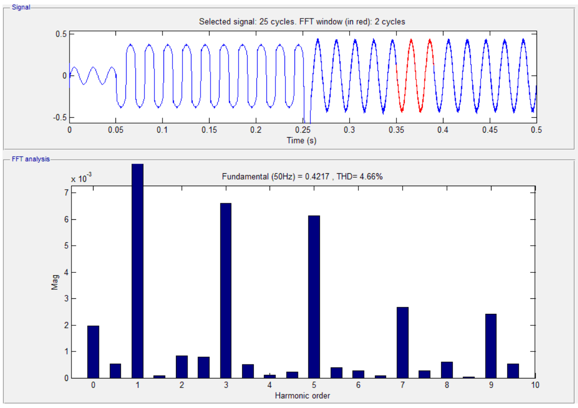

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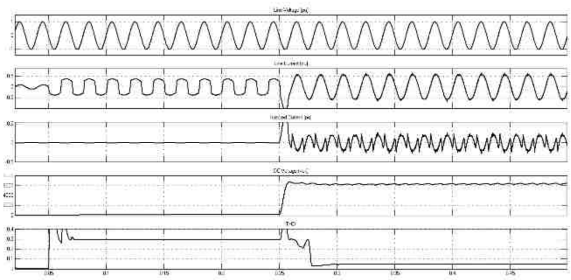
Fig.11: Asymmetric and dissimilar nonlinear loads compensation with a low single phase linear load (a) voltage, line current, injected current, dc voltage, and THD (b) three phase instantaneous and rms currents (c) power flow (d) injected power (e) THD of line currents before and (f) after compensation



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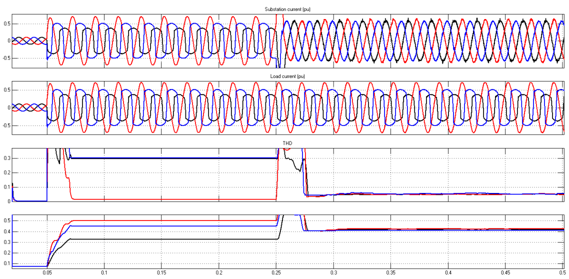

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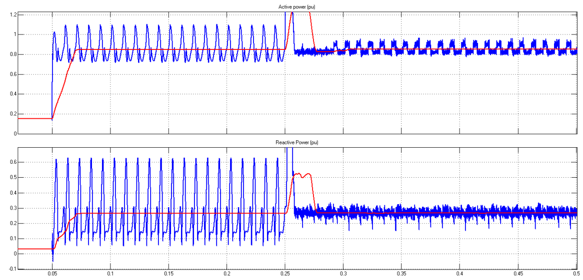

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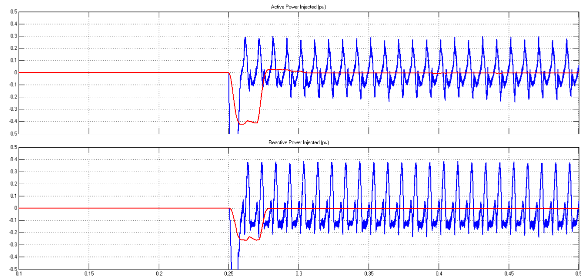

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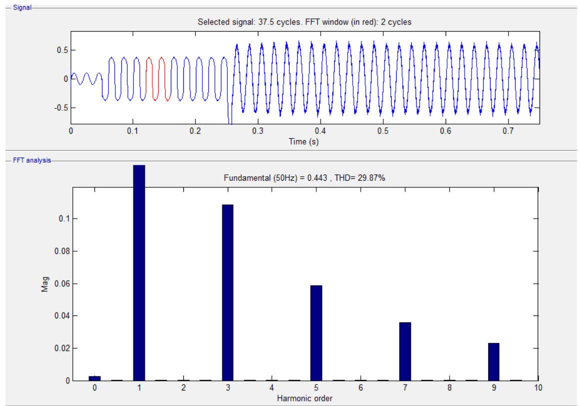

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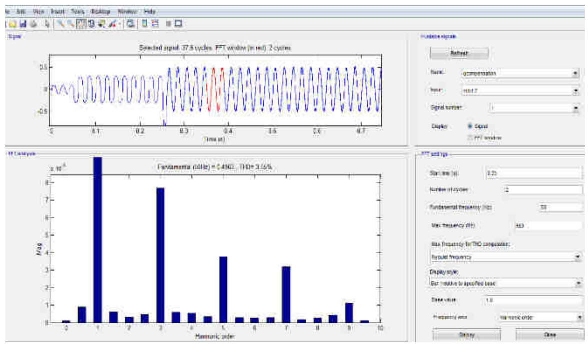

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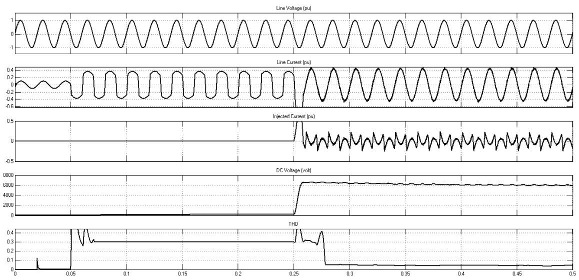
Fig.12: Asymmetric and dissimilar nonlinear loads compensation with a high single phase linear load (a) voltage, line current, injected current, dc voltage, and THD (b) three phase instantaneous and rms currents (c) power flow (d) injected power (e) THD of line currentsbefore and (f) after compensation.

7.3 FUZZY LOGIC BASED UNBALANCE COMPENSATION USING DQ-PQ THEORY

A fuzzy logic control is also used in SAF for compensating unbalance nonlinear loads. As shown in figure (13) the response, THD, and the ripple in power is modified. The

THD is reduced to 3.57% compared with PI controller the THD was 4.66% absolutely this leads to decrease in ripple of power flow.



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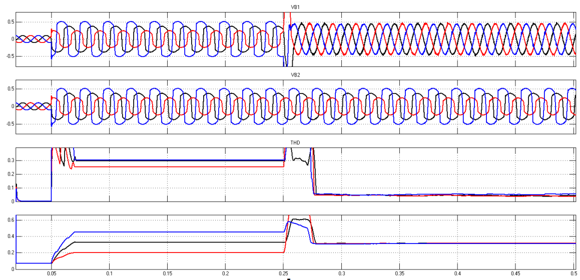

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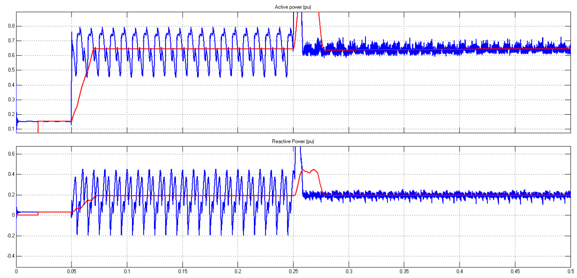

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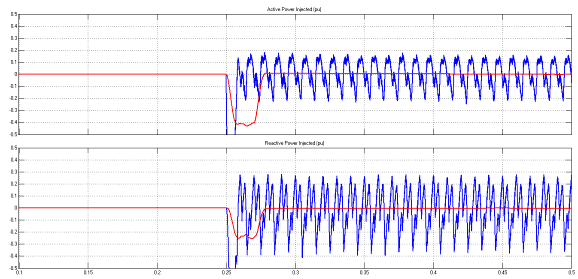

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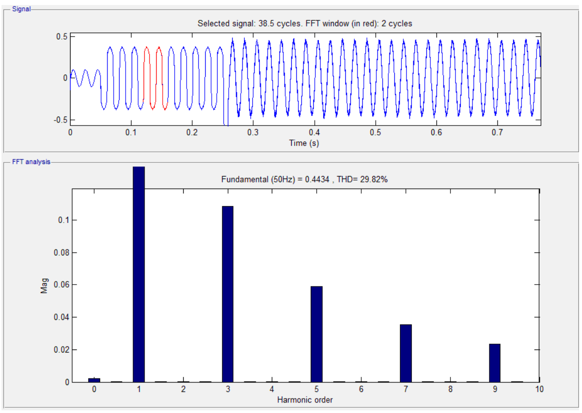

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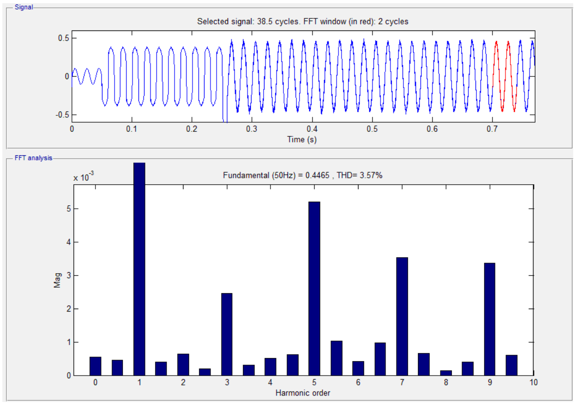

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Fig.13: FLC for asymmetric nonlinear loads compensation(a) voltage, line current, injected current, dc voltage, and THD (b) three phase instantaneous and rms currents (c) power flow (d) injected power (e) THD of line currents before and (f) after compensation

VIII. CONCLUSION

Unbalance harmonics currents cause a high ripple in power flow, increase the losses and effect on the PCC that connect another loads.A pq theory could not compensate unbalance nonlinear loads even in three phase balance voltage system. The proposed dq-pq theory has the ability to compensate unbalance nonlinear load as well as dissimilar load currents efficiently. The angular frequency based on line current rather than the voltages this has an evident effect on the compensation. The proposed controller minimizes the ripple in power flow. Referring to all the figures it is clear that the real power consumed for compensation is equal to zero and the compensation is not effect on the power flow of the power system. Finally, FLC improve the performance of the SAPF and reduces the THD from 4.66% to 3.57%.

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