# POWER QUALITY IMPROVEMENT USING A FUZZY LOGIC CONTROL OF A SERIES ACTIVE FILTER

**S.S. MORTAZAVI , M. RAZAZ, AND E. KHAVARI**

Department of Elect. Egg, Shahid Chamran University, Ahvaz, Iran

**Abstract**: A fuzzy logic controller (FLC) with fast reference voltage generation to correct and regulate unbalance voltage in three-phase system is proposed. The compensation algorithm is not based on three-symmetrical component decomposition so the controller can yield a fast response that is essential in such a critical real time control work. The reference voltage is fed to the FLC , which is a robust closed loop controller. The proposed algorithm and control scheme of series active filter may correct and regulate unbalance voltage in three-system under different conditions of the utility supply.

Key words: *Series Active Filter, Fuzzy Logic Control, Power Quality Improvement, Voltage Unbalance*

## 1. INTRODUCTION

Power quality in ac three-phase systems could be analyzed by; Voltage unbalance, Voltage sags, Voltage swells, partial or total loss of one or more phases (IEEE std. 1159-1195).

A major cause of voltage unbalances is the uneven distribution of single-phase loads, which may be continuously changing across a three-phase power system. Additional causes of power system voltage unbalances can be asymmetrical transformer winding impedances, open wye and open delta transformer banks, and asymmetrical transmission impedances [1].

Voltage unbalance causes a lot of ill effects on induction motors. The adverse effects of voltage unbalance in induction motors are overheating, line-current unbalance, derating, torque pulsation, and inefficiency. The overheating leads to winding insulation degradation [2].

The poor power quality can degrade or damage the electrical equipment connected to the system. Improving the power quality may be provided using a three-phase series active filter, active filter may correct the voltage unbalances and regulate it to the desired level.

So far, few algorithms of regulation has been proposed in the literature[3-7].This study proposes a compensation algorithm using a series active filter (SAF) associated with the fuzzy logic controller to correct and regulate the unbalance voltage in three-phase system .

The proposed SAF is composed of a three-phase PWM voltage source inverter injecting compensation voltage through three separate 1-Ø transformers. The output of inverter is connected to a second order filter to eliminate high frequency caused by the switching action of the inverter. The secondary winding of each transformer is connected in series with each phase of the power supply as shown in Fig. 1.

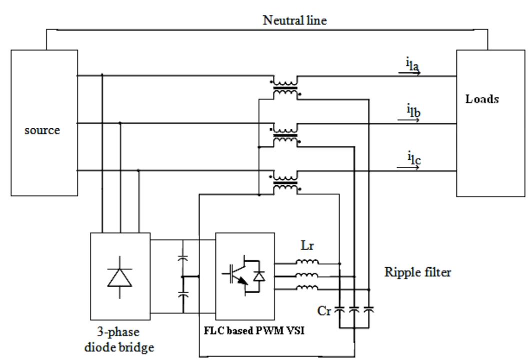



Fig. 1: Diagram of proposed series active filter

## 2. Principle of voltage correction :

Reference voltage generation: The phasor diagram of a balanced voltage of utility three-phase line is shown in Fig. 2. The vectors formed by $v_{ab}$ , $v_{bc}$ and $v_{ca}$ represent the line-to-line voltages while $v_a$ , $v_b$ and $v_c$ represent the phase voltages.

Under fault condition, the phase voltages in Fig. 2 are unbalanced. The instantaneous voltage of phase A with amplitude $v_a$ and phase angle Ø can be derived by Eq. 1:

$$v_a(t) = \frac{1}{\sqrt{3}}(v_{ab}(t) - v_{ca}(t)) \qquad (1)$$

Where:

$$v_a(t) = V_a \sin(\omega t + \phi)$$

(2)

Where, $v_{ab}$ and $v_{ca}$ represent the instantaneous line-to-line voltages shown in Fig. 2.

The amplitude, $v_a$, can be calculated from data in a short time window using two samples of the signal $v_a(t)$ as shown in Eq. 3[6] :

$$V_a = \frac{[v_{a(k+1)}^2 - v_{a(k)}^2 - 2v_{a(k+1)}v_{a(k)}\cos(\omega T_s)]^{0.5}}{\sin(\omega T_s)} \qquad (3)$$

$V_{a(k+1)}$ and $v_{a(k)}$ are the phase-A voltage at instant $t_{(k+1)}$ and $t_{(k)}$ respectively and sampling period $T_s$ is equal to $[t_{(k+1)}-t_{(k)}]$.

The reference voltages for FLC are calculated as following:

$$v_{ref}(t) = \frac{V_{rated}}{V_n} \times v_a(t) \qquad (4)$$

$$\begin{bmatrix} v_{refa} \\ v_{refb} \\ v_{refc} \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} 0 \\ v_{ref} \\ 0 \end{bmatrix}$$

(5)

Where:

$V_{rated}$ is the rated amplitude of load voltage and $\alpha$ is phase shift operator.

**3. Fuzzy logic controller (FLC)**

The reference voltage generated in Eq. 4 and Eq. 5 is fed to the FLC as shown in Fig. 3.

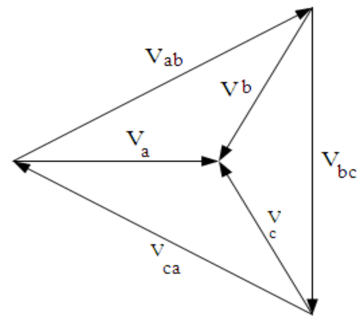



Fig. 2: Phasor diagram of a balanced voltage of utility three-phase line

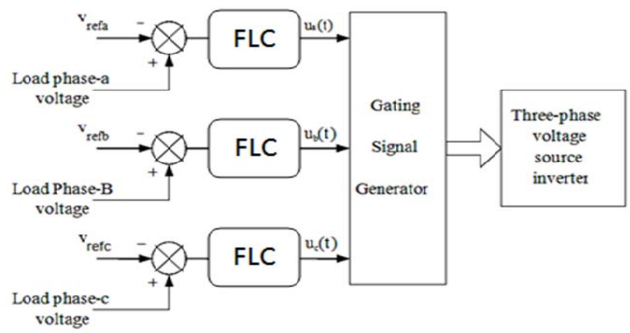



Fig. 3 : Fuzzy logic controller structure block diagram

The fuzzy control algorithm is implemented to control the load phase voltage based on processing of the voltage error e(t) and its variation Δe (t) in order to improve the dynamic of SAF.

The main advantages of fuzzy control are its linguistic description, independence of mathematical model, robustness, and its universal approximation.

A fuzzy logic controller is consisting of four stages: fuzzification, knowledge base, inference mechanism and defuzzification. The knowledge base is composed of a data base and rule base and is designed to obtain good dynamic response under uncertainty in process parameters and external disturbances .The data base consisting of input and output membership functions, provides information for the appropriate fuzzificztion operations, the inference mechanism and defuzzification. The inference mechanism uses a collection of linguistic rules to convert the input conditions into a fuzzified output. Finally, defuzzification is used to convert he fuzzy outputs into control signals. In designing of a fuzzy control system, the formulation of its rule set plays a key role in improvement of the system performance. The rule table contains 9 rule as shown in table 1 , where (N , Z ,P ) are linguistic codes (N : Negative , Z : Zero , P : Positive )[8].

The mamdani type fuzzy logic controller is used; the max-min inference method is applied in this study. The relation surface between inputs (e, de) and output (du) of FLC is shown in Fig. 4.

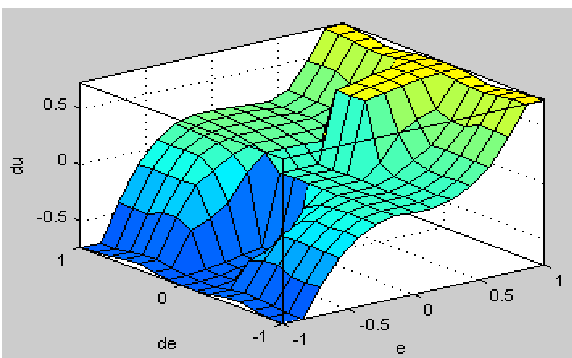



Fig. 4 : The relation surface between inputs and output of FLC

## 4. PWM gating signal generation

The gating signals of the inverter are generated by comparing the outputs of fuzzy controller with a triangular waveform whose frequency is kept constant at 6KHZ as shown in Fig. 5.

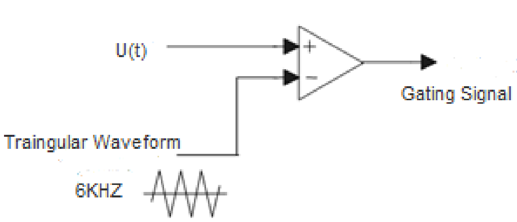



Fig. 5: Gating signal generation diagram

## 5. Power circuit implementation

As shown in Fig. 1, the power circuit of the series active filter consists of a three-phase PWM voltage source inverter, three separator 1- Ø transformers and a second order passive filter. The circuit design for the implementation can be found in [9], hence it is not include here.

## 6. Design example

In order to prove and validate the concept of the proposed algorithm, a design example is done in accordance as the procedure illustrate above. The design parameters are shown in table 1.

Table 1: Design example

| | |
|---|---|
| Utility supply frequency | 50 Hz |
| Rated load phase voltage | 220 V |
| Load power factor | 0.3 |
| Series transformer turn ratio | 0.5 |
| DC link voltage | $\frac{380\sqrt{2}}{\sqrt{3}} * 2$ |
| Invert switching frequency | 6 kHz |
| Filter inductance | 1 mH |
| Filter capacitance | 55 μF |

## 7. Results and Discussion

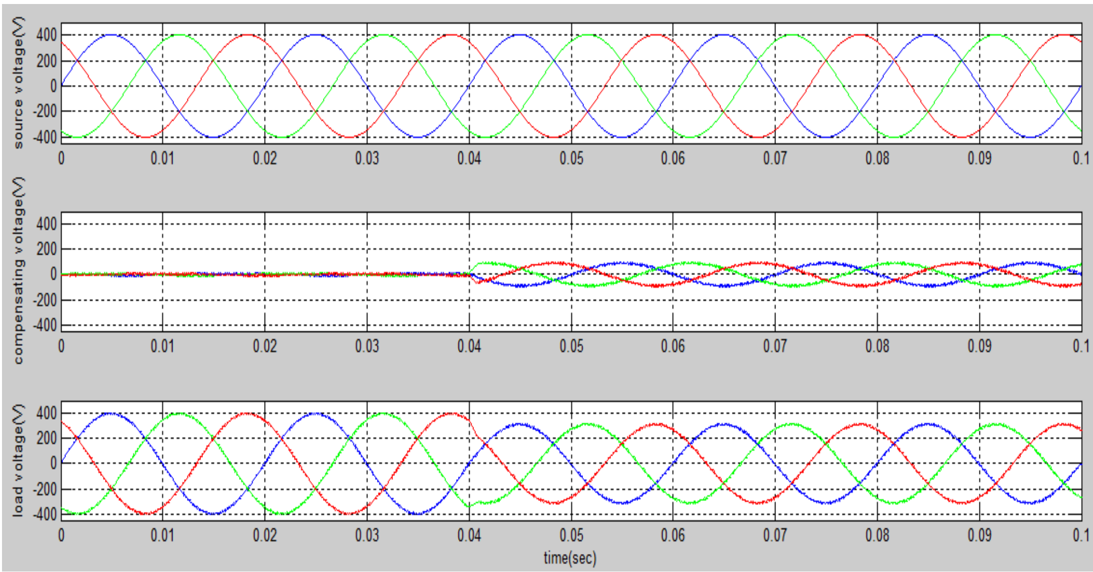
The proposed FLC has been verified by simulation in MATLAB area. Simulation of filter and loads and network is done in Simulink, Matlab. Few arbitrary supply voltage changes are applied and results are shown in Fig. 6-10. In each case the compensator begins to operate at 4msec to show changes before and after compensation.

The unbalance factor, UF is defined as the ratio between the negative sequence voltage $V_{-}$ and the positive sequence voltage $V_1$ to quantify the degree of unbalance factor as following:

$UF = (V_0 + V_-)/V_+$

Magnitude factor, MF is also defined as the ratio between the positive voltage and rated voltage required by loads $V_{rated}$ :

$$MF = \frac{V_+}{V_{rated}}$$

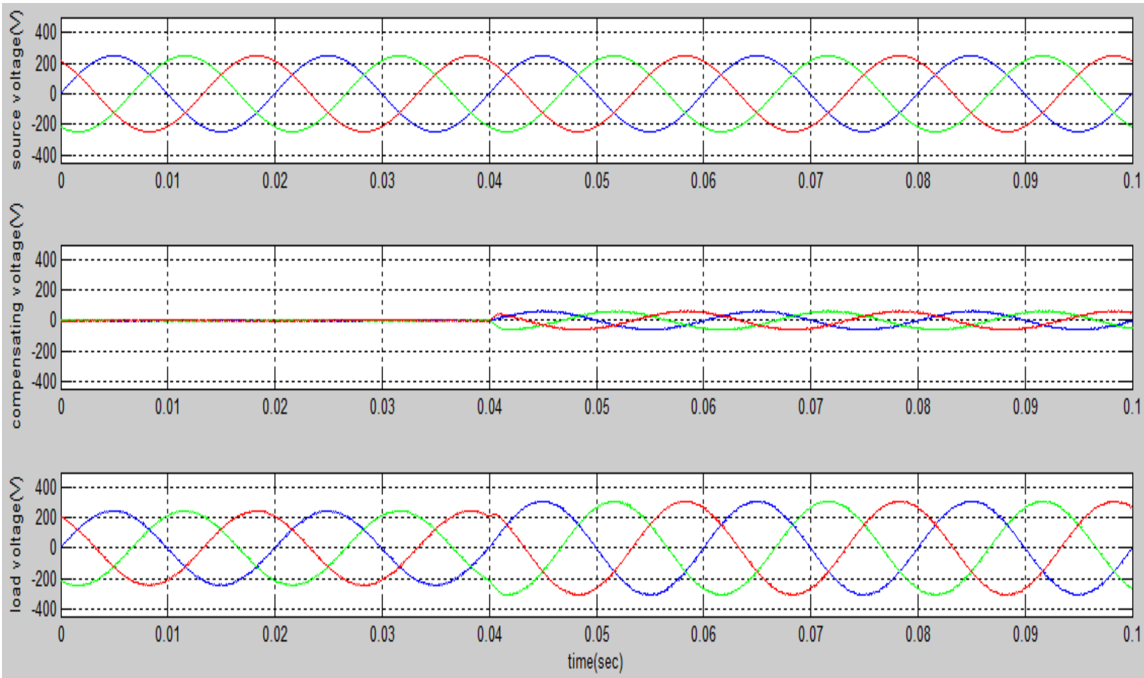



(a)


(b)

Fig. 6: (a): Source phase voltage, compensating voltage and load phase voltage in case of balance voltage swells with $|MF| = 1.3$;

(b): Null current in this case

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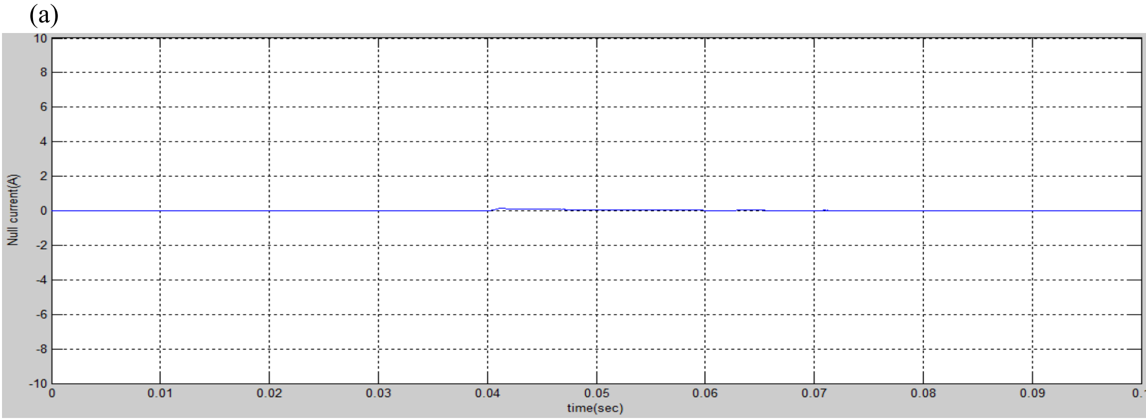
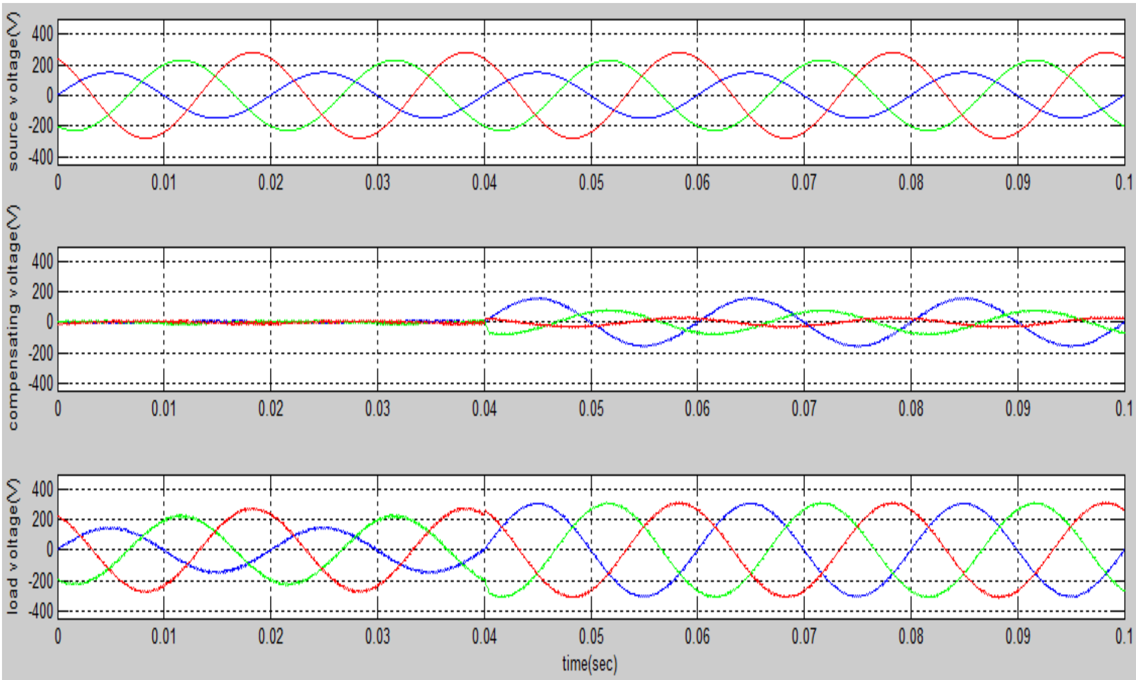



(b)

Fig. 7: (a): Source phase voltage, compensating voltage and load phase voltage in case of balance voltage sags with $|MF| = 0.8$;

(b): Null current in this case

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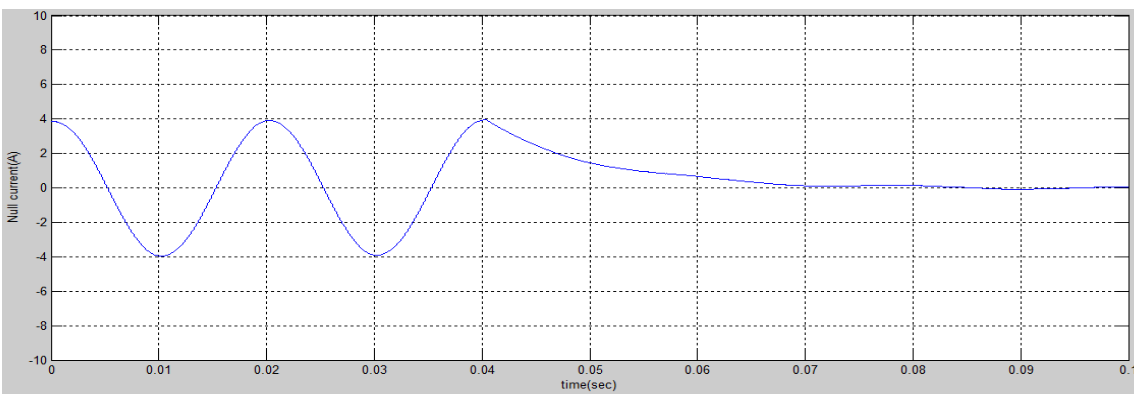
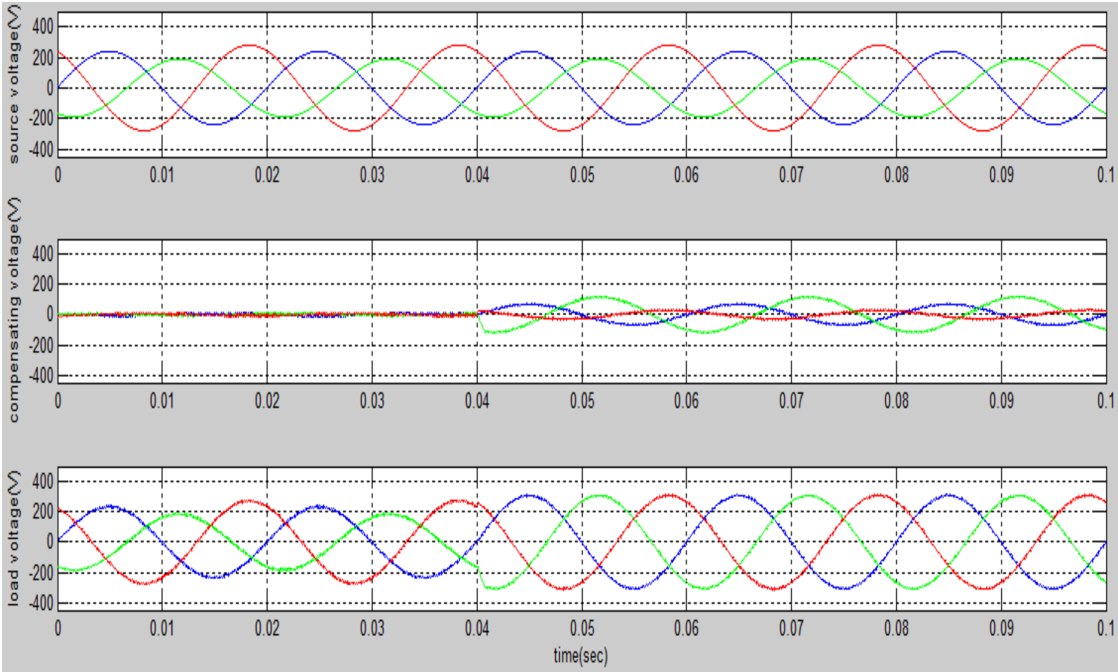



(b)

Fig. 8: (a): Source phase voltage, compensating voltage and load phase voltage in case of balance voltage swells with $|UF| = 0.35$ and $|MF| = 0.7$;

(b): Null current in this case

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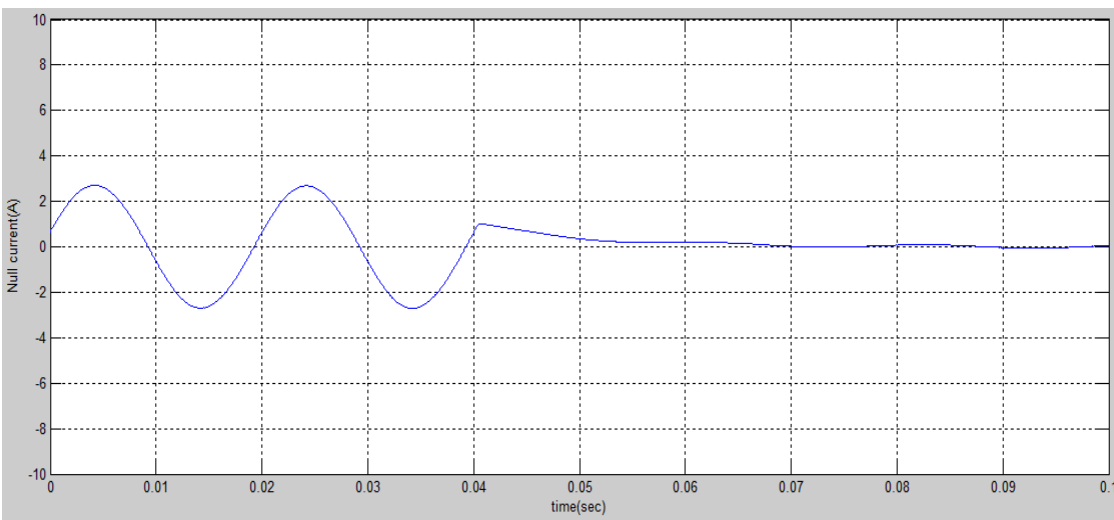
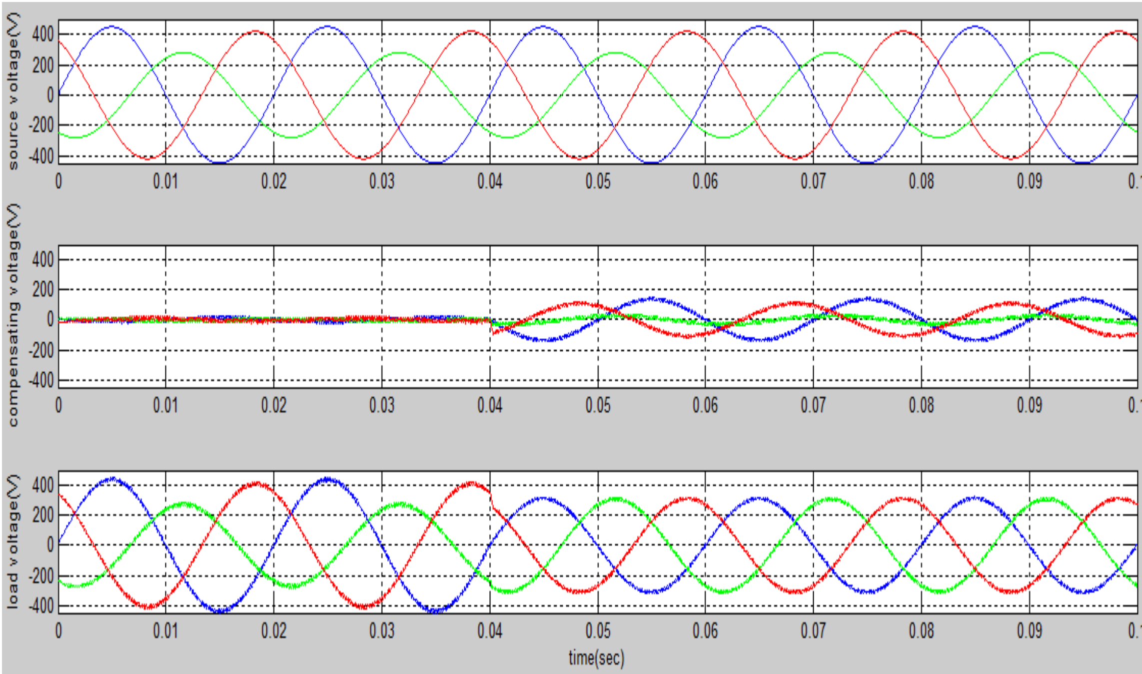



(b)

Fig. 9: (a): Source phase voltage, compensating voltage and load phase voltage in case of balance voltage swells with $|UF| = 0.22$ and $|MF| = 0.75$;

(b): Null current in this case

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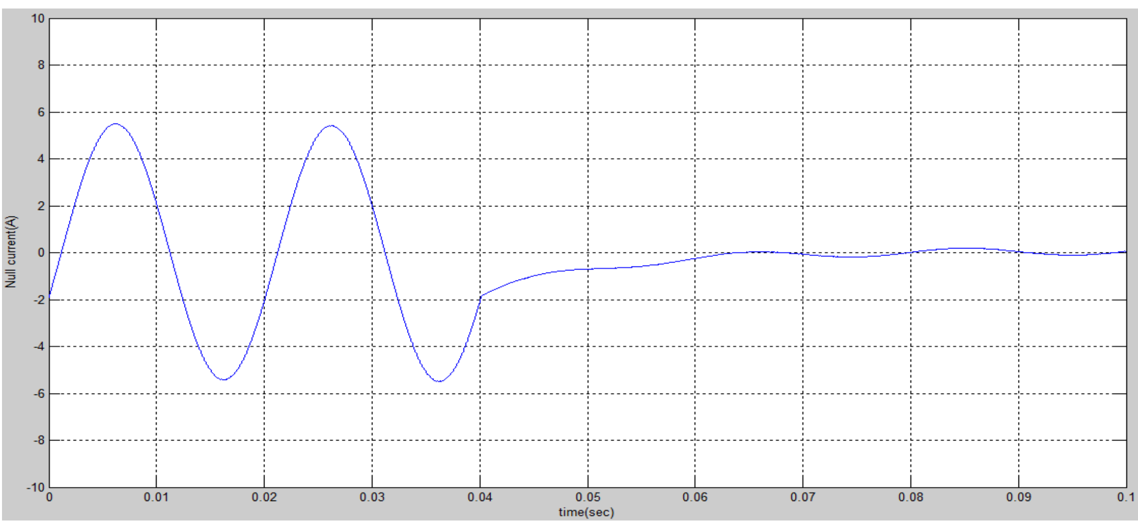


(b)

Fig. 10: (a): Source phase voltage, compensating voltage and load phase voltage in case of balance voltage swells with $|UF| = 0.27$ and $|MF| = 1.2$;

(b): Null current in this case

The error between the load voltage and the required rated voltage can be quantified using magnitude factor. In each of different simulation study, magnitude and unbalance factors are calculated and given with each figure. It is clear that proposed filter has been able to bring the load phase voltages to their normal condition by inserting compensation voltages to the system. It also causes the null current approaches to zero.

## 8. CONCLUSION

In this study, a fuzzy controller with fast reference voltage generation to regulate Unbalance voltage in three-phase system is presented and analyzed. The algorithm avoids the computational load by symmetrical components decomposition.

The simulation results show a very good performance of the proposed algorithm and control scheme under arbitrary fault conditions of the utility supply.

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