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Utilizing the MATLAB-SIMULINK Based Technique for Teaching the Harmonic Compensation Using Fuzzy Based Control of Series Active Filters for Two Different Case Studies, Balanced and Unbalanced Nonlinear Loads

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ABSTRACT

Harmonic filtering is the most important method of preventing the harmonics from entering the distribution system and mitigating their adverse effects on electrical equipment. One of harmonic compensation in electrical power system is the utilization the active power filters instead of traditional passive filters. Active filters don't have the problems due to passive filters implementation such as resonance and point setting variation due to system upgrading. Due to educational purpose of this paper to teaching compensation advantages to graduate students the well-known software MATLAB-SIMULINK has been employed to simulate and investigate the series active filters on harmonic elimination and also to understand the fuzzy controlling approach to compensate the balanced and unbalanced load.

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INTRODUCTION

Once the harmonic sources are clearly defined, they must be interpreted in terms of their effects on the rest of the system and on personnel and equipment external to the power system. Each element of the power system must be examined for its sensitivity to harmonics as a basis for recommendations on the allowable levels. The main effects of voltage and current harmonics within the power system are [3-5]:

- Amplification of harmonic levels resulting from series and parallel resonances.
- Reduction in the efficiency of the generation, transmission and utilization of electrical energy.
- Ageing of the insulation of electrical plant components with consequent shortening of their useful life.
- Malfunction of system or plant components.

The effects of voltage distortion are:

- Thermal stress
- Load disruption
- Insulation stress

Harmonics increase the equipment losses and thus the thermal stress. The triple harmonics result in the neutral carrying a current which might equal or exceed the phase currents even if the loads are balanced. This dictates the derating or over sizing of neutral wires. Moreover, harmonics caused resonance might damage the equipment. Harmonics further interfere with protective relays, metering devices, control and communication circuits, and customer electronic equipment. Sensitive equipment would experience mal-operation or component failure.

Harmonic currents in the power distribution system can cause [6, 7]:

- Transformer secondary voltage distortion
- Overloaded neutrals and capacitors
- Telephone and communication system noise
- Increased power losses and thermal stress
-

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1. Harmonics Module:

This module consists of 5 weeks theoretical course was held in *Marvdasht Branch of Islamic Azad University*. The most important contents of this module includes of harmonic principles and its difference with other power quality phenomena. The harmonics effects on power system are introduced, analyzed and finally the method of harmonics compensation and elimination based implementation of shunt active power filter are investigated. It also covers some examples in this area. The aim of this module is to introduce a helpful method to instructor for teaching the examples of harmonic distortions, its effects on power system and its mitigation and compensation with their results. Therefore, the author of this article has been using MATLAB-SIMULINK as an instructional tool to teach this subject. This method of instruction has enabled students to understand the harmonics concept and the necessity of harmonics elimination and compensation subject.
The success rate of students in understanding the subject shows the ability of this method.
An essential feature of using MATLAB-SIMULINK is to incorporate the visualization and control of results in a graphical form on a computer screen. This is particularly important in the analysis or simulation of power networks because of their large size and wide geographical distribution.
In order to better describe of harmonic concepts, at first four questions as follows are presented:

- What is harmonics?
- What are the effects of harmonics on power system?
- What is method of harmonics elimination?
- What is the performance of series active power in harmonic compensation?
- What is basic of fuzzy approach in the controlling of active filters?
- What id difference between the active filter in harmonic compensation under balanced with unbalanced load?

2. Control of Series Active Power Filter With Fuzzy Logic controller:

Fig.1 shows a three-phase circuit with a voltage source that feeds a balanced nonlinear load and a series hybrid filter. The source impedance is constituted by a resistance RS and an inductance LS. The active power filter is connected in series with the source through a coupling transformer. The passive filter is connected in parallel with the load. It consists of two LC branches tuned to 5^{th} and 7^{th} current harmonics.

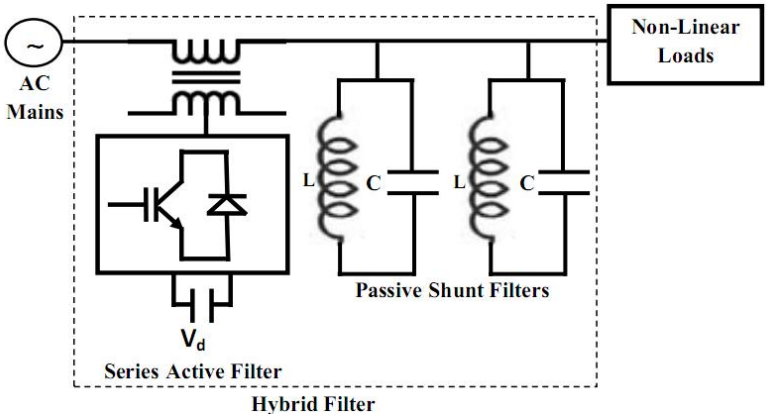

Fig. 1: basic configuration of hybrid filter

As shown in Fig.2 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.

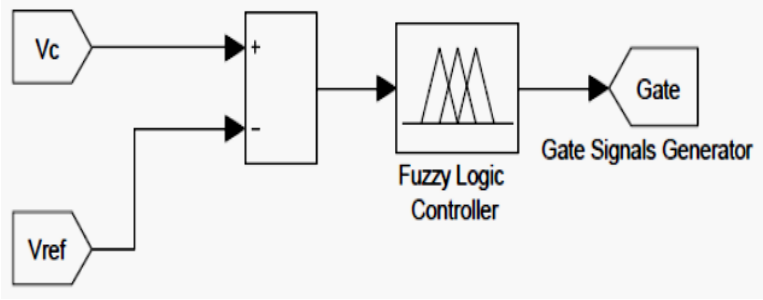

Fig. 2: Fuzzy controller structure block diagramThe main advantages of fuzzy control are its linguistic

Description, independence of mathematical model, robustness, and its universal approximation [11].

As shown in Fig.3 the fuzzy logic controller is consisting of four stages: fuzzification, knowledge base, inference mechanism and defuzzification.

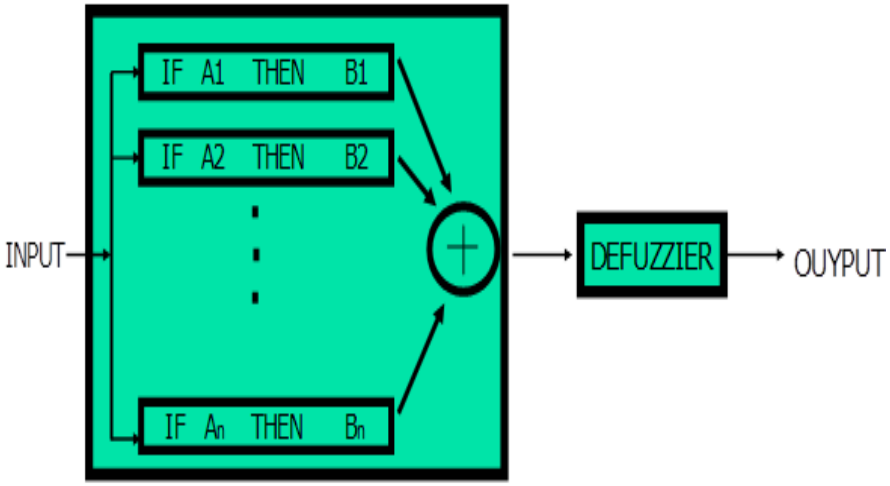

Fig. 3: the basic scheme of fuzzy logic controller

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.

As shown in Fig.4 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 the fuzzy outputs into control signals.

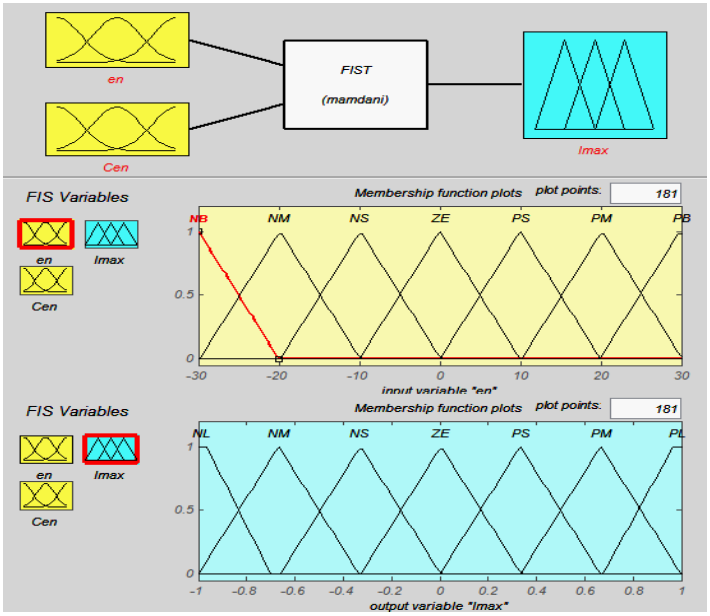

Fig. 4: the GUI interface of fuzzy logic controller setting in MATLAB

3. Simulation and Results:

In this section the simulated test system to investigate the performance of series active filter for harmonic compensating due to connection of balanced and unbalanced nonlinear load at demand side of system in MATLAB-SIMULINK software is presented. In balanced case, as indicated in Fig.5, the three-phase load is built with three single phase uncontrolled rectifiers with capacitors and resistors connected in parallel at the dc side.

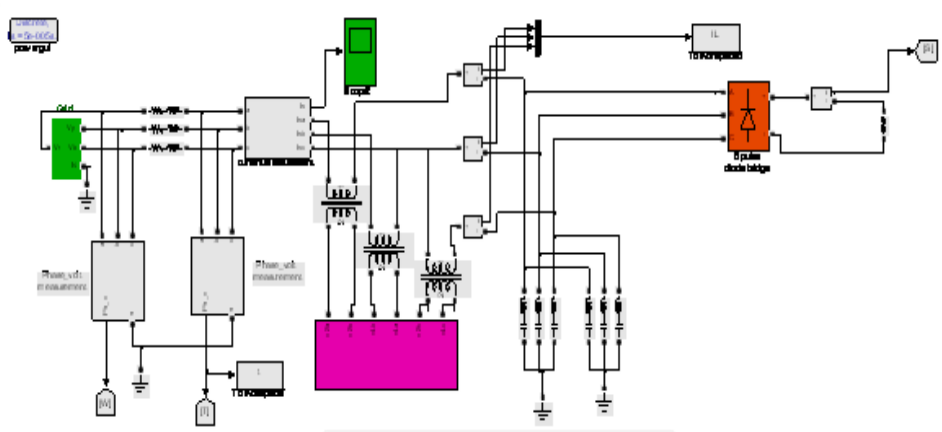

Fig. 5: Simulated test system with active filter with balanced nonlinear load

In unbalanced case, as shown in Fig.6, the nonlinear load consists of an uncontrolled three-phase rectifier with an inductance of 45 mH and a 32 resistor connected in series on the dc side.

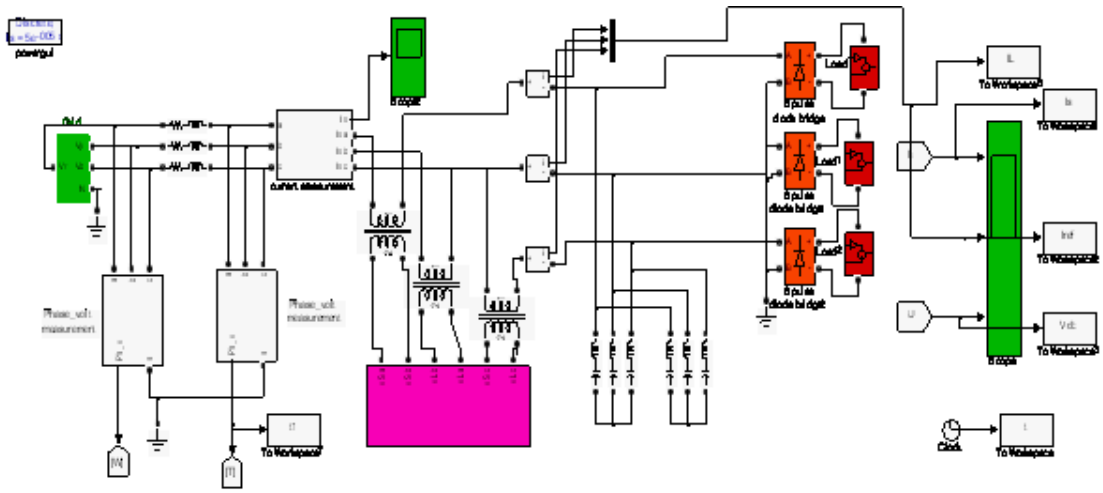

Fig. 6: Simulated test system with active filter with unbalanced nonlinear load

The configuration of series active filter is presented in Fig.7.

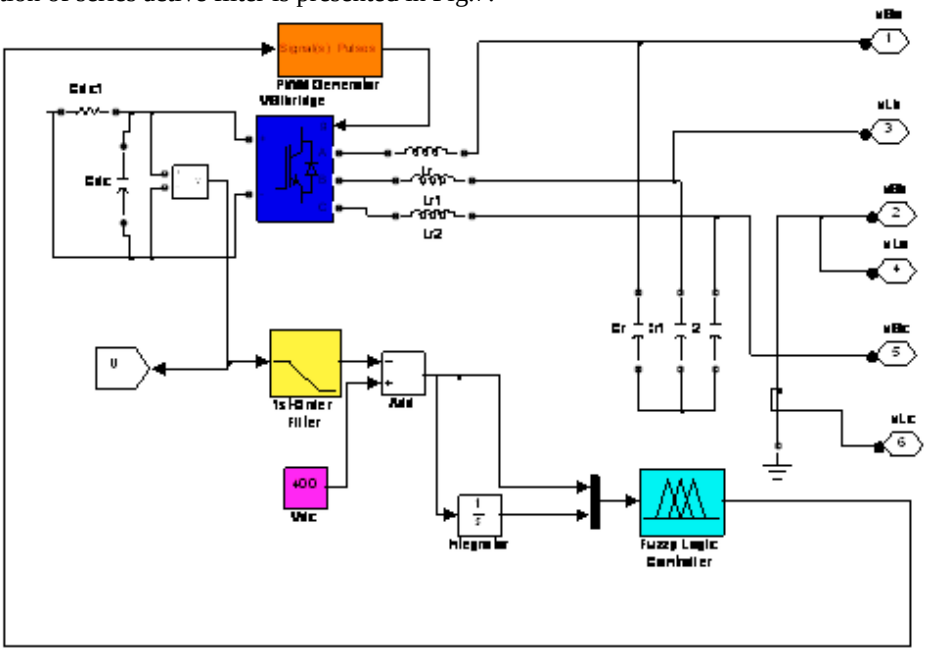

Fig. 7: The circuit of series active power filter

The source current with and with\out filters as shown in Figs.8-9.

In first case due to considering the balanced load in this study only the source currents of a phase ‘a’ current wave form with and without filters as shown in below Figs.8-9 respectively.

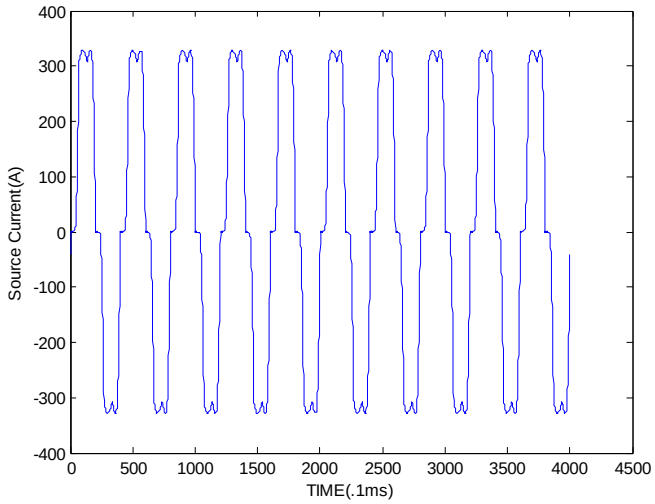

Fig. 8: The source current of phase ‘a’ of balanced nonlinear load without any compensation

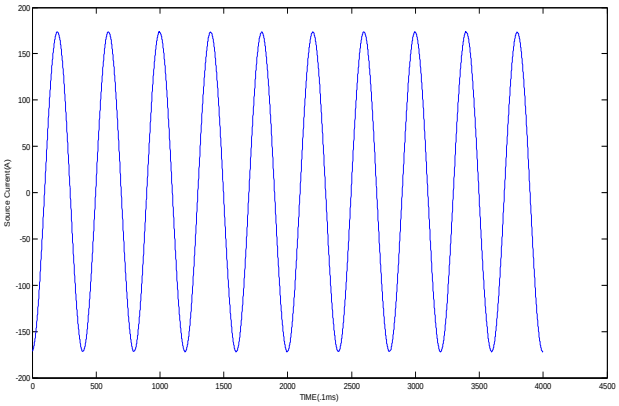

Fig. 9: The source current phase ‘a’ of balanced nonlinear load after compensation

In the second case with unbalanced load the three phase source current without/with filter is indicated in Figs.10-11.

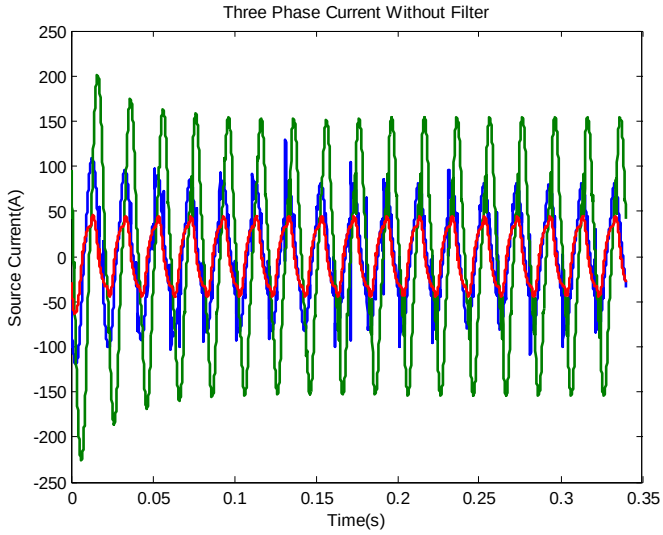

Fig. 10: The three phase source current without hybrid series active filter

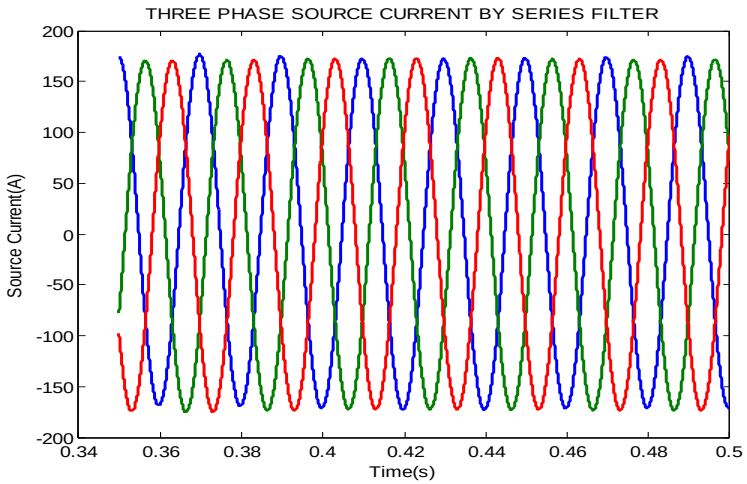

Fig. 11: Three phase source current with series active filters

4. Students Feedback:

The methodology illustrated in this paper has explained for 30 senior undergraduate students in power system, all of them have passed power quality courses. The students employ the methodology and in the presence of instructor filled a questionnaire form. The questionnaire, comprising six questions, is listed in Table 1. The students graded them as 1(poor), 2 (medium), 3 (good), and 4 (excellent). Figure 12 shows the global results obtained from the students' questionnaire.

Table 1: Questionnaire Answered by the Students and Engineers

Question		Score
1.	The content of this practical is valuable for a student of engineering course	
2.	Are you understanding the concept of harmonics and its difference with other power quality phenomena	
3.	Are you more familiar with the influence of harmonics on power system operation	
4.	Are you more familiar with the influence of harmonics compensation on power THD and power factor	
5.	Are you more familiar with the influence of harmonics on deceasing iron and copper loss	
6.	Are you more familiar with the performance of shunt active filters in harmonics compensation under steady state	

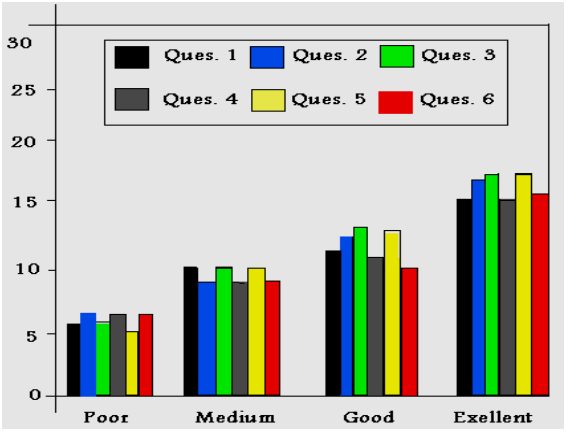

Fig. 12: Answers of students to the questionnaire.

Table 2 gives the average scores for each question out of students' feedback.

Table 2: Average Score Obtained From Students' Answers

	Average Score
Question 1	3.00
Question 2	3.50
Question 3	4.00
Question 4	3.82
Question 5	3.75
Question 6	3.53
Total	3.34

5. Conclusion:

In this research the power quality improvement through harmonic compensation using combination of a series active filter and a traditional passive filter is presented and analyzed. The considered passive filter in this research is consists of two passive LC filters, one for 5^{th} harmonic filtering and another for 7^{th} harmonic order. Due to deficiency in operation of passive filters, a series active filter also connected to system at PCC which nonlinear load is connected to system as parallel to passive filter. The proposed harmonic compensation approach has been simulated using MATLAB/SIMULINK and results showed the validity of research. The simulation results indicated that using harmonic compensation by a hybrid configuration based of series active filter the harmonic frequencies of source current decreases and also in unbalanced case the active filter is able to harmonic compensate effectively and it also could mitigate the degree of unbalance of system and in presence of active filter the source current will be balanced which the source current wave after harmonic compensation verified this matter.

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