Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345 (Online)
An Open Access, Online International Journal Available at www.cibtech.org/sp.ed/jls/2014/03/jls.htm
2014 Vol. 4 (S3), pp. 957-963/Nafar et al.
Research Article

ANALYSIS THE P_Q THEORY IN HARMONIC COMPENSATION USING ACTIVE FILTERS FOR TEACHING TO GRADUATE STUDENTS USING MATLAB-SIMULINK

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ABSTRACT
The paper deals with teaching the theory of instantaneous reactive power (p-q Theory) to graduate students in harmonic compensating course. This theory is most used in control system of harmonics equipment compensator such as active filters. Harmonic current which is generated during connection of a nonlinear load to system, if it multiplied by the network impedance it will distort the network voltage. In this research the basic concepts of this theory is first analyzed and reviewed and in second step to better understanding this theory in harmonic compensation a simplest simulation in analyzed. Due to educational purpose of this paper to teaching compensation advantages to graduate students the well-known software MATLAB-SIMULINK is used to simulate and investigate the effects of harmonics mitigation.

INTRODUCTION
Non-linear loads, especially power electronic loads, create harmonic currents and voltages inthe power systems. If the mains voltage is undistorted, but nonlinear loads are connected to the electrical grid, the current harmonics produced will cause voltage distortions in the line impedances, and the voltage at the load terminals will also be distorted. For many years, various active power filters (APF) have been developed to suppress the harmonics, as well as compensate for reactive power, so that the utility grid will supply sinusoidal voltage and current with unity power factor (Habrouk, 2000). Due to advancement in the technology, active power filters have become most habitual compensation methods. Shunt active power filters for three-phase three-wire and three-phase four-wire distribution systems have been presented (Nastran *et al.*, 1994; Morán *et al.*, 1997). This filter was widely used in transmission systems but has fewer effects on the distribution systems. In (Lesli and Negaard, 2001), author itself mentioned that shunt active filter compensation was not perfect solution. Improved solution to harmonic problem uses a hybrid active filter, which consists of shunt active and passive filter or series active and passive filters (Rahmani *et al.*, 2006). In many cases, non-linear loads consist of combinations of harmonic voltage sources and harmonic current sources, and may contain significant load unbalance (ex. single phase loads on a three phase system). To compensate for these mixed non-linear loads, a combined system of a passive filter (PF) and a series APF can be effective (Jou *et al.*, 2001). In this paper the instantaneous reactive power theory is utilized to teach the harmonic compensation concepts by means of shunt active filter to graduate students. Due to educational purpose of this research a simplest simulation of harmonic compensation using connection of a shunt active filter to system is presented and discussed.

The Instantaneous Reactive Power Theory
The control strategy is based on the p-q theory introduced by (Akagi *et al.*, 1983) and expanded to three-phase four-wire systems by (Aredes *et al.*, 1995). As shown in Figure 1 it applies an algebraic transformation (Clarke transform) of the three-phase system voltages and load currents in the *a-b-c* coordinates to the α-β-0 coordinates.

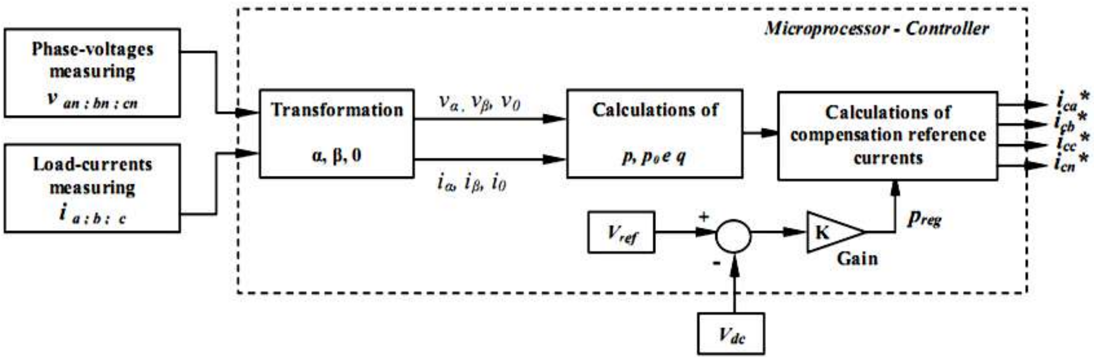

Figure 1: The schematic of P-Q theory in harmonic compensation

After the transformation, the p-q theory components are achieved by the expressions (1-3), where *p* is the instantaneous real power, *q* is the instantaneous imaginary power (by definition) and $\boldsymbol{p_0}$ is the instantaneous zero-sequence power.

$$p = \bar{p} + \tilde{p} = v_\alpha \times i_\alpha + v_\beta \times i_\beta \qquad (1)$$

$$q = \bar{q} + \tilde{q} = v_\alpha \times i_\beta - v_\beta \times i_\alpha \qquad (2)$$

$$p_0 = v_0 \times i_0 \qquad (3)$$

Each one of the instantaneous power components can be separated into an average value and an oscillating value. The physical meaning of each of the instantaneous powers is:

- $\bar{P}$ - average value of the instantaneous real power ***p***. Corresponds to the energy per time unit transferred from the source to the load, in a balanced way through the 3 phases.
- $\tilde{P}$ - Oscillating value of the instantaneous real power. It is the energy per time unity that is exchanged between the power source and the load, through the 3 phases.
- q - The instantaneous imaginary power, ***q***. Corresponds to the power that is exchanged between the phases of the load. This component does not imply any transference or exchange of energy between the power supply and the load, but is responsible for the existence of undesirable currents imply any transference or exchange of energy between the power source and the load.
- $\bar{P}_o$ - Mean value of the instantaneous zero-sequence power. It corresponds to the energy per time unity that is transferred from the power source to the load through the zero-sequence components of voltage and current.
- $\tilde{P}_o$ - Oscillating value of the instantaneous zero sequence power. It means the energy per time unity that is exchanged between the power source and the load through the zero-sequence components of voltage and current.

In addition to the standard power components, two new ones were also used in order to consider the energy coming from the renewable energy sources: $\boldsymbol{p_{res}}$ and $\boldsymbol{q_{res}}$.
The first one corresponds to the energy per time unit transferred from the renewable energy sources to the electric grid. As for $\boldsymbol{q_{res}}$, it is used because according to the Portuguese Law, it is compulsory to inject capacitive reactive "energy" during certain periods of the day, and therefore this must be considered in the control system.
There is also a component, $\boldsymbol{p_{reg}}$, which is used to regulate the capacitor voltage when there is no energy available from the renewable power sources.

The power components that will be injected by the Shunt Active Filter, p_x and q_x, include the undesired power quality effects to be compensated (harmonics, unbalance and reactive power) as well as the energy available in the renewable sources.

$$P_X = P_{res} - P_{reg} + \tilde{P} \quad (4)$$

$$q_X = \bar{q}_{res} + q \quad (5)$$

Finally, it is possible to calculate the reference currents, in the ***α-β-0*** coordinates, by applying the expressions (6). The reference currents are then translated to the ***a-b-c*** coordinates through the inverse Clarke transform.

$$\begin{bmatrix} i_{ref\_\alpha} \\ i_{ref\_\beta} \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} P_x \\ q_x \end{bmatrix} \quad (6)$$

$$i_{ref\,0} = i_{Lo} = \frac{1}{\sqrt{3}}(i_{La} + i_{Lb} + i_{Lc})$$

RESULTS AND DISCUSSION

In this section to analyse the presented teaching approach a simple model with nonlinear load is considered. Due to connection of this nonlinear load, the harmonics injected to system and so destroyed the voltage. To compensate the harmonics a shunt active filter is utilized. Due to special objective of this research, the controller system of shunt active filter is implanted based on instantaneous reactive power theory. This model is shown in Figure 2.

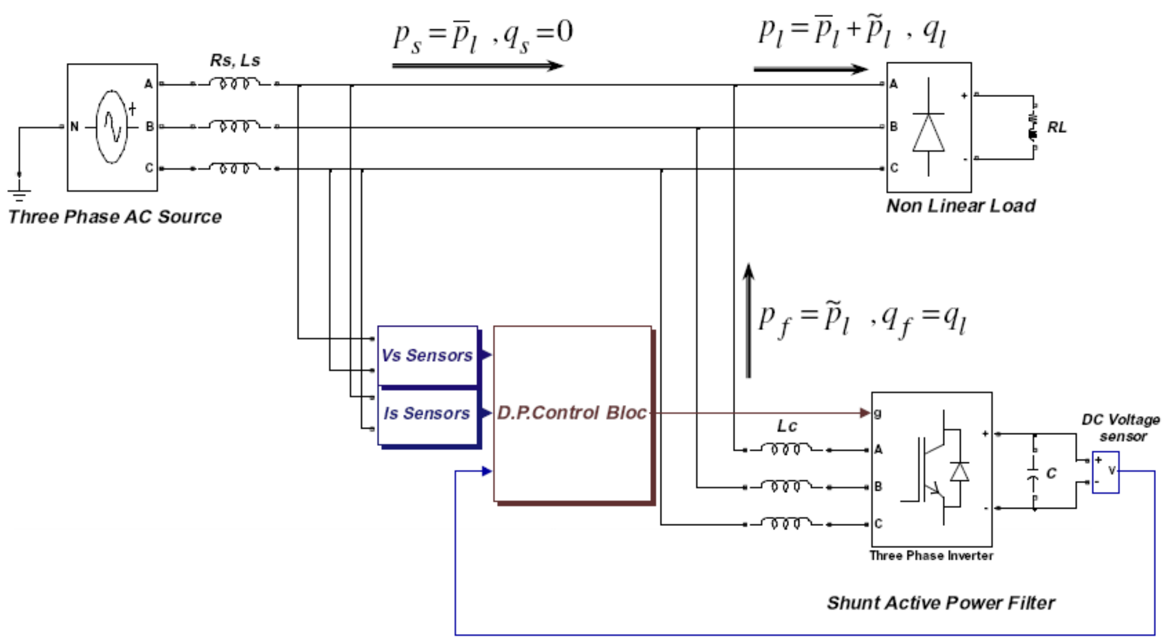

Figure 2: The presented model to study and teach the p-q theory in harmonic compensation

Figure 3 shows the source voltage, source current, dc side capacitor voltage. The filter is switched on at 0.10 s. The instant the filter is switched on the source current becomes sinusoidal from the stepped wave shape, and capacitor voltage reaches a steady-state value within a few cycles.

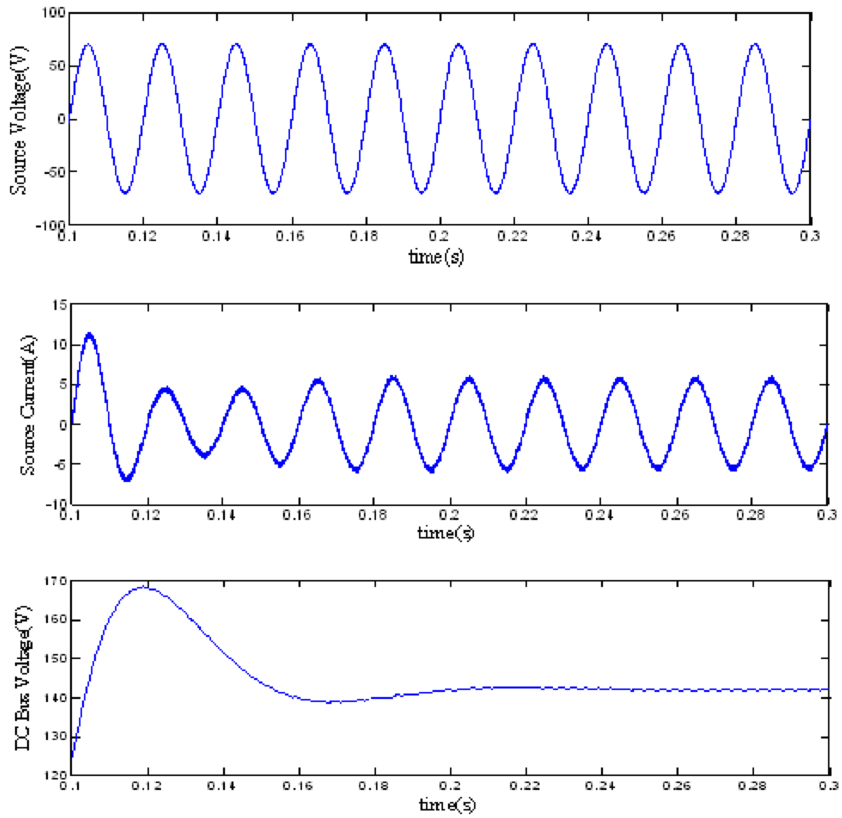

Figure 3: Source voltage, source current, DC side capacitor voltage waveforms, Filter switched on at 0.10 s.

In Figure 4 one can see that the active power joined its nominal value and that reactive energy becomes null when the active filter is activated at this moment.

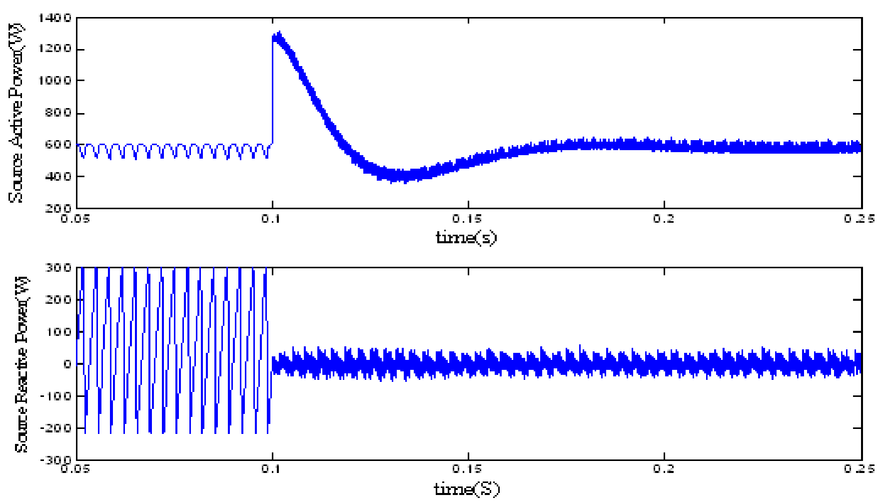

Figure 4: Active and reactive powers source, Filter switched on at 0.10 s.

Figure 5 shows the current of source before and after harmonic compensation. As seen in the above curve which is related to before compensation, the current is distorted to harmonics and after filtering the current is close to sinusoidal curve. This confirms that harmonic is compensated.

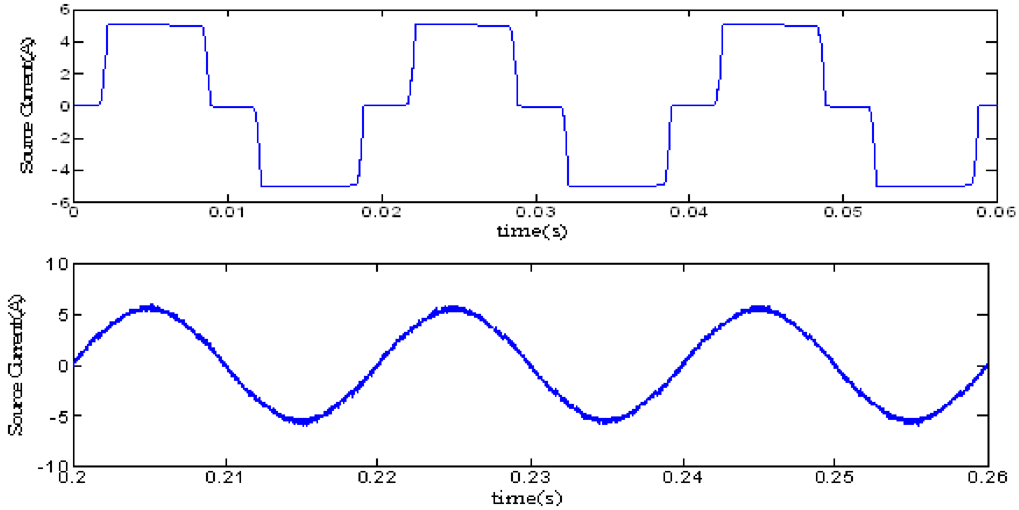

Figure 5: Source curent before and after harmonic compensation

Figure 6 shows the source current spectrum analysis beforeand after filtering. Before filtering; one can see the current harmonics distortion value was THDi= 27.03% and after filtering it will be THDi= 0.03%.

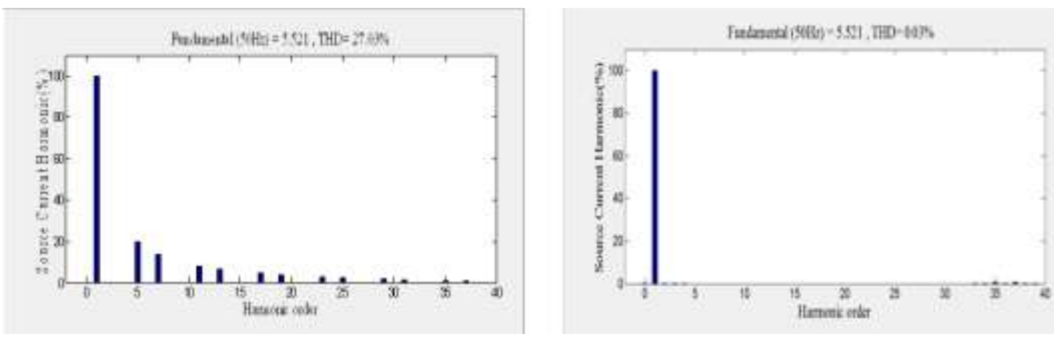

Figure 6: The THD of source current before and after filtering

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.

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	

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 7 shows the global results obtained from the students' questionnaire.

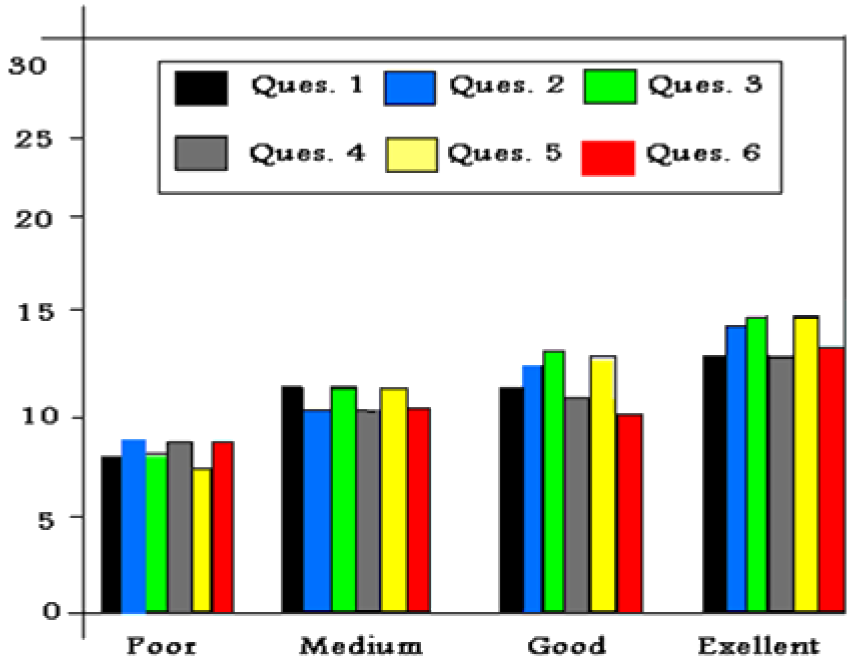

Figure 7: Answers of students to the questionnaire

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	3.32
Question 2	3.52
Question 3	3.78
Question 4	3.56
Question 5	3.12
Question 6	3.28
Total	3.45

Conclusion

This paper has outlined and presented an educational based MATLAB-SIMULINK model to illustrate and describes to how harmonics compensation using P-Q theory. At first the p-q theory is review and formulated and consequently a harmonic compensation problem due to nonlinear load is presented and solved. To use this p-q theory in harmonic compensation a shunt active filter based this theory is employed end simulated. The results of harmonic compensation using shunt active power filter based p-q theory is analyzed and presented also. Therefore, it is very useful for educational purposes and useful preparatory exercises for student to learn the subject. The evaluation of the project involving more than 30 students indicates benefits of this project in teaching the subject. The following conclusions could be achieved regarding the studied active filter and its control system:

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