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# ANALYSIS AND SIMULATION IN SIMULINK/MATLAB OF A THREE-PHASE ACTIVE POWER FILTER

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**Abstract:** In this article, the authors present the analysis and simulation process in the Simulink/MATLAB environment for a three-phase active power filter. Active power filters are used in power distribution systems to compensate for voltage and current disturbances. The Simulink model reproduces the key components of the filter, and simulations allow evaluation of its performance. The aim is to optimize the parameters and the control algorithm, thus ensuring a superior quality of the supplied electricity. This approach contributes to the development of more efficient and reliable electrical power distribution systems by providing a deeper understanding of the behavior and performance of the three-phase active power filter.

**Keywords:** Simulink/Matlab, Active Power Filter, Three-Phase, p-q theory, shunt.

## 1. INTRODUCTION

Three-phase shunt active power filters (APF) represent a modern and efficient solution for managing power quality in distribution systems. Good power quality is vital for power systems to ensure optimal operation of electrical and electronic equipment and to avoid disruptions in the network. Active power filters provide solutions to compensate for voltage and current disturbances through controlled current injection into the power grid.

This technology utilizes advanced power converters, electronically controlled, and sophisticated control algorithms to mitigate harmonics and compensate for reactive power. The principle of operation involves continuous monitoring of the network's state and generating a compensating current that eliminates disruptions and provides a power factor close to unity.

The analysis and simulation in Simulink/MATLAB of a three-phase shunt active power filter are crucial tools in the design and development of these devices. Through the Simulink environment, it is possible to create a virtual model of the filter, allowing the evaluation of its performance and optimizations before implementation in a real system.

Simulations enable the testing of different operating scenarios and the analysis of their effects on the system. Parameters and control algorithms can be adjusted to achieve the desired results. Thus, modeling and simulation in Simulink/MATLAB streamline the design process, reducing costs and the time necessary for the development of a three-phase shunt active power filter before real implementation.

This particular approach provides an in-depth understanding of the behavior and performance of a three-phase shunt active power filter, as well as the ability to identify and address potential problems before implementation. Thus, modeling and simulation in Simulink/MATLAB contribute to the development of more effective and reliable electrical energy distribution systems.

In recent years, the growth of harmonic pollution has become a major concern due to the proliferation of linear loads consumed by industrial and end-users.

Non-linear devices, where the current is not proportional to the applied voltage, include fluorescent lighting, diode rectifiers, thyristors, and uninterruptible power supplies (UPS). The existence of harmonics in the system can lead to significant losses, a decrease in power factor, and potential system failures [1], [2].

Harmonics can be defined as integral multiples of the fundamental frequency. They can also be understood as additional waveforms at frequencies that are multiples of the fundamental frequency. Electrical power systems can be seriously affected by problems related to harmonics.

In a three-phase system with a neutral conductor, when each phase is fully loaded, the combined fundamental current in the neutral will be zero. However, for odd harmonic triplets (3, 9, 15), the combined current is additive instead of canceling each other. Due to these issues, additional heating in the neutral conductor may occur [3], [4].

In Fig.1 [5] the connection principle of the shunt APF into power network is shown, the low voltage power source supplying nonlinear current into a uncontrolled rectifier load.

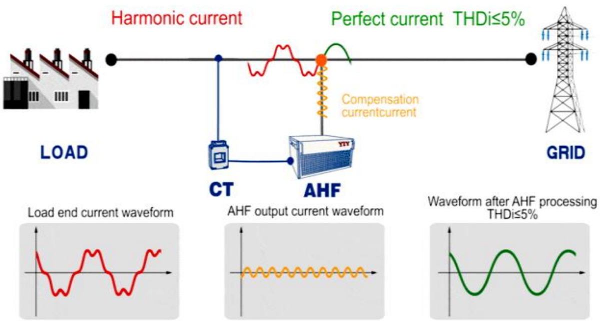


Fig.1. The principle of APF Low voltage power supply [5]

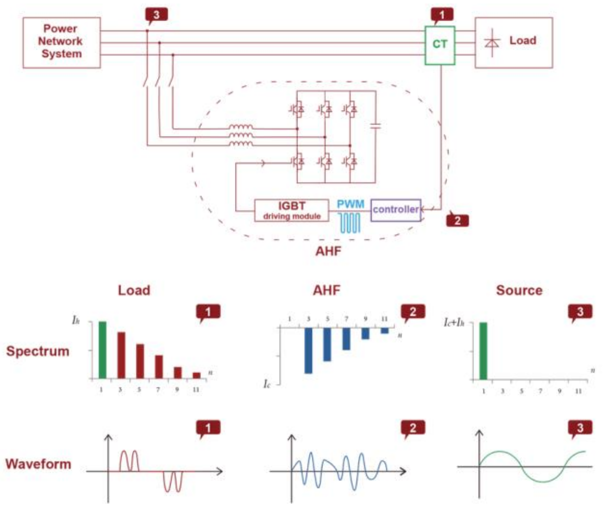


Fig.2. The spectrum and the waveforms of the currents into respective power network [5]

## 2. THREE-PHASE POWER FILTER ACTIVE SHUNT

Several types of mitigation methods have been introduced over the years and one of the most effective methods is APF. Other method used is Passive Filter (PF) but due to some disadvantages [6], APF is widely chosen as a viable method to solve harmonics problem in power distribution system [2],[8]. Figure 3 shows the diagram of the shunt APF integration into a 3-phase system electrical distribution system.

An active three-phase shunt power filter is an advanced solution used in electrical distribution systems for compensating voltage and current disturbances and improving the quality of delivered electrical energy. It is designed to function as a controlled current source, injecting a compensating current into the network to cancel harmonics and compensate for reactive power.

The main components of an active three-phase shunt power filter (Fig.2) include a power converter, an inductive current filter, a capacitive filter, and a controller. The power converter is responsible for converting energy and controlling the injected current into the network. The current filter ensures the mitigation of harmonics generated by devices connected to the network, while the voltage filter regulates the voltage at the filter terminals to compensate for voltage disturbances. The DC link capacitor (Fig.2) is responsible for reactive power production. The controller is responsible for monitoring and adjusting operating parameters of the filter, ensuring efficient compensation and stability in the system.

The goal of using an active three-phase shunt power filter is to improve the quality of provided electrical energy, reduce harmonics and voltage distortions, compensate for reactive power, and maintain a power factor close to unity. Through the control of the injected current, the active three-phase shunt power filter can quickly adjust the compensation level depending on the variations in the network and the requirements of the system.

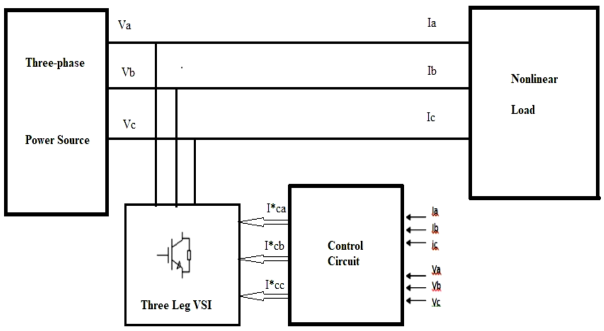


Fig.3. Shunt active power filter in three-phase system

The implementation and optimization of an active three-phase shunt power filter require modeling and simulation in the adequate programming platform. Through the Simulink/MATLAB environment, the performance and features of the filter can be evaluated under various operating conditions, identifying control solutions and parameters for achieving compensation objectives and improving the quality of electrical energy.

Therefore, the active three-phase shunt power filter represents a promising technology in the field of electrical energy distribution systems, offering significant benefits in enhancing the quality and efficiency of energy. Through modeling and simulation in the Simulink/MATLAB environment, detailed analysis and optimizations can be performed to ensure the required performances of the active three-phase shunt power filter in electrical power distribution systems.

## 3. PQ THEORY

The PQ theory (or reactive power theory) is a theory used in the field of power systems to analyze and control electrical power systems. It focuses on the separation and analysis of the active (real) and reactive components of a signal or an electrical system.

The PQ theory is based on decomposing a signal or a system into two components: **p** (active power) and **q** (reactive power). Active power is the component that performs useful work and produces useful outputs, such as generating light, heat, or mechanical work. On the other hand, reactive power is the component that does not directly perform useful work but is needed to support the operation of the electrical system, such as creating magnetic fields in coils and motors.

The PQ theory, also known as the instant power theory, was proposed by Akagi, Kanazawa, and Nabae in 1983 and is designed for a three-phase system with three wires [9]. After further research, Watanabe and Aredes extended it to a three-phase system with four wires, including the neutral wire [10]. The PQ theory is based on a time-domain transformation that converts the three-phase voltage and current from coordinates ABC to the αβ coordinates [11]. This transformation is applied using the Clarke transformation, for voltage (1.1) and current equations (1.2) [1].

The decomposition in PQ is typically realized using the (α,β) coordinate transformation method (or Clarke coordinates). This method transforms signals or phase variables into two components: $p$ and $q$. The $p$ component represents the active power, while the $q$ component represents the reactive power.

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{1.1}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{1.2}$$

The use of the theory is beneficial as it allows for a more efficient analysis and control of power systems. It provides detailed information about the balance and power flow in the system, enabling the identification and correction of problems such as energy losses, low power factor, and voltage fluctuations.

Furthermore, the PQ theory is employed in algorithms and controllers for optimizing and improving the performance of power systems. Figure 4 illustrates the flow for the PQ theory in calculating the necessary compensation current. The three-phase voltage and current are transformed into the αβ coordinates using the Clarke transformation.

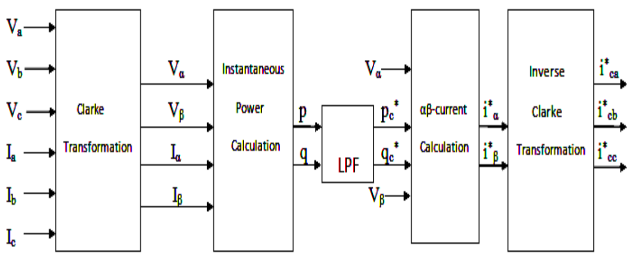


Fig.4. Shunt active power filter in three-phase system

The calculation of instantaneous active and reactive power components is accomplished in equation (2):

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{2}$$

As can be observed in the equations (3.1) and (3.2), real power, $p$, and the reactive power, $q$, are made up of two components: continuous current (cc) component and alternatively current (ac):

$$p = \bar{p} + \tilde{p} \tag{3.1}$$

$$q = \bar{q} + \tilde{q} \tag{3.2}$$

where $\bar{p}$ and $\bar{q}$ are the continuous current components, while $p$ and $q$ are the alternative current components.

For real power, $p$, only the alternatively component side $\bar{p}$ needs to be compensated, while for reactive power, $q$, both components will be compensated [11]. This is because only the alternative components flow to the loads among the four components. The other remained three components simply represent energy exchange between the source and loads [10].

Based on the above explanation, the power to be compensated, $p_c^*$, and $q_c^*$, can be defined as shown in equations (4.1) and (4.2):

$$p_c^* = p \tag{4.1}$$

$$q_c^* = \bar{q} + q \tag{4.2}$$

The reference power $p_c^*$ and $q_c^*$ can be selected through designed intermediate filters [9]. Then, the (α/β)– current components are obtained from the compensated power by using equation (5).

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} p_c^* \\ q_c^* \end{bmatrix} \tag{5}$$

The compensation current is calculated through the Inverse Clarke transformation, as per equation (6) [1]. The PQ theory is relatively friendly from calculus point of view (its calculation only involves only algebraic expressions that can be implemented using standard processors) [1].

$$\begin{bmatrix} i^*_{ca} \\ i^*_{cb} \\ i^*_{cc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} i^*_\alpha \\ i^*_\beta \end{bmatrix} \tag{6}$$

## 4. ANALYSIS AND SIMULATION SIMULINK/ MATLAB

To evaluate and validate the performance of a three-phase active power shunt filter, the Simulink development environment within the MATLAB platform is used. This section focuses on the analysis and simulation of the filtering system using Simulink/MATLAB tools.

**Modeling Components:** Initially, each key component of the three-phase shunt power filter, such as the power converter, current filter, voltage filter, and controller, is modeled. Each component is represented by specific Simulink blocks, and their parameters and characteristics are specified according to system requirements.

**Interconnecting Components:** Following the individual modeling of components, they are interconnected according to the filtration system's scheme. It is ensured that signals and power flow are properly propagated between components.

**Defining Input Signals**: Relevant input signals for simulation, such as the input voltage signal and disturbing current signal, are specified.

**Configuring Control Algorithms:** The necessary control algorithms for the three-phase active power shunt filter are implemented. These control algorithms ensure constant monitoring and adjustment of operating parameters to achieve efficient and stable compensation.

**Simulation and Analysis**: The simulation is run in the Simulink/MATLAB environment, using defined input signals. The system's response to disturbances, harmonic mitigation, resulting power factor, and other relevant parameters are monitored and analyzed.

**Performance Evaluation:** Based on the simulation results, the performance of the three-phase active power shunt filter is evaluated against established objectives. Efficiency of compensation, harmonic mitigation, and other aspects of electrical energy quality are analyzed.

**Optimization and Adjustment**: If deficiencies are identified or improvements are desired, the model and control algorithms can be adjusted to achieve optimal performance. Simulations are repeated to validate and verify the new modifications.

Through analysis and simulation in Simulink/MATLAB, a deeper understanding of the behavior and performance of the three-phase active power shunt filter is obtained. This process facilitates system optimization, improving the quality of the delivered electrical energy and ensuring stable and efficient operation of electrical power distribution systems. In Fig. 5, the Simulink implementation of the entire power system connected to the grid is shown.

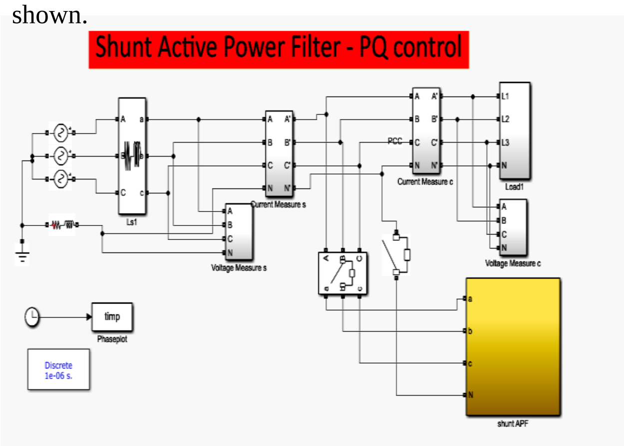


Fig.5. Nonlinear power system with enhance Power Quality feature

In Fig. 6 the power structure of the APF is shown. Additionally, the PQ control block diagram is implemented, providing the adequate gate signals for the three-phase APF.

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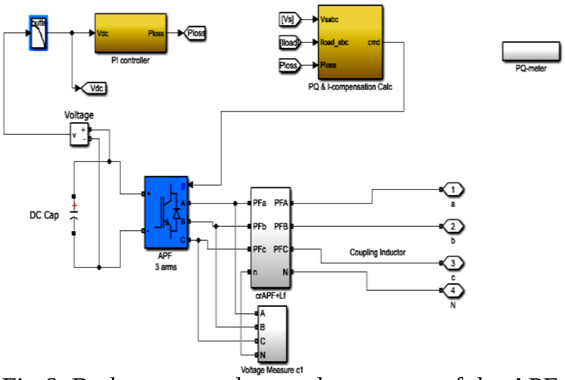


Fig.6. Both power and control structures of the APF

In Fig. 7 the implemented DC link voltage control loop is shown.

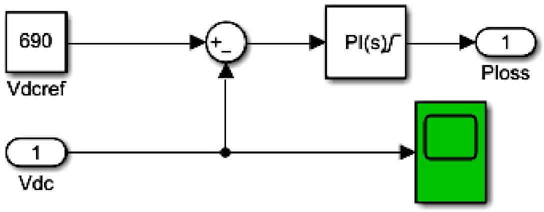


Fig.7. DC link voltage control loop

In Fig. 8 the control parameters of the DC link voltage controller are depicted and in Fig. 9, the PQ control of the 3-phase shunt APF is shown.

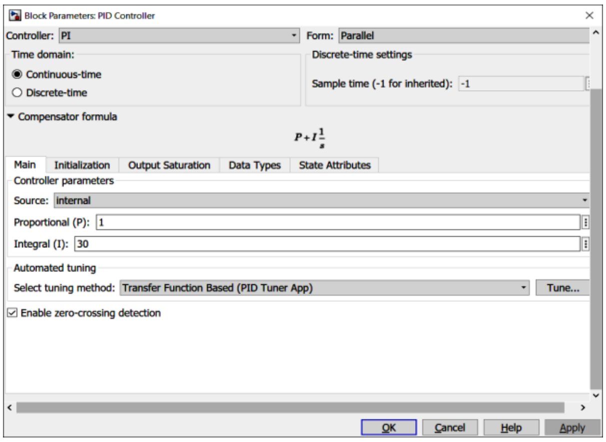


Fig.8. Control parameters of the DC link voltage controller

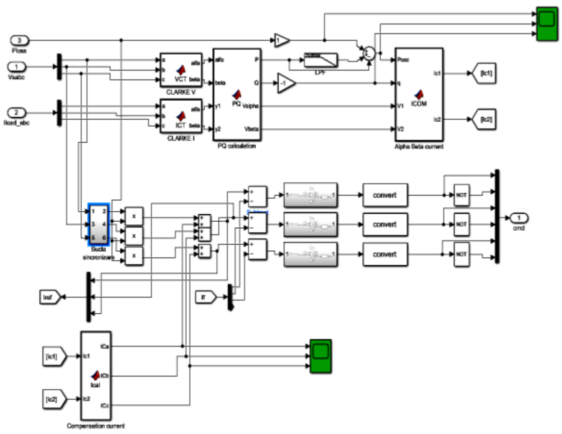

Fig.9. Control parameters of the DC link voltage controller

## 5. NUMERICAL RESULTS OF THE IMPLEMENTED APF

A simulation of a three-phase active power shunt filter system has been carried out extensively, and it is freely available. The simulation was implemented using Simulink/MATLAB [11]. In Fig. 10 the 3-phase nonlinear load currents obtained from the uncontrolled power bridge are outlined.

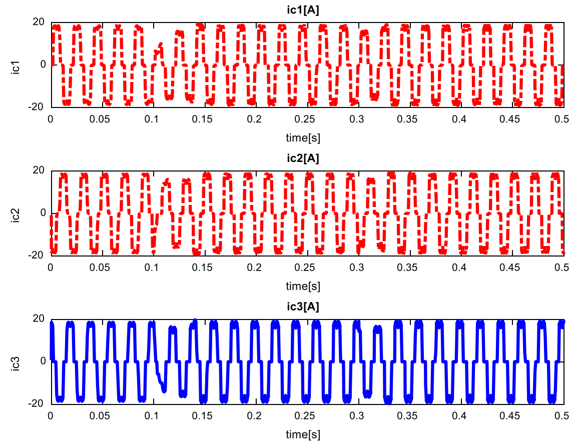


Fig.10. The 3-phase nonlinear load currents

In Fig. 11, both the phase source voltage and source current without APF connection are presented.

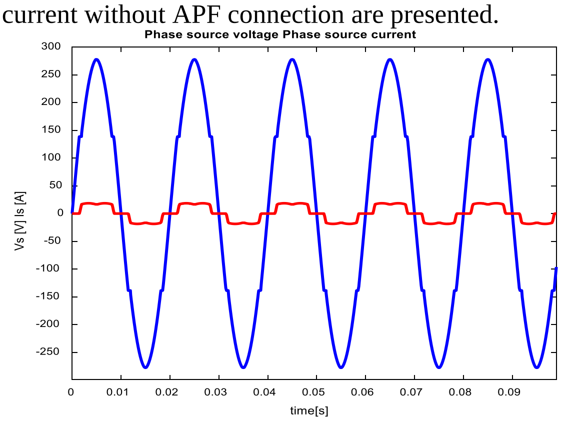


Fig.11. The phase source voltage and source current without APF connection

In Fig. 12 the 27,66% Total Harmonic Distortion value of the source current without APF connection is obtained.

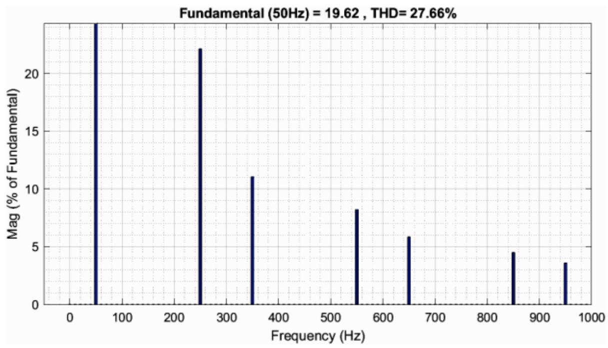


Fig.12. The THDi of the source current without APF connection

In Fig. 13, both the phase source voltage and source current are presented by using shunt APF.

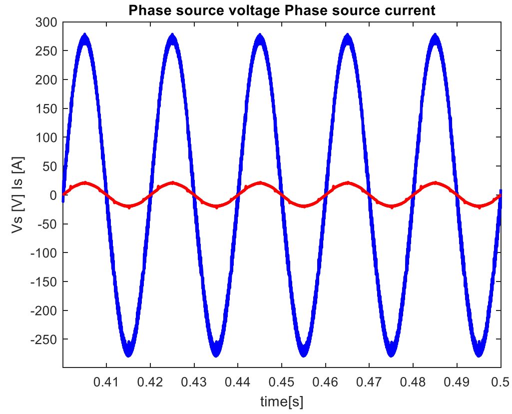


Fig.13. The phase source voltage and source current with APF connection

In Fig. 14 the 3,68% Total Harmonic Distortion value of the source current with APF connection is obtained.

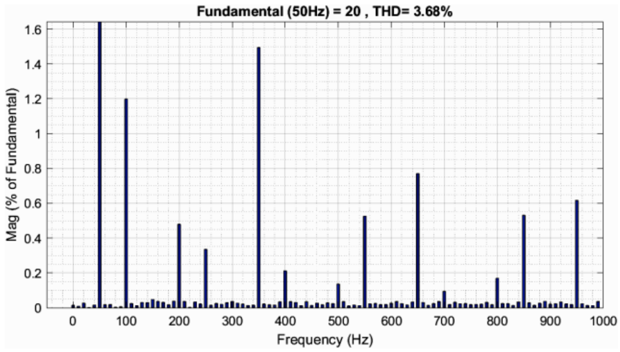


Fig.14. The THDi of the source current with APF connection

In Fig. 15 the FFT analyses of the phase source voltage without APF connection (red line in the upper figure) conduct to the 12,09% of THDu.

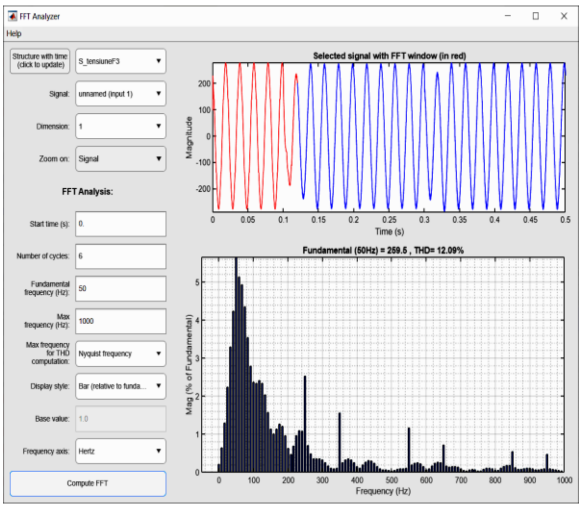


Fig.15. The FFT analyses of the phase source voltage without APF connection (red line in the upper side)

In Fig. 16 the FFT analyses of the phase source voltage with APF connection (red line in the upper figure) conduct to the 3,56% of THDu.

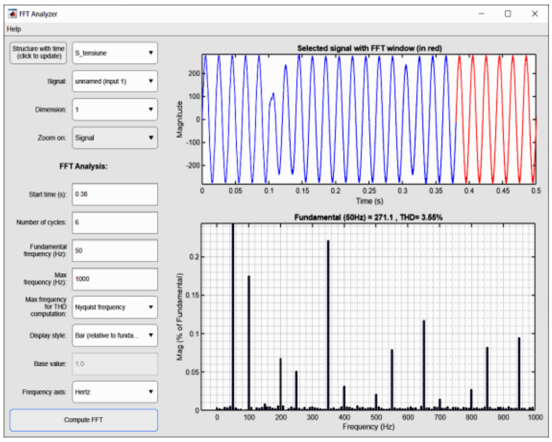


Fig.16. TThe FFT analyses of the phase source voltage with APF connection (red line in the upper side)

In Fig.17 the 3-phase voltages of the nonlinear load are shown.

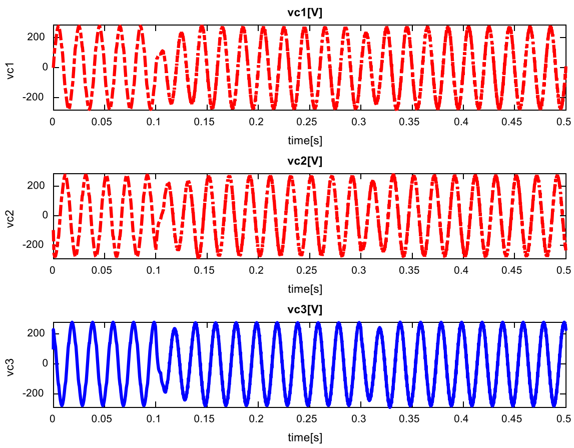


Fig.17. TThe FFT analyses of the phase source voltage with APF connection (red line in the upper side)

## 6. CONCLUSIONS

Three-phase active power filters represent a technology in the field of three-phase power signal filtering. These filters offer numerous advantages, including higher efficiency, significant harmonic suppression capabilities, and the ability to be controlled to meet specific filtering requirements.

However, three-phase active power filters are more expensive, and complex compared to passive three-phase power filters, and their design and implementation demand elevated expertise. Additionally, voltage distortions or current disruptions may arise in the event of inappropriate design or implementation.

The paper research focused on the development of more effective methods and algorithms for the control and design of three-phase active filters, as well as their integration into energy supply systems to enhance energy quality and system efficiency. The using of a shunt active three-phase power filter the quality improving of electrical energy is provided, reduced current harmonics and voltage distortions are obtained, compensation of the reactive power, and maintaining a power factor closed to unity.

This entails addressing cost issues and complexity, exploring advanced control strategies, and improving their adaptability to different scenarios in energy systems. A steady progression in three-phase active power filter technology can contribute to the creation of reliable, efficient, and rentable solutions for enhancing energy quality in electric distribution systems.

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