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Elimination of the Single Phase Parallel Active Power Filter Harmonic in Distribution Network

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Abstract:

In this work, the harmonics of the semiconductors used in industrial applications are given. Harmonics allowed voltage and current waveforms to move away from basic waveforms cause a decrease to power factor, an increase to power losses and damage to electronic elements. Harmonics formed by non-linear loads at the source were eliminated by means of Parallel Active Filter (PAF). A non-linear single-phase load model was formed by Matlab /Simulink program, and harmonics formed at source were simulated. Harmonics were eliminated by forming at single-phase PAF simulation environment. Thus, power factor was enhanced and power losses were reduced to minimum.

Keywords

Active filters, active power filter, harmonic filtering

1. Introduction

Power electronics have been used as switching elements in control systems in the energy sector since 1970. However, these elements produce harmonics when switching on and off depending on the switching frequency. For example, when a linear ohmic load is used independently, it does not draw reactive power; however, when used with switching elements such as thyristors or triacs, this charge draws reactive power and produces effective harmonics. Furthermore, the use of such switching elements in particular distorts the sinusoidal shape of the current and voltage waveforms. Power quality has become an important problem with the increasing use of static power converters in energy systems [1]. Nowadays, power electronic components are used more widely to increase the efficiency in the use of energy [2].

Harmonics cause various deformations in the electrically operated system elements. In plants with high harmonics;

• If the capacitors fail frequently,

• If some malfunctions occur without reason or the cause cannot be understood,

• If measuring instruments in factories sometimes do not measure correctly,

• If the switches open without cause,

• If the automation system can operate incorrectly,

• If electronic card malfunctions occur continuously,

• If the neutral cables become hot due to overload and the insulation is damaged,

These and similar events may occur as a blended source. All of these events indicate the presence of harmonics that exceed many acceptable levels.

Harmonics increase power losses by reducing the power coefficient. In order to prevent losses, many studies have been carried out in scientific sense, and the trend towards solid-state lighting devices that produce not harmonic or very little harmonics instead of saving lamps in lighting area which corresponds to 25% of the energy consumption in the whole world continues [3]. In addition, they cause overheating of capacitors and electric machines, decreasing their working life, and deterioration of the counters and protective circuit elements.

Although most countries have their own harmonic standards, the most well-known is the IEEE 519 standard. The first version of the IEEE -519 standard is IEEE-519 1981, which was introduced in 1981 as the 'IEEE Guide for Harmonic Control and Reactive Compensation ında by the IEEE Static Power Converter Committee of Industry Applications Society. This paper was revised between 1989 and 1992 and updated ics IEEE Recommended Practices and Requirements for Harmonics Control in Electric Power Systems Bu. This paper consists of a number of recommendations which have been applied more than some of the limitations [1,4].

In this study, single phase PAF is designed which can be used in distribution systems and smart grids today [5]. The mathematical model of single-phase PAF in Matlab / Simulink has been investigated and the success of harmonic removal of this filter in different loads has been investigated.

2. Power Filters

The harmonics created by non-linear loads and power converters in power systems have a significant share in the distribution of power losses generated by these harmonics [6,7]. In order to minimize losses and increase the energy performance of the system in

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distribution systems, minimizing the harmonics has become a necessity today [8,9].

Passive Power Filters (PF) have first emerged for this purpose. The low cost and ease of design increased the attractiveness of PGF. The more intensive use of semiconductor elements with developing technology has caused PFs to be insufficient in filtering. However, this time, the use of high success rate PAF increased in the elimination of harmonics. The disadvantage of PAF compared to PFs is that the initial cost is high. In contrast, the success of PAFs in harmonic removal eliminates these disadvantages. The PGF consists of resistors, coils and capacitors (R-L-C). The goal in PFs is to determine the L and C values to form a resonance at the frequency of the harmonic component to be destroyed [10].

Filtering techniques have been developed to minimize the impact of problems in power systems, reduce the harmonic components of line currents and voltages, and increase the power factor. PFs are commonly used in power factor correction and suppression of harmonics. PFs can only be set to filter basic harmonic frequencies, such as the 3rd and 5th harmonic currents in power system currents. They are affected by welding impedance and cause unwanted resonance problems in compensation process [11,12].

Due to the disadvantages of PF, AFs have been developed for power factor and harmonic compensation. With the inclusion of renewable energy sources and related control units in the energy system, the use of active power filters has become a necessity due to the increasing harmonic effects of the power electronics circuits with the rapid development. Active power filters are used to compensate for harmonic currents and to eliminate voltage drops [13,14]. PAF is used to suppress the harmonics generated by nonlinear loads by producing the opposite signal in the same amplitude with the capacitor used. Today, the increase of the transition to the smart grid, the network software and remote access, SCADA and artificial learning ability to gain the need for active power filters are increasing [15-20].

3. Modeling of Single-Phase PAF

Depending on the load, it is to eliminate unwanted harmonics that occur in the current drawn from the single-phase AC source. IGBTs are used as switches T1, T2, T3, T4. In order to perform the charge-discharge process, the capacitor C is used. The DGM signal is sent to the T1 and T4 switches from the respective 1 and 4 probes, while the DGM signal is sent to the switches T2 and T3 from the 2 and 3 probes. When T1-T4 is in transmiss ion, T2-T3 is in cut, T2-T3 is in transmission while T1-T3 is in transmission, while T1-T3 is in transmission. A single-phase PAF model flowchart designed in Figure 1 is shown.

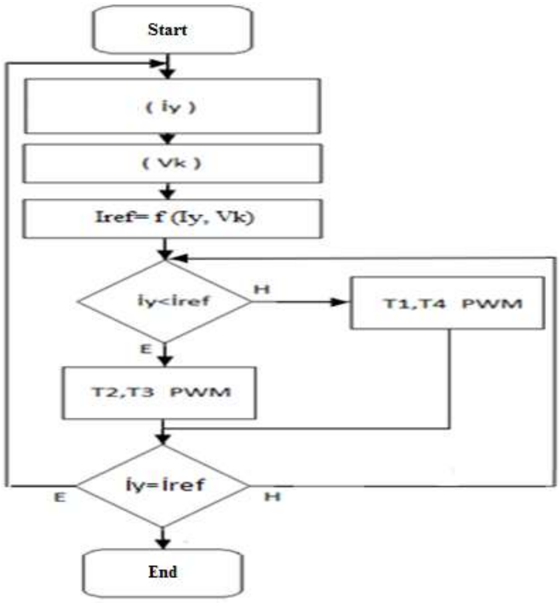

Figure 1. Flow diagram of the designed single-phase PAF model

Figure 2 illustrates explanatory information about the control of the system and it is seen from this figure that alpha / beta and d / q transformations are analyzed and system sizes are analyzed. Accordingly, the dq-axis components of the current harmonics to be filtered are obtained. Reference vectors are produced in abc plane by applying reverse Park and reverse Clarke transformations to these vectors. In addition, a Proportional + Integral (PI) controller is used to keep the de-line capacitor voltage constant. The signal obtained from the output of the controller is added to the reference currents obtained from YGF [21-23].

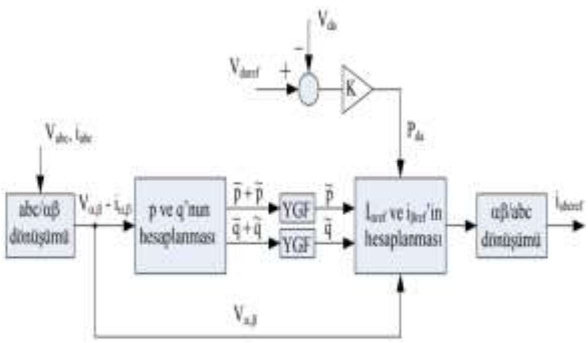

Figure 2. Block diagram for obtaining reference currents

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3.1. Simulated single-phase PAF system model

A current signal is generated from the current sensor connected in series to the nonlinear load, depending on the voltage information from the voltage sensor connected to the voltage source and the current information of the current drawn by the filter. The harmonics generated by the reference signal are controlled. The harmonic signal generated by the nonlinear load was compared to the reference signal on the hysteresis current controller. As a result of comparison, Pulse Width Modulation (DGM) signals are generated and the switches of the inverter are activated.

3.2. Single-phase PAF model

Figure 3 shows the single-phase PAF model. The capacitor and the resistance are connected to each other in parallel with the system and representing the nonlinear load. The PAF block consists of a filter capacitor which performs charge-discharge operations depending on the state of the switching elements. The non-linear load and the PAF have a current-limiting coil.

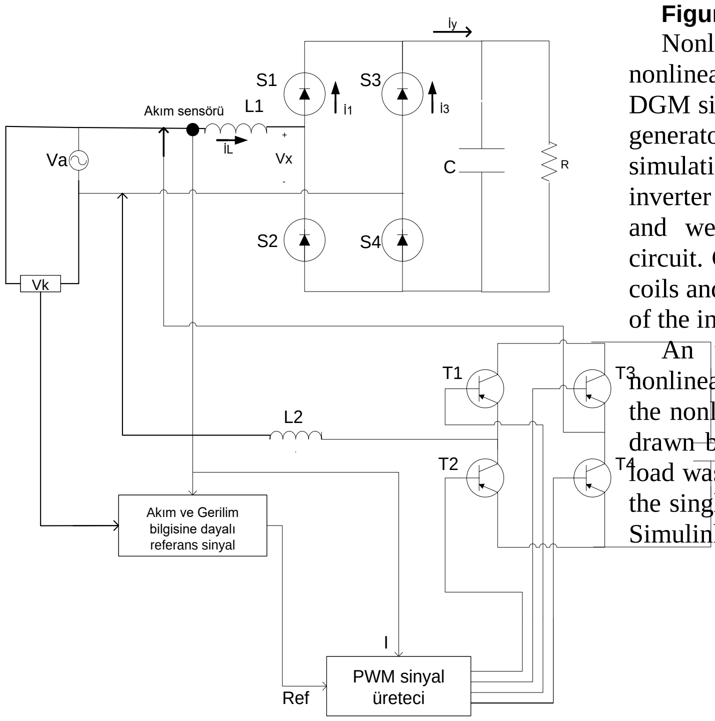

Figure 3. Single-phase PAF model

Single phase Parallel active power filter prepared in Matlab / Simulink program is designed as block diagrams and codes written when entered into related blocks can be seen. Figure 4 shows the simulated, single-phase PAF simulation detail.

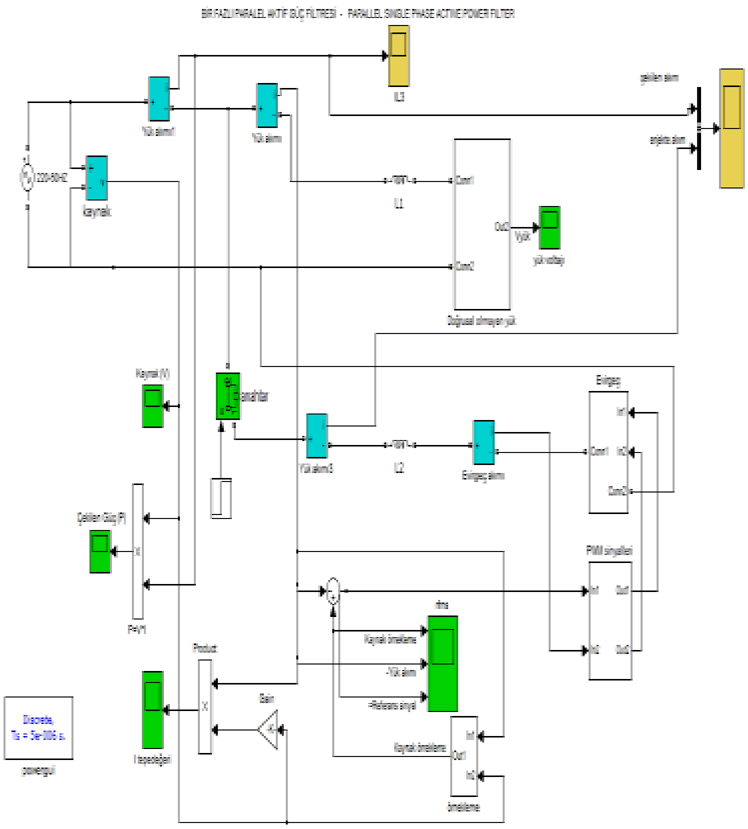

Figure 4. Single-phase PAF simulation detail

Nonlinear load block formed by representing the nonlinear load consists of the inverter block, the DGM signal generator block and the reference signal generator block, which make up the PAF. In the simulation, welding current, charge current and inverter current with voltage meter, voltage meter and welding voltage values are used in control circuit. Coils L_1 and L_2 are used as current softening coils and are placed in the nonlinear load and in front of the inverter.

An uncontrolled bridge rectifier is used for nonlinear load and input ends. It was observed that the nonlinear load generated harmonic in the current drawn by Matlab / Simulink and an ideal nonlinear load was obtained for the simulation. Figure 5 shows the single-phase PAF units simulated in the Matlab / Simulink environment.

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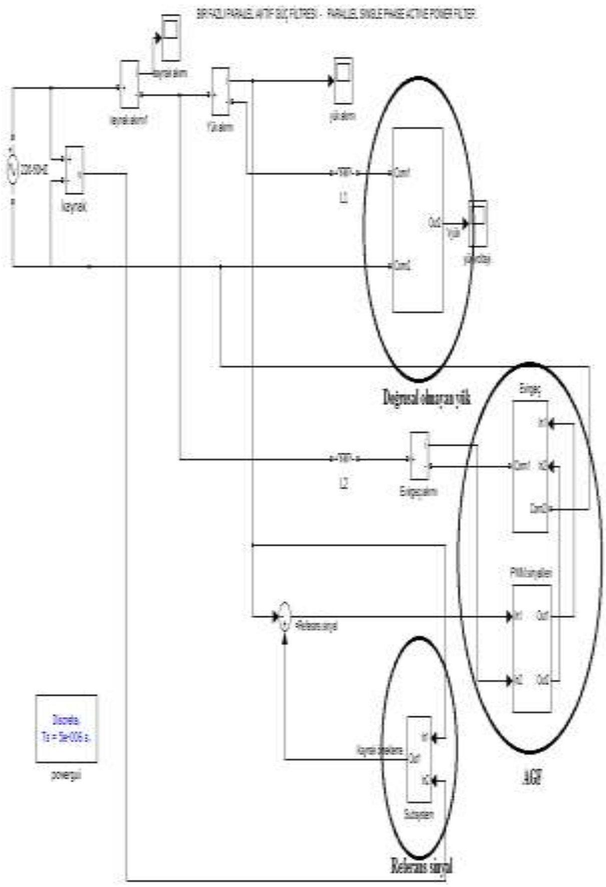

Figure 5. Simulated single phase PAF units

The second factor that affects the performance of AFs as much as the design of the power circuit is the control method. In terms of flow control methods in AFs, two main topics can be examined. The first part is the method of calculating the current reference which must be produced in order to eliminate the current produced by the harmonic source and keep the DC bus voltage at the desired value, the second part is the current control method [20-24].

Figure 6 shows the PAF control method. During the operation of the AF circuit, samples are taken from the load current (IL), the input voltage (Vs) and the filter current (IF). The area of the sampled welding current is calculated over each period. The peak value of the sine wave shape is calculated to spread this calculated area in sine wave form in each period. Figure 7 shows the reference source current when the unit sine vector obtained from the sampling of the source voltage is multiplied by the present peak value.

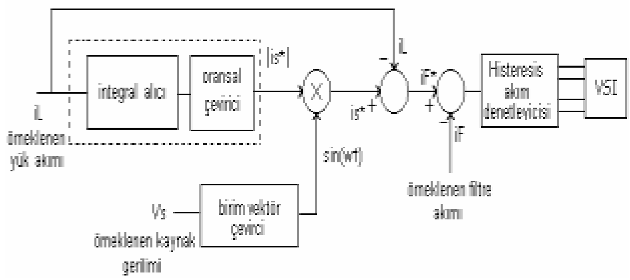

Figure 6. PAF control method

From the reference source current found there is the reference filter current that the AF circuit must draw when the sampled load current is removed. Using the hysteresis current method, pulse width modulation (DGM) signals are to be applied to the semiconductor switches of the inverter to draw a current similar to the reference filter current of the AF. Although there are many current inspection methods, hysteresis current control method and DGM current control method are the current flow control methods in terms of both applicability to numerical application and applicability in real time systems. Although DGM current control method is one of the most preferred PAF control methods in terms of ease of application and production of a fixed frequency switching signal, hysteresis method has been found to be more successful in terms of Total Harmonic Distortion (THD) in comparison with current control methods in literature. In addition, the only method in which we use the direct current reference to find the trigger signals in the voltage-induced PAF is the hysteresis band method. That is, there is no need to transfer the voltage to the PI controller after the reference currents are found or to convert it to voltage by applying different methods. Because of these advantages, hysteresis flow control method has been used. Figure 7 shows the DGM signals applied to the IGBT in figure 5. Here, DGM signals are generated by comparing the current drawn and the reference current in the hysteresis current controller. [20-24].

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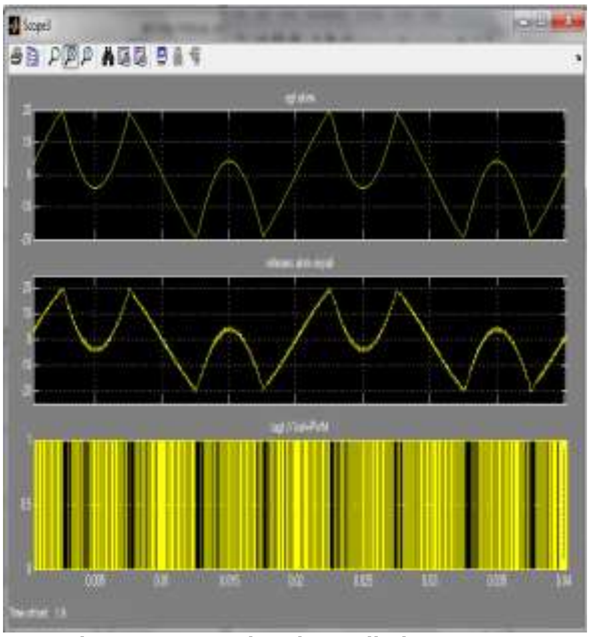

Figure 7. DGM signals applied to IGBTs

4. Simulation of single-phase PAF

Simulation of the single-phase PAF The results of the non-linear load, which were originally designed in the Matlab / Simulink program, were followed by PAF to the non-linear load. The total harmonic distortion of the PAF's current in the current and in the absence of the load is investigated. The magnitudes of the circuit elements used in simulation are shown in Table 1.

Table 1. Sizes of circuit elements used in simulation

Supply voltage / hertz	220 V / 50 Hz
Non-linear load resistance	15 ohm
For non-linear load, current softening coil	0.2 mH
Non-linear load capacitor	14 mF
For non-linear load, current softening coil	0.2mH
Inverter capacitor	25 µF
Inverter resistance	8 kΩ
For inverter, current softening coil	150mH

Figure 8 shows the current form drawn by the nonlinear load. In this study, it was aimed to minimize the THD of the non-sinusoidal current signal and to obtain a sinusoidal signal.

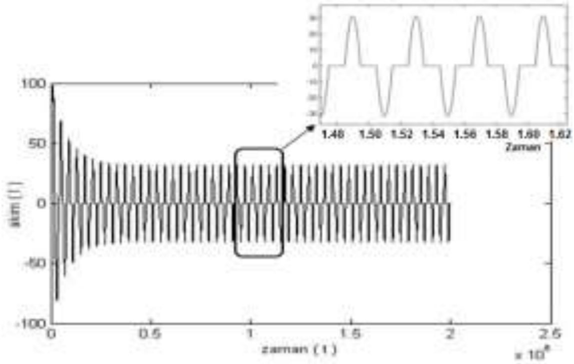

Figure 8. Current form drawn by nonlinear load

Figure 9 shows the power drawn by the nonlinear load. The harmonic current received influences the quality of the drawn power, resulting in a non-sinusoidal power signal pattern. This situation caused a loss of power.

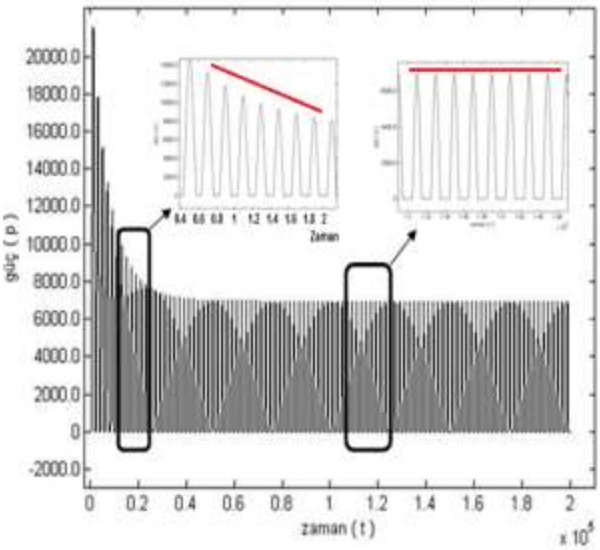

Figure 9. Power drawn by nonlinear load

Figure 10 shows the THD of the current drawn by the nonlinear load. There was no filtering in the time interval t = 0.1-0.3 s and 59.31% THD.

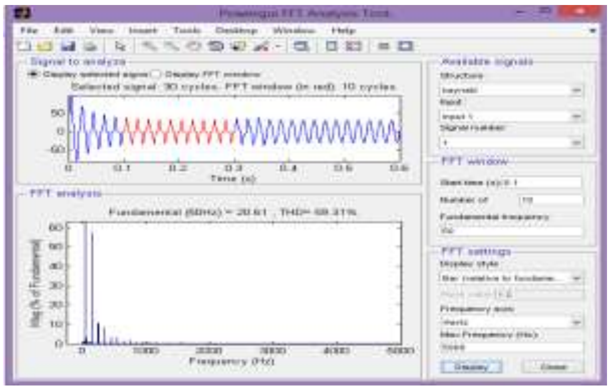

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Figure 10. THD value of current drawn by nonlinear load

t = 0.3 seconds when PAF is active and the current waveform is shown in Figure 11. In the current signal drawn by the non-linear load in Figure 11, the harmonics of the current signal have decreased and become sinusoidal by the activation of PAF. The harmonic current, which is drawn with a histeless current controller, is approximated to the reference current.

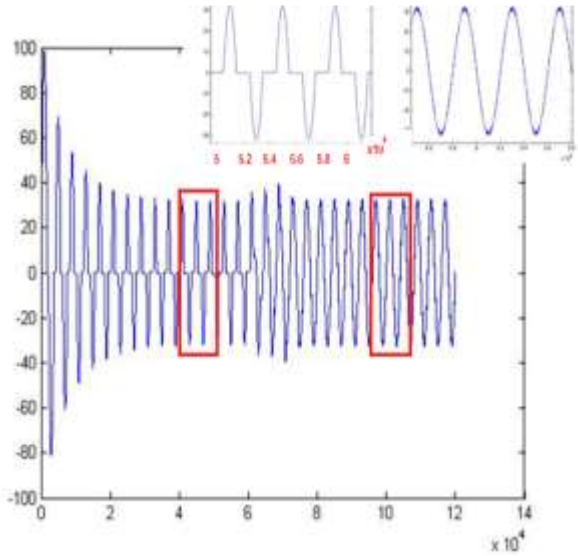

Figure 11. Current signal drawn by non-linear load (PAF)

In Figure 12, the PAF was activated at t = 0.3 and the THD of the welding current at the time t = 0.4-0.6s was 1.36%. Figure 12 shows the THD change when PAF is active.

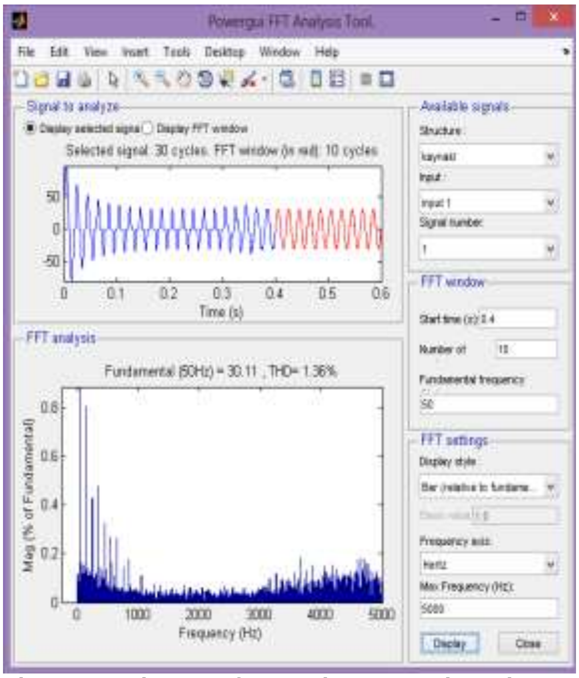

Figure 12. Change of THD when PAGF is active

The quality of the power drawn to the nonlinear load in Fig. 13 improved with the activation of the modeled PAF. At first, the load current approaches the reference current and the harmonic signal appears to enter the sinusoidal form.

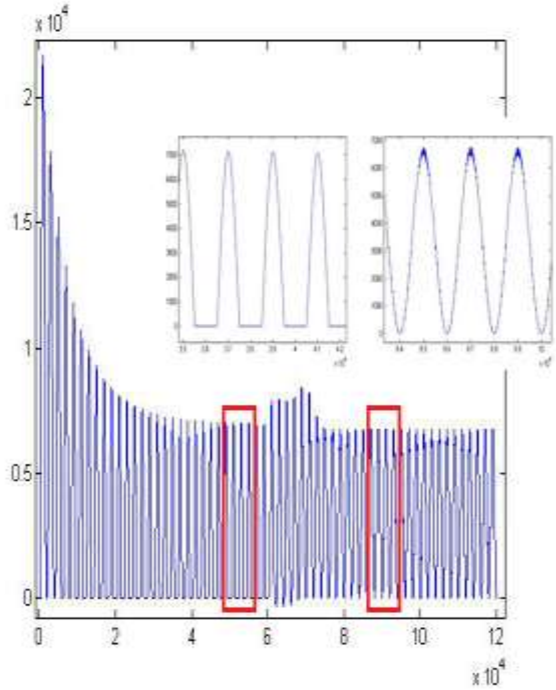

Figure 13. Power drawn by non-linear load

The harmonic current generated by the nonlinear load in the grid current is a sinusoidal grid current

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with the injected current applied by PAF. Figure 14 shows the non-linear load of the injected current applied by the filter against the harmonic current. This shows that the power factor has improved and the approximate non-harmonic current form has been reached.

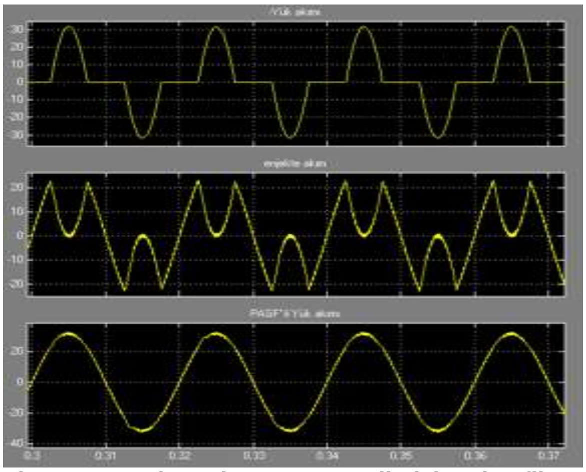

Figure 14. Injected current applied by the filter against the harmonic current drawn by the non-linear load

Table 2 shows the system's unfiltered and PAF THD values according to the current flow.

Table 2. Unfiltered and PAF THD values of the system according to the current flow

PAF t = 0.3s later when activated		
Current drawn rms	THD without filter t = 0.1s-0.3s	Filtered THD t = 0.4s-0.6s
85.3	14.19	10.19
57.6	33.95	6.74
45.7	44.35	1.29
38.7	51.34	1.03
27.19	64.79	1.13
21.7	71.92	1.1
16.3	79.44	1.48
13.5	83.31	1.53
11.2	86.48	2

Referring to the graph in Figure 15, the modeled PAF was found to be effective at low power loads such as 15 A to 45 A.

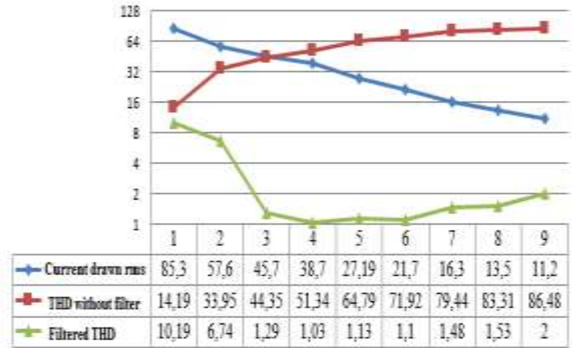

Figure 15. Unfiltered and PAF THD values according to the drawn currents

5. Results and Discussion

In this study, PAF was used and the filter was applied to 220V$_{AC}$, 50 Hz sinusoidal single phase load. In the control method of PAF, the control method is determined by reference to the welding voltage, the load current and the filter current.

Nowadays, the rapid development of technology, in parallel, the low-power systems to gain sensitivity, has created the need to remove the harmonics formed in the network connected to single-phase systems. In order to increase the efficiency and energy quality of the system, it is necessary to minimize the reactive component of the power drawn from the source and suppress the harmonics. The PGFs used in the suppression of harmonics were found to suppress the harmonics only at certain intervals and therefore did not give the desired performance. PAF successfully eliminated the system harmonics. PAF has been found to provide successful results according to IEEE-519 1992 standard current harmonic limitations.

In this study, intelligent optimization techniques can be used to determine the optimal components of the SAPF simulation circuit.

In addition, future studies have to investigate the fluctuations occurring during the triggering of semiconductor IGBTs used in the SAPF circuit depending on their current aspects. In this way, the effects of harmonics on the system can be minimized.

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