New Series Active Power Filter for Small Non-Linear Loads Simulation and Experimental Work

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Abstract

This paper explains the behaviors of the new version f the series active power filter based on high input power factor and low input harmonics. The filter is designed to meet the requirements of voltage-current sourced harmonic loads it is based on a load current estimation of the active power filter sensing the load current. The proposed filters can improve the distortion of a small a non-linear loads power. In addition, it can suppress the harmonic current and compensate for the reactive power at the float charge mode. The experimental results verify that the proposed filters have the expected performance [1] [2].

1. Introduction

Always the current harmonics produced, by any load, will cause voltage distortions at the load terminals hence, the loads absorb distorted currents causing heat lost exceeds in most cases 30% of the consumed power.

The experimental measurement, of the load current and load voltage are done, before and after corrections, to verify that the minimization of the load becomes zero or the power factor becomes one. In addition, the shape of the current becomes clearly sinusoidal and in-phase with the main-voltage. The proposed prototypes filter achieving both tasks by using digital signal processor (PIC family) [3]. The main target here is to compensate for voltage harmonics or current harmonics very effectively. Figure 1 illustrates the connection of the proposed SAPF. the main components of the proposed system is the active filter circuit, adjustable controller circuit, current sensor circuit, current limiter (inductance), nonlinear load circuit and the power resistor R. The non-linear load and the filter circuits are grouped in series with the source in case of SAPF; and in parallel in PAPF case. The load is formed of 25 μF capacitor in parallel with 200 Ω resistor for SAPF and 40 mH, 20 Ω and 30 μF for PAPF or different R, C.

2. Active Power Filter Control Algorithm

An APF configuration is coming from the switching converters; it is based on pulsed operation and can be categorized as a nonlinear dynamic system [4].

On the customer side, there is a high demand of top power quality electrical energy demanded for the new IT technologies, automated production plants, banking and other service industries. When these performances are not guaranteed by the utilities, in house solutions have to be found by the end users themselves. Such Active Filters with electrical energy storage capacities can solve at least 80% of the problems [8].

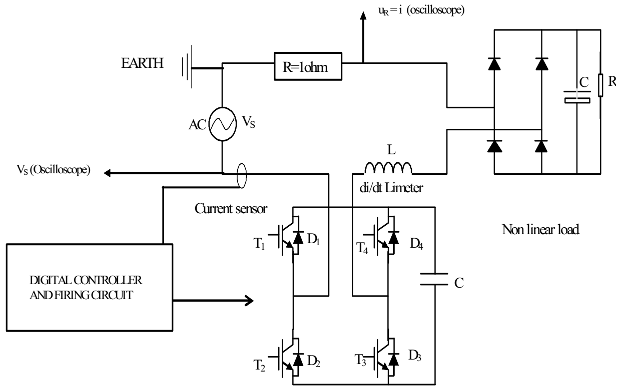

Fig. 1. Non-linear load with SAPF compensator

Figure 2 displays the switching operating principle of the filter, if in the positive half cycle, the operating transistors are (T_1&T_3) and the operating diodes are (D_2&D_4) then, during the negative half cycle the operating transistors are (T_2&T_4) and the operating diodes are (D_1&D_3). When the line current below the reference current, the appropriate pair of transistors are turned on and hence, the capacitor C is connected to the line circuit, in such a way, to increase the value of the load current above the value of the reference current and thus discharging the capacitor [7].

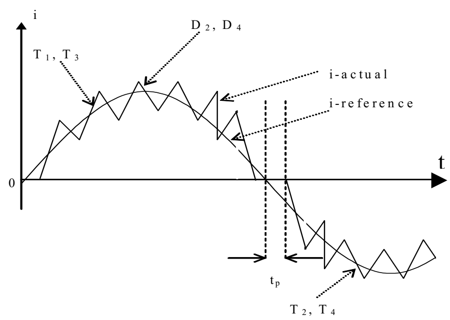

Fig. 2. Operation principle

3. Mathematical Concepts of Series Active Power Filter

Assuming that the filter voltage compensates for the load harmonic voltage, hence we can consider only the behavior of the fundamental current and voltage.

$$v_f = (V_m - \frac{4}{\pi}U_{dc})sin(\omega t) - L\omega I_m cos(\omega t) \quad (1)$$

When the voltage across the capacitor becomes constant, the capacitor will not receive or deliver energy and its power p_C can be written as:

$$P_C = \int_0^T v_f I_m \sin(\omega t) dt \quad (2)$$

$$= \int_0^T \left(I_m \left(V_m - \frac{4}{\pi} U_{dc}\right) \sin^2(\omega t) - L\omega I_m^2 \cos(\omega t) \sin(\omega t) \right) dt = 0$$

$$V_m = \frac{4}{\pi} U_{dc} \quad (3)$$

Equation (3) gives the relation between the maximum of the source voltage and the required DC voltage of the load, in order to have constant voltage on the filter capacitor at steady state when operates in unity power factor model [5] [6].

3.1. Simulation of the Load without SAPF (Using PSIM program)

Consider the power circuit parameters shown in Table 1 to simulate for the load current and load voltages without compensator.

Figure 3 shows the connection of the non-linear load to the main voltage without any compensation. Figure 4 shows the variation of the load current and the voltage of the main with respect to time. Figure 5 shows the harmonic contents in the line current which is very high compared by the acceptable values (<7%).

Table 1. Power Circuit Parameters

Supply voltage	110 V
Frequency	50 Hz
Load resistor	220 Ω
Load capacitor	25 μF
Limiter	100 mH
Filter capacitance	C_{dc} = 2000 μF

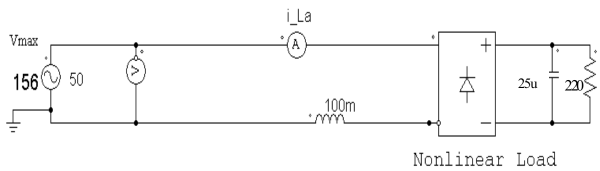

Fig. 3. Non-linear load circuit without compensator

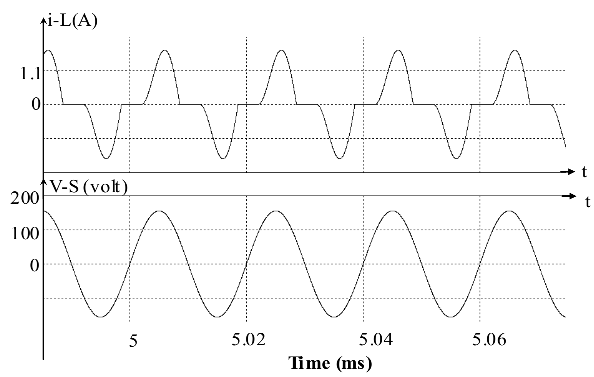

Fig. 4. Non-linear load current and source voltage

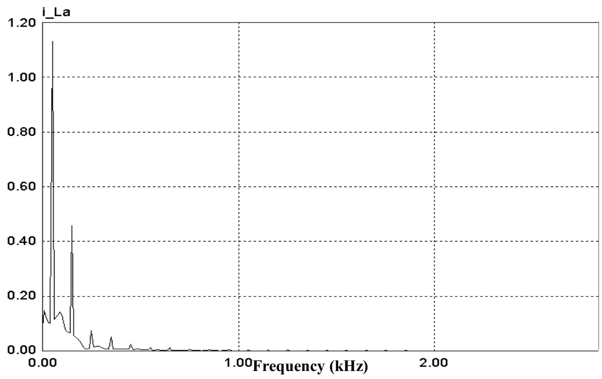

Fig. 5. Non-linear load current harmonics of uncompensated system

3.2. Simulation of the Load with SAPF (Using PSIM program)

Consider the same power circuit parameters of Table 1 to simulate for the load current and load voltages with series active power filter compensator.

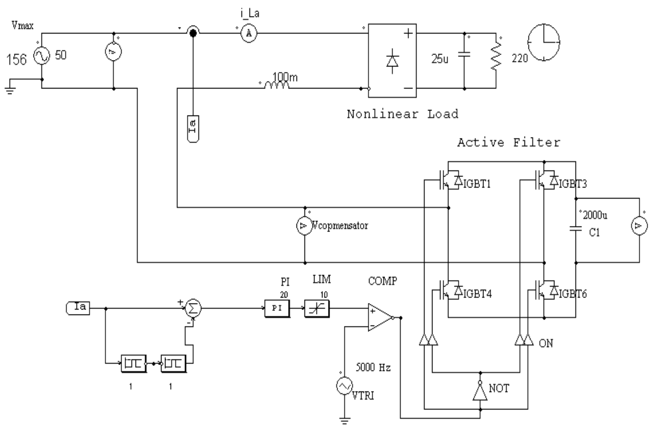

Fig. 6. Non-linear load circuit with SAPF

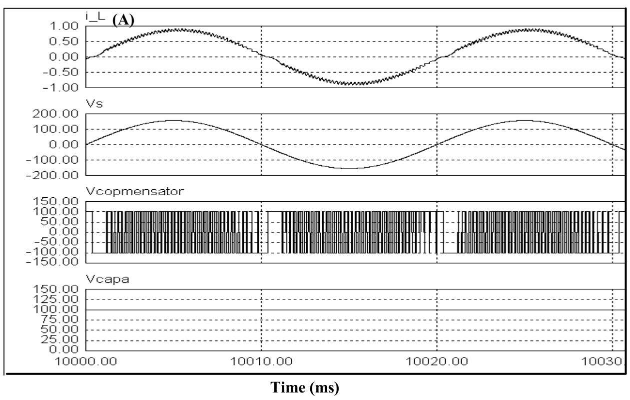

Fig. 7. Non-linear load current, main voltage, filter voltage and the capacitor voltage

Figure 6 shows the connection of the load in presence of the SAPF compensator. In Figure 6 we observe the variation of the load current, supply voltage, filter voltage and the capacitor voltage versus time. The current after filtration approaches the sinusoidal shape, it is in-phase with the supply voltage, and this is a good evidence for the validity of the proposed filter.

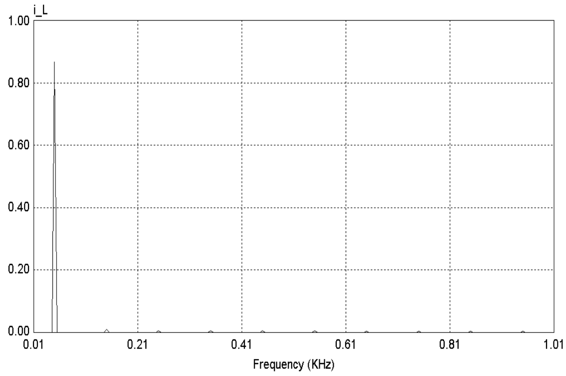

Fig. 8. Harmonic content of compensating circuit

4. Experimental Setup

The main goal of the active power filter (series or parallel) is to eliminate the voltage harmonics and current harmonics. In this case, the reference voltage is always known (the fundamental of the distortion voltage or current) and it is installed in a PIC16F877 as 80points (point by point of known reference voltage and of known fundamental value) the time difference between two consecutive points is $\Delta t = 250$ µs. Then, it is possible to generate the reference synchronized with the main voltage and thus we can use the controller algorithm.

A laboratory prototype of the single-phase series active power filter, of F was built and tested with the same power circuit parameters specified in Table 1. The complete control circuit was implemented and the controller used is PIC16F877 microcontroller [9] [10].

The simple control circuit of Fig. 9 consists of five parts:

(1) Power supply and zero crossing detectors.
(2) Hall-effect current sensor and signal conditioning circuit added with a small DC negative voltage to neutralize the small drift (positive DC bias)
(3) Microcontroller circuit (with digital module; inverter) is used at the output of the optocoupler as a driver to turn on/off the MOSFETs with high speed.
(4) The inverter bridge.

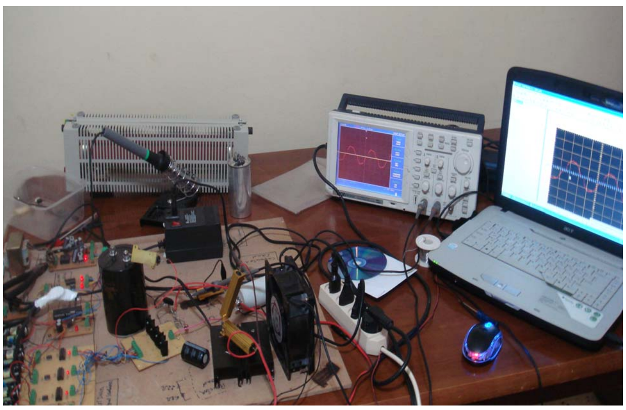

Fig. 9. Overall circuit

5. Experimental Measurement

Figures 10 and 11 show the experimental main voltage and source current before and after filtration of the proposed series active power filter respectively. The shape of the source current after filtering becomes approximately sinusoidal

Note: by adjusting the variable potentiometer of the current sensor, we can use the same controller for different type of capacitive loads, or we can use this controller for different type and values of non-linear loads. The reference current is 1A peak the fundamental of the load current [12].

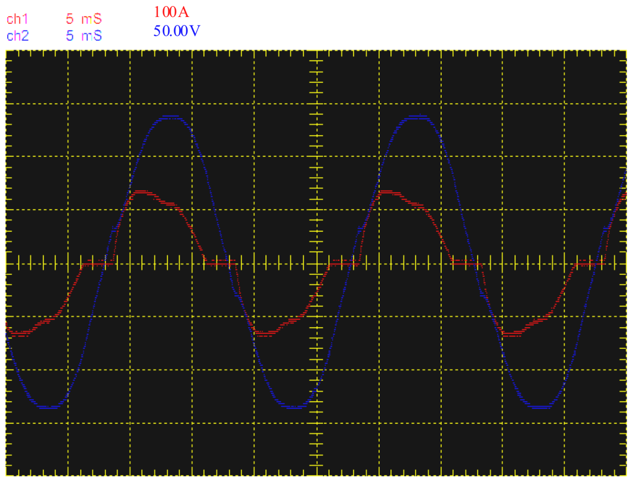

Fig. 10. Variations of main voltage and main current versus time

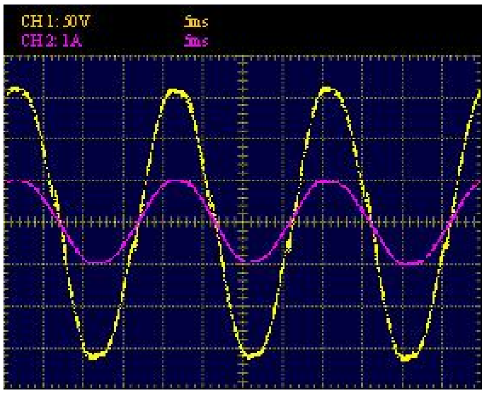

Fig. 11. Variations of the main voltage and main current versus time

6. Conclusions

In this paper, a SAPF has been constructed and tested. The main objective of SAPF is to compensate for the voltage distortion and current distortion and to regulate the reactive power or the power factor of the circuit.

The principle of compensation technique is based on the elimination of both the negative and zero sequence components from the supply voltage followed by the regulation of the remaining component.

In general, the proposed single-phase series active power filter reduces effectively the voltage total harmonic distortion providing better power quality than it is available on the main.

Within certain limits, it is also capable of correcting fundamental voltage amplitude as in Fig. 11 the voltage of the main becomes totally sinusoidal while in Fig. 10 the distortion in the main voltage is very clear. Although the tested series compensator was a single-phase version, it may be easily adapted to a three-phase system.

The amplitude of the fundamental current is controlled through the microcontroller or PIC16f788 between the load voltage and a pre-established reference. The control allows an effective correction of power factor, harmonic distortion, and load voltage regulation and reaching its steady state in about two or three cycles of the fundamental. Compared with other methods of control for a series and parallel filters, this method is simpler to implement, because it is only required to generate a sinusoidal current or voltage, in phase with the mains voltage, the amplitude of which is controlled through the proposed cheep circuit, confirmed the theoretical analysis

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7. References

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