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# Photovoltaic Source Powered Shunt Active Power Filter Optimized by Cuckoo Search Algorithm

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*harmonics, shunt active power filter, photovoltaic, maximum power point tracking, cuckoo search algorithm, P&O method*

**ABSTRACT**

Non-linear loads such as computers, televisions, arc furnaces, inverters, etc. generates harmonic currents infecting the quality of the power supply and causing damage. To remedy this problem, the shunt active power filter presents the best way to fight against harmonic currents. This paper gives a new technique of shunt active power filter which has tested to be the satisfactory answer to improve energy high-quality in phrases of removing harmonics caused by means of non-linear power loads distribution networks. Our work presents an SAPF powered by a photovoltaic system whose energy control is managed via metaheuristic cuckoo search optimization as the fastest and most reliable optimization unlike traditional strategies like the Perturb and Observe (P&O) algorithm used as the MPPT for PV systems, which gives us a stable power supply to further eliminate harmonics. The simulation on the Matlab Simulink environment truly suggests that the proposed model improves the excellent quality of energy and the control method is efficient and in accordance to the international standard recommendations IEEE 519-1992.

## 1. INTRODUCTION

Electrical appliances, which depend on the switches of power electronics, are widely used in household use such as computers, televisions, etc., lighting by fluorescent lamps, discharge lamps and dimmers, thus in industry such as variable speed drives, arc furnaces, welders, electrical transformer magnetic circuits [1-3] all have adverse effects on power quality by increasing the reactive power [4], reducing the lifetime of the devices and causing nuisance tripping, which leads to very significant economic losses. Several solutions are then proposed to solve these problems, including the implementation of appropriate filtering techniques, among which the parallel active filter which is capable of compensating both the current harmonics and the power factor. Moreover, it helps to balance the load by suppressing the current in the neutral wire [5]. The power stage is a voltage source inverter whose DC side capacitor is supplied with DC voltage delivered by a photovoltaic generator connected to a DC-DC converter to obtain a higher DC voltage through an MPPT controller based on the algorithm cuckoo research proposed in this article to generate the maximum power of the PV system. From the measured values of the source voltages and the load currents, the reference currents are deduced by the PQ theory used to control the harmonic current compensation inverter, Figure 1 general overview of the SAPF. The results obtained by our model clearly show a good improvement in the composition of harmonics with a speed of convergence, unlike the P&O model as shown by the results obtained on MATLAB/Simulink. On the basis of these comparison results, the measurements were carried out with the two models of the SAPF whose THD of the source currents obtained are lower than the 5% required by the standards.

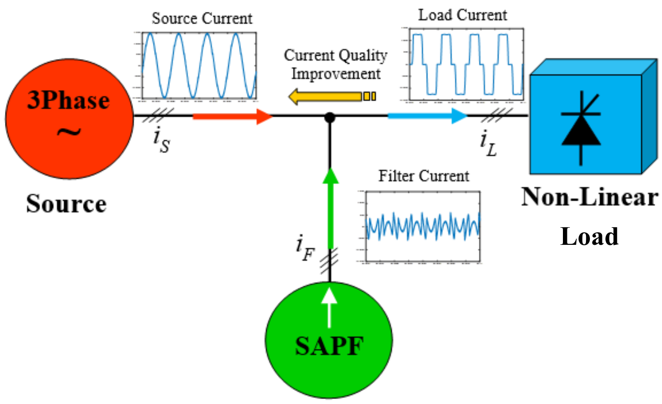


**Figure 1.** The principle of SAPF

## 2. THE SHUNT ACTIVE POWER FILTER

### 2.1 The shunt active power filter description

The shunt active power filter first proposed by Gyugyi and Strycula [6, 7]. It is the most popular type. It injects the harmonic components of the load like a current source, but with a phase shift of 180°. Shunt active power filter calculates the compensation current reference in real time with several methods, in our case by the PQ method of and forces an inverter to synthesize it correctly. This method provides adaptive and selective active filtering. In other words, an SAPF corrects the harmonic current of a nonlinear load and periodically follows the changes of the harmonics content [8]. Figure 2 illustrates the principle of the three-phase shunt active power filter.

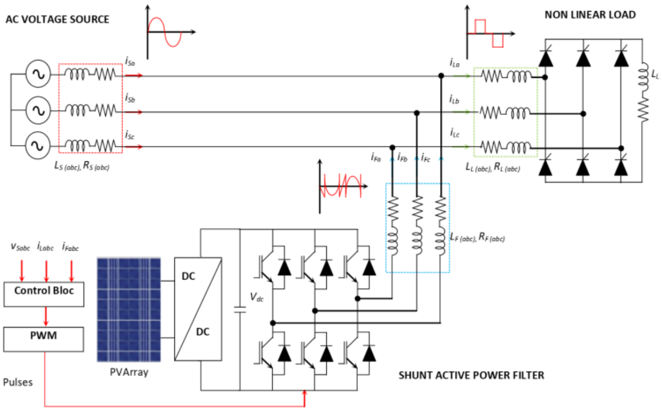


**Figure 2.** The structure of the three-phase SAPF

### 2.2 The instantaneous active and reactive power theory

The instantaneous active and reactive power theory extracts harmonic components from source current. The principle of this theory is to transform a stationary reference system in a-b-c coordinates into a α-β coordinate system [7]. Using Concordia transformations, source voltage and load current in a-b-c coordinates transform into α-β coordinates as shown in the Figure 3 and given by the following equations:

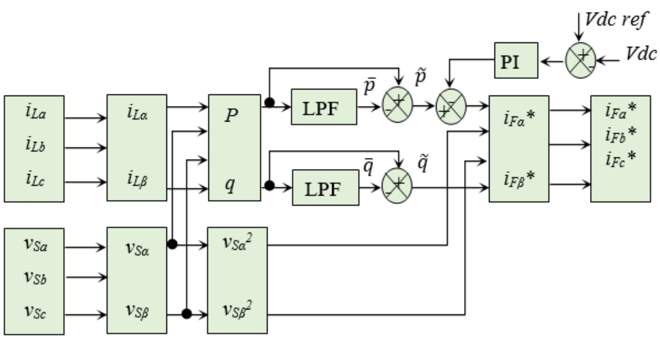


**Figure 3.** Instantaneous active and reactive power theory [7]

$$[v_S] = \begin{bmatrix} v_{Sa} \\ v_{Sb} \\ v_{Sc} \end{bmatrix} \text{ and } [i_L] = \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} v_{S\alpha} \\ v_{S\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_{Sa} \\ v_{Sb} \\ v_{Sc} \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \tag{3}$$

Once the voltages are balanced and in sinusoidal form, the Concordia transformation is applicable. In this reference, the active and reactive powers will be denoted by:

$$p = v_{S\alpha}.i_{L\alpha} + v_{S\beta}.i_{L\beta} \tag{4}$$

$$q = v_{S\alpha}.i_{L\beta} - v_{S\beta}.i_{L\alpha} \tag{5}$$

From Eqns. (4) and (5), in AC and DC components pand $q$ can be expressed, as follows:

$$p = \bar{p} + \tilde{p} \tag{6}$$

$$q = \bar{q} + \tilde{q} \tag{7}$$

where,

$\bar{p}$: DC element of active power $p$ bound to conventional active fundamental current,

$\tilde{p}$: AC element, bound to currents harmonic generated by AC components of the real instantaneous power,

$\bar{q}$ : DC element of reactive power $q$ generated by fundamental components of currents and voltages,

$\tilde{q}$: AC element, bound to harmonic currents caused by the AC components of the instantaneous reactive power.

The expression function of the currents of the instantaneous powers in the $\alpha$-$\beta$ plane is:

$$\begin{bmatrix} i_{F\alpha}^* \\ i_{F\beta}^* \end{bmatrix} = \frac{1}{v_{S\alpha}^2 + v_{S\beta}^2} \begin{bmatrix} v_{S\alpha} & -v_{S\beta} \\ v_{S\beta} & v_{S\alpha} \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \tag{8}$$

The reference currents are calculated by:

$$\begin{aligned} \begin{bmatrix} i_{F\alpha}^* \\ i_{F\beta}^* \end{bmatrix} &= \frac{1}{\Delta} \begin{bmatrix} v_{S\alpha} & -v_{S\beta} \\ v_{S\beta} & v_{S\alpha} \end{bmatrix} \begin{bmatrix} \bar{p} \\ 0 \end{bmatrix} \\ &+ \frac{1}{\Delta} \begin{bmatrix} v_{S\alpha} & -v_{S\beta} \\ v_{S\beta} & v_{S\alpha} \end{bmatrix} \begin{bmatrix} 0 \\ \bar{q} \end{bmatrix} + \frac{1}{\Delta} \begin{bmatrix} v_{S\alpha} & -v_{S\beta} \\ v_{S\beta} & v_{S\alpha} \end{bmatrix} \begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix} \end{aligned} \tag{9}$$

where, $\Delta = v_{S\alpha}^2 + v_{S\beta}^2$

By the inverse of Concordia transformation, the reference currents in the *a-b-c* frame, not including the zero sequence component, are:

$$\begin{bmatrix} i_{Fa}^* \\ i_{Fb}^* \\ i_{Fc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{F\alpha}^* \\ i_{F\beta}^* \end{bmatrix} \tag{10}$$

The low pass filter LPF is used for extract the harmonique components and for stable and continuous voltage $V_{dc}$, the use of a PI controller is necessary.

## 3. THE PHOTOVOLTAIC SOURCE AND DC-DC CONVERTER

The entire PV system which consists of a number of PV modules and panels thus giving a photovoltaic array. Each module has many built-in photovoltaic cells. The model as a current source of the PV cell with associated series and parallel resistors a single anti-parallel diode [9, 10] where $I_{PV}$ is the photo current linked to the level of illumination, $I_D$the diode current, $R_{sh}$ and $R_s$ are the shunt and series resistors respectively. The dependence of output voltage and current can be:

$$I_{PV} = I_{ph} - I_0 \left[ e^{\frac{V_{PV}+R_S I}{V_T}} - 1 \right] - \frac{V_{PV} + R_s.I_{PV}}{R_{sh}} \tag{11}$$

where, $V_T$ the thermal voltage written as:

$$V_T = (A.K.T)/q \tag{12}$$

where,
$I_0$: Saturation reverse current (A),
$q$: Elementary charge ($1.602176634\times10^{-19}$ C),
$K$: The Boltzmann constant ($1.380649\times10^{-23}$ J·K$^{-1}$),
$A$: The ideality factor typically between 1 and 2,
$T$: The temperature of the cell and G: the solar irradiance.

Figure 4 displays the photovoltaic source with the equivalent electrical circuit of the DC-to-DC converter whose control is ensured by the MPPT technique to get the maximum power. Several MPPT method techniques are used to get better performance. In our case we will go to compare two of them: the conventional method (P&O) against the metaheuristic artificial intelligence method (cuckoo search algorithm).

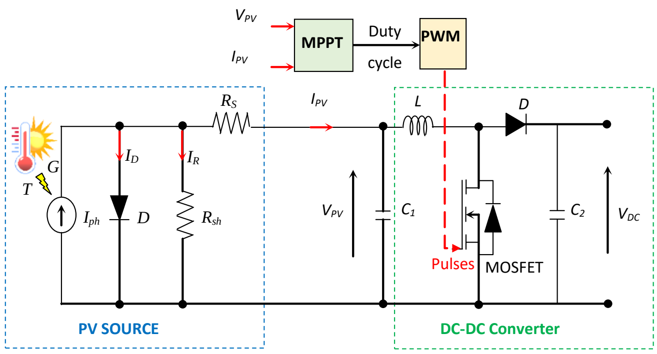


**Figure 4.** Photovoltaic system structure

## 4. THE CUCKOO SEARCH ALGORITHM

The Cuckoo search algorithm, initially proposed by Yang and Deb [11], is an algorithm based on bird behavior called "cuckoo". Indeed, he has several species of "cuckoo" have been observed to perform brood parasitism, that is, by laying their eggs in the nests of other birds (called host birds), previously observed. When searching for nests of host birds, certain mathematical functions model the choices of directions and trajectories of cuckoos [12]. The most widespread model that describes the stages of the search for the cuckoo's nest is the Levy flight.

In order to generate new cuckoos from existing cuckoos, Yang and Deb integrated Levy flight in the following way:

$$x_i^{k+1} = x_i^k + \gamma \oplus Levy(\lambda) \tag{13}$$

$$\gamma = \gamma_0(x_{best}^k - x_i^k) \tag{14}$$

where, $x_i^k$ is samples (eggs), $i$ is the sample number, $k$ the iteration number, $\gamma > 0$ is the step size and $\gamma_0$ is the initial step change.

A simplification of the Levy distribution is given by:

$$\gamma_0\left(x_{best}^k - x_i^k\right) \oplus Levy(\lambda) \approx K \times \left(\frac{u}{(|v|)^{\frac{1}{\beta}}}\right)(x_{best}^k - x_i^k) \tag{15}$$

where, $\beta = 1.5$, $K$ is the Levy multiplier (chosen by the designer), while $u$ and $v$ are determined from the normal distribution curves:

$$u \approx N(0,\sigma_u^2), v \approx N(0,\sigma_v^2) \tag{16}$$

Knowing that $\Gamma$ denotes the gamma function, then the variable s$\sigma_u^2$ and $\sigma_v^2$ are defined by:

$$\sigma_u = \left(\frac{\Gamma(1+\beta)\times\sin(\pi\times\beta/2)}{\Gamma\left(\frac{1+\beta}{2}\right)\times\beta\times2^{\left(\frac{\beta-1}{2}\right)}}\right)^{\frac{1}{\beta}} \text{ and } \sigma_v = 1 \tag{17}$$

The first use of CS in the tracking of the maximum power point (MPP) of a PV system took place in 2013 [13]. In that study, the authors used the standard or original CS (OCS) algorithm introduced in [12]. The Figure5 show the MPPT method based on the Cuckoo Search algorithm defines well how to find the best duty cycle d.

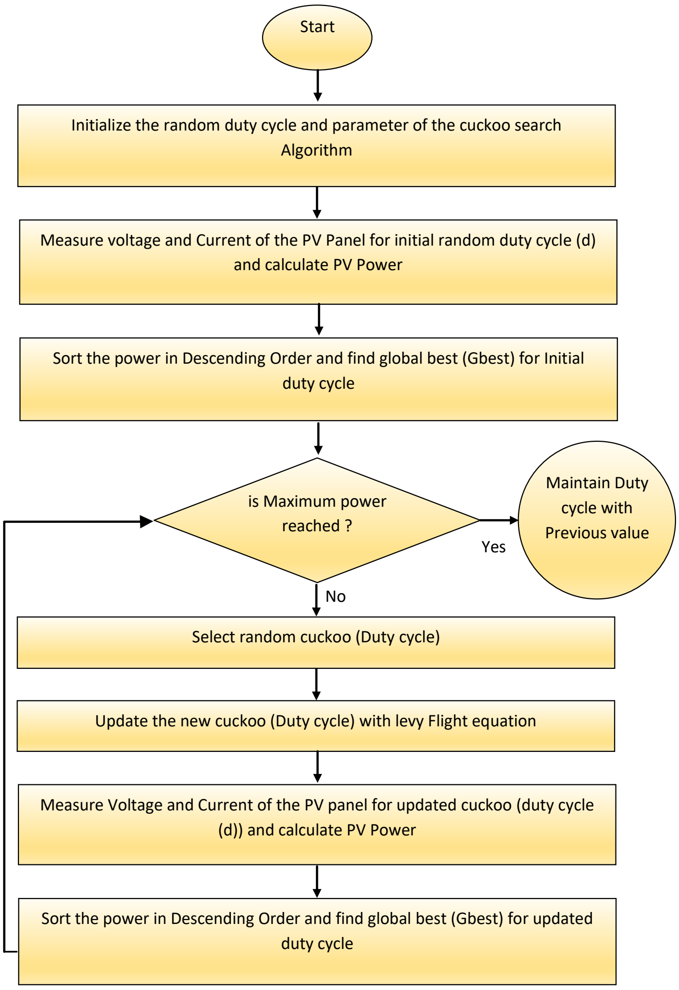


**Figure 5.** Flow chart of MPPT method based on CS algorithm

## 5. SIMULATION AND RESULTS

For the simulations, we used Matlab/Simulink and Table 1 presents the parameters of the simulation model.

The photovoltaic voltage $V_{PV}$ value of 400V that the form is shown in Figure 6 obtained per SPR-76R-BLK-U PV modules (20 parallel strings and 25 series-connected modules per sting) at 1000W/m$^2$ irradiance and 25°. The duty cycle determined by the Figure 7 clearly show that the P&O method has fluctuations and slowly converges that the CS algorithm. The Figure 8 shown the $V_{DC}$ voltage source of inverter. The wave form of the source current, load and filter currents of the phase *a* overlapping on Figure8 after compensation with the SAPF. Figure 9 shown the source current after compensation and the load current degraded by non linear load and filter current componsation. In Figure 10, now current and voltage are in phase and power factor is improved (0.0006s, so $\varphi$=10.8° and cos $\varphi$=0.98) and the form of source current $i_{Sa}$ is again sinusoidal. In Figure 11, we can clearly see that THD of the source current without SAPF componsation is behind 24.74%. Figure 12 illustrates the THD measurement of the source current after compensation of the phase *a* after compensation and becomes 2.21% for P&O algorithm and 2.18% for cuckoo search algorithm lower than the 5% required by the standards.

**Table 1.** The simulation values

| Settings | Symbols | Values |
|---|---|---|
| Electrical network | Phase neutral RMS | 230 V/50 Hz |
| | $R_S$ | 0.1 Ω |
| | $L_S$ | $0.03\times10^{-3}$H |
| Nonlinear Load | $L_F$ | $0.3\times10^{-3}$H |
| Linear load | $R_L$ | 5 Ω |
| | $L_L$ | $25\times10^{-3}$H |
| DC-DC Converter | $C_1$ | $1000\times10^{-6}$F |
| | $C_2$ | $800\times10^{-6}$F |
| | L | $10\times10^{-3}$H |
| SAPF | $L_F$ | $1.3\times10^{-3}$H |
| Cuckoo search Algorithm | Levy multiplier *K* | 0.8 |
| | Probability *Pa* | 0.25 |
| | Nb of Nest | 04 |
| | Nb of iteration *i* | 10 |

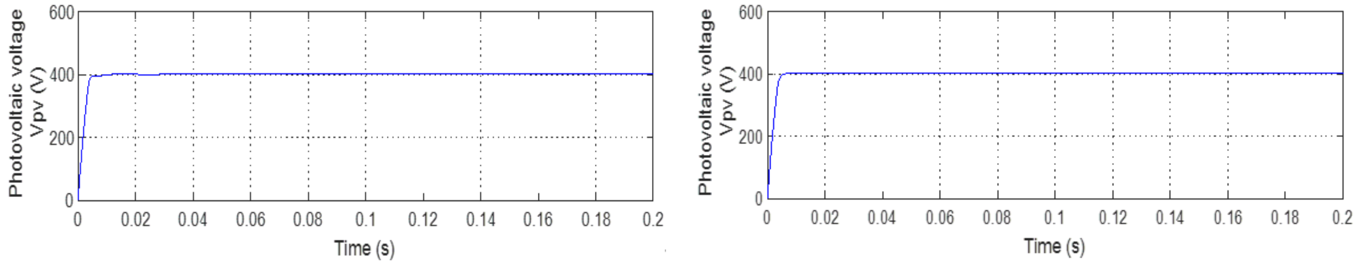


**Figure 6.** The photovoltaic voltage source $V_{PV}$ for the P&O (Left) and CSA (Right)

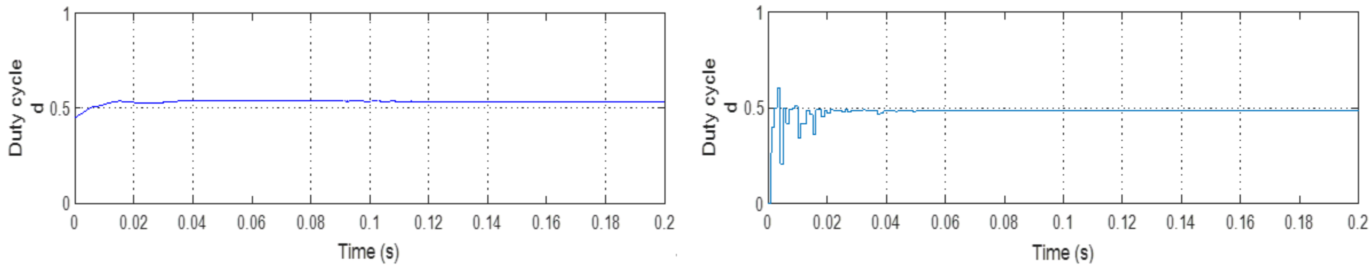


**Figure 7.** The duty cycle d for the P&O (Left) and CSA (Right)

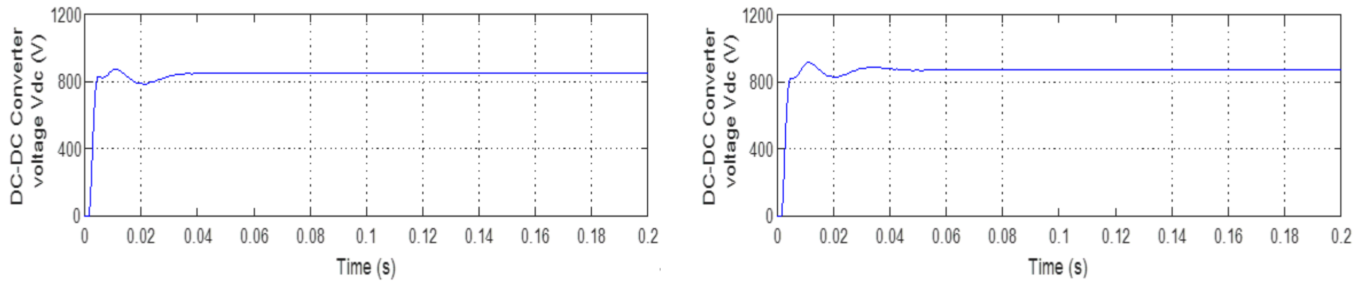


**Figure 8.** The DC-DC converter voltage VDC for the P&O (Left) and CSA (Right)

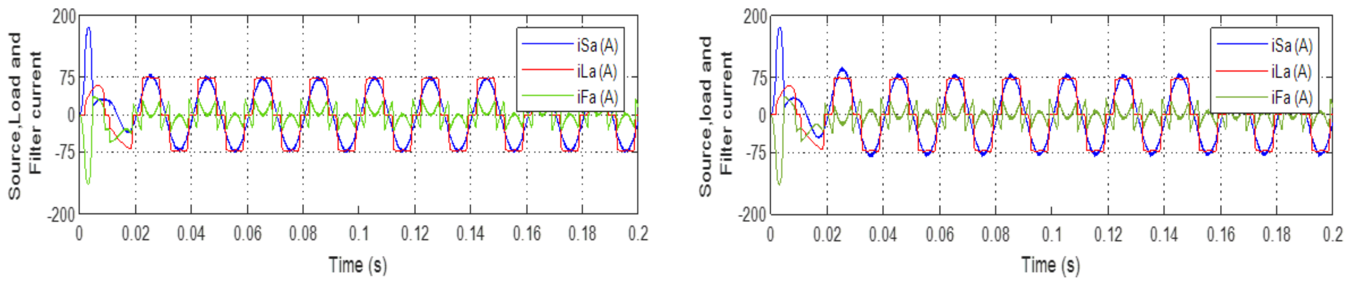


**Figure 9.** The source, load and filter currents of phase a after compensation for the P&O (Left) and CSA (Right)

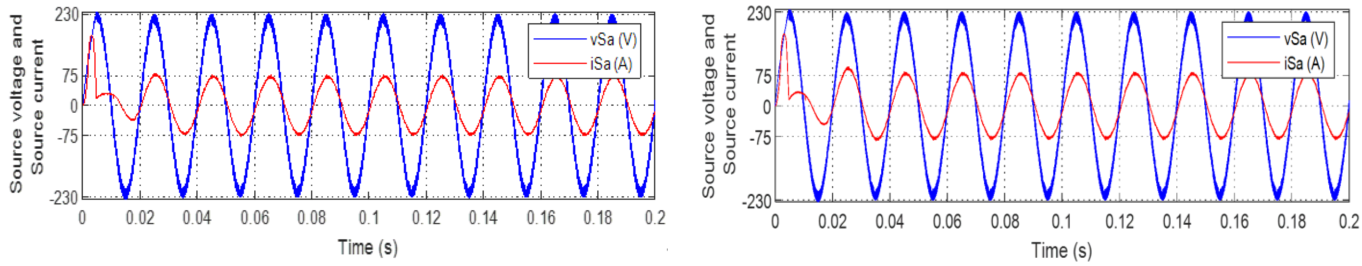


**Figure 10.** The voltage and current source of the phase a after compensation for the P&O (Left) and CSA (Right)

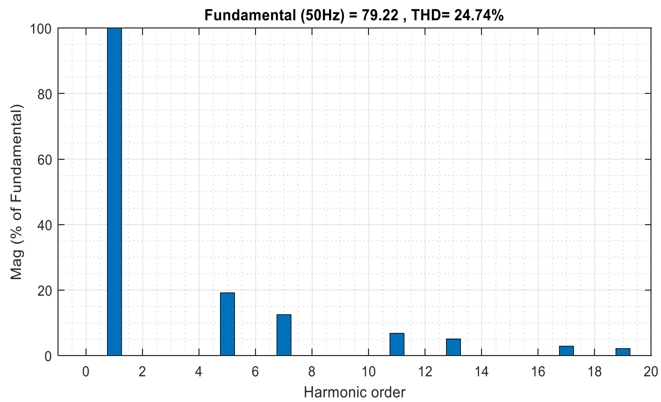


**Figure 11.** THD measurement of phase *a* before compensation with SAPF

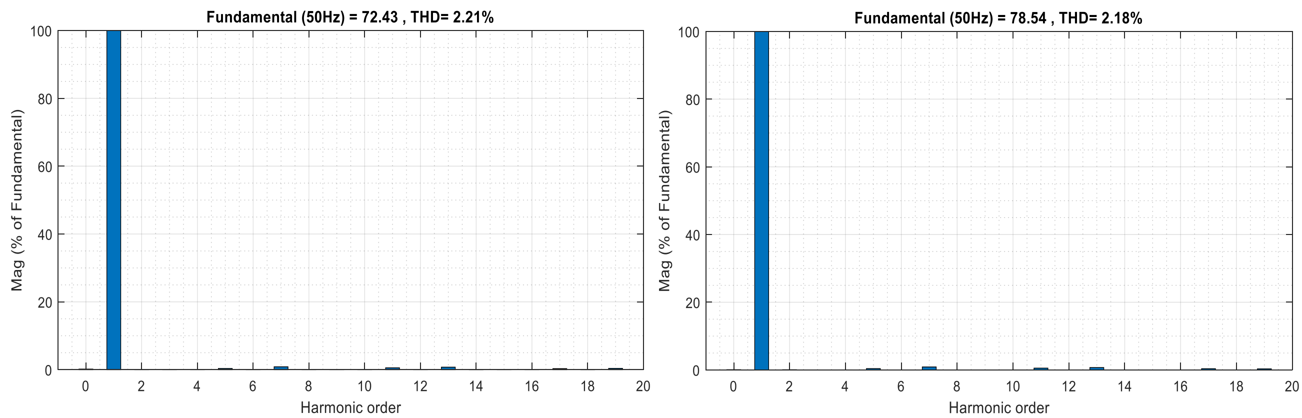


**Figure 12.** THD measurement of phase *a* after compensation for the P&O (Left) and CSA (Right)

## 6. CONCLUSION

In this article, we exposed the resolution of the problems of harmonics in the distribution networks by the insertion of the type of shunt active filters fed from the PV systems, the first based on the Cuckoo Search algorithm as a metaheuristic search algorithm, which attempts to learn the characteristics of a problem in order to find an approximation of the best solution, the second uses the P&O algorithm widely used in PV systems. The results demonstrate that CS performs better in terms of convergence speed, transient fluctuations and steady-state performance as well as further improves the power quality of the source currents.

We hope in future research to use this model against other metaheuristic models to see these performances, and with constraints such as partial shading for more efficiency.

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## NOMENCLATURE

### Abreviations

| | |
|---|---|
| p | Active power, W |
| q | Reactive power, VAR |
| D | Duty cycle |
| MPPT | Maximum Power Point Tracking |
| PSO | Particle Swarm Optimization |

### Greek symbols

| | |
|---|---|
| $\alpha$ | Reference fram of $\alpha$ axe |
| $\beta$ | Reference fram of $\beta$ axe |
| $\phi$ | Solid volume fraction |
| $\varphi$ | Angle between current and voltage |

### Subscripts

| | |
|---|---|
| S | Source |
| F | Filter |
| L | Load |
| PV | photovoltaic |
| s | Series |
| sh | shunt |
| ph | Photon |

### Constant values

| | |
|---|---|
| $q$ | Electron charge ($1.602\times10^{-19}$ Coulomb) |
| $K$ | Boltzmann's constant ($1.381\times10^{-23}$J/K) |
| $n$ | Ideality factor varies between 1 and 2 |
| $z$ | Number of cells in series |