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Mohamed MASMOUDI[1], Hamza TEDJINI[2], Abdelfettah NASRI[3]

Smarts grides and renewable energies, University TAHRI Mohamed, Bechar 08000
ORCID: **2** 0000-0003-1955-951X

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ACO Control of Three-level Series Active Power Filter Based Fuel Cells

*Abstract***.** *Hydrogen has been generally accepted as a power source with productivity with zero emissions ideal for the development of mobile power and stationary electricity. This paper presented an integration of PEMFC into a series filter for preventing the propagation of harmonics and minimizing the current ripple and preserving the AC micro-grid. For better performance, the ants' colony optimization algorithm is used on the software side and three-level NPC in the hardware parts of this filter.*

Streszczenie. *Wodór jest powszechnie akceptowany jako źródło energii o wydajności z zerową emisją, idealne do rozwoju mobilnej i stacjonarnej energii elektrycznej. W artykule przedstawiono integrację PEMFC z filtrem szeregowym w celu zapobiegania propagacji harmonicznych i minimalizacji tętnienia prądu oraz zachowania mikrosieci prądu przemiennego. Aby uzyskać lepszą wydajność, algorytm optymalizacji kolonii mrówek jest używany po stronie oprogramowania, a trzypoziomowy NPC w części sprzętowej tego filtra.* (***Kontrola ACO trójpoziomowych ogniw paliwowych opartych na filtrze mocy czynnej***)

Keywords: PEMFC, Ant colony optimization, AC micro-grid, Series active power filter, Three-level NPC inverter.
Słowa kluczowe: optymalizacja kolonii mrówek, mikrosieć AC, filtr mocy aktywnej serii, trójpoziomowy falownik NPC.

1.Introduction

In potential power systems focused on PV and other clean energy, sources hydrogen was visualized as the backbone of the energy system. Many scientists around the world have researched the idea of the use of hydrogen as an energy carrier in energy storage and transmission. [1] [2].

The abundance of water on the earth will produce hydrogen from water through electrolysis.

Oxygen is normally released into the atmosphere during water electrolysis. The hydrogen has a good environmentally affable energy cycle if hydrogen is derived from natural energy sources.

Because PV energy can be considered a limitless energy supply for all practical purposes, the cycle of hydrogen is one of the better choices in the future[3][4].

For the compensation of harmonics in industrial power networks, the active power filters have been researched because of the compensation theory of H.Sasaki and T. 1971 in Machida. In those years, active filtering was only progressing at the same time theoretical stage in the laboratory [5] [6]. Semiconductor technology was not yet sufficiently developed for the practical implementation of the compensation principle [7].

A few years later, power semiconductor technology was in a remarkable state of flux. The active filter is connected in series or in parallel and simple or hybrid as it is designed respectively to compensate for voltages or harmonic currents [8].

The object of this work is to study of the impact of combination of series power filters and hydrogen power as a source in the elimination of harmonics propagation to AC micro-grid; we introduce the ant colony optimization (ACO) and three-level NPC structure to improve performances of this filter

2. Development of fuel cell

The scientific advancement of fuel cells began soon after the Second World War when Francis T. Bacon of Cambridge, England built a high-pressure fuel cell successfully. The resulting creation of space programs involves alkaline fuel cell (AFC) and proton membrane fuel cell exchange (PEMFC) (Gemini, Apollo, Space-lab). The production of phosphoric acid (PAFC), high-temperature molten carbonate (MCFC), and solid oxide fuel cells (SOFCs) began at the beginning of the 1970s [9-11]... Until the late 1970s, PEMFC was not investigated with considerable efforts. These intensified activities have resulted in significantly better membrane electrode assembly by Ballard, Siemens, H Power, International Fuel Cells, and many universities and research centers in the US. The PEMFC's weight and costs could therefore be significantly reduced and its performance dramatically improved. The PEMFC's first commercial power plant started operations with a 200kW in 1992.

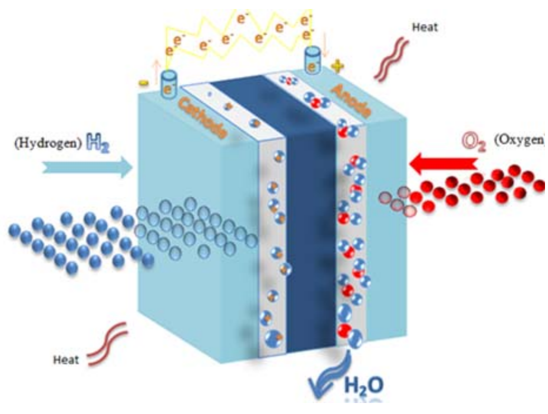

Fig.1. Schematic of PEM fuel cell operation

The majority of experts agree that the chosen electrolysis technology coupled with renewable generators would transition from incumbent AFC to PEMFC systems by 2020 until 2030.

Although the capital cost gap has been substantially decreased by 2020, the PEMEC costs combined with higher operating stability are only converted into a market gain by 2030. Experts on SOFC systems should be encouraged to meet the expense and lifespan of the AFC and PEMFC systems by 2030, while they are linked to high incertitude [12].

3. AC Macro grids

The AC power grid has been the most popular choice for the commercial energy sectors. Generation from alternators and the ability to transmit power over a long distance has made the AC grid the primary choice.

Recently, modern techniques such as FACTS compensators, renewable energies, energy storage systems (ESS), vehicle to grid (V2G), and AC micro-grids have allowed us to rethink conventional electrical systems.

Micro-grid AC systems use existing AC power system standards such as voltage range, frequency, and protection techniques for their operation [13,14]. Fig.2 presents an example of AC micro-grid.

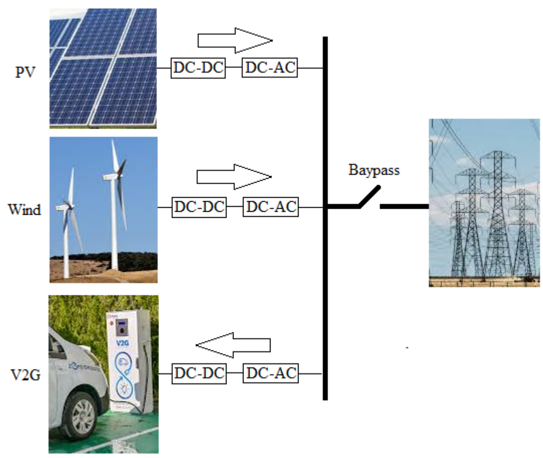

Fig.2. AC micro-grid

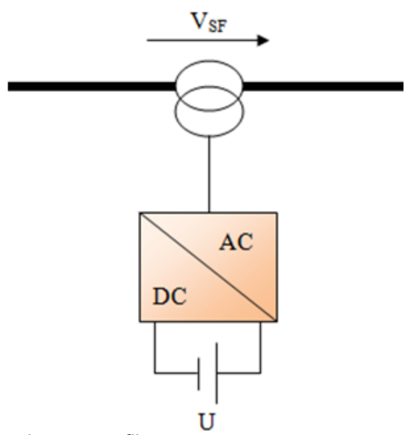

Fig.3. Series active power filter

4. Series active power filter

The operational theory of series active filter (SAPF) is focused on having the required frequency and magnitude of a voltage waveform for neutralizing imbalance or distortion of the supply voltage, such that the voltage at the load ends has the correct waveform [15].

SAPF has been proposed in manufacturing settings as a way to reduce the effect of voltage disturbances on such loads. However, most of the time these machines only wait for any disruption and typically operate way below their power., These devices often create additional impedance in the network (because coupling transformers link it to the network), with subsequent losses. In addition to their operation as a SAPF, it is also normal to provide additional functionality in these devices. Fig.3 illustrates the SAPF structure.

Since increasing the levels of the converter allows for better signal quality; and a shape closer to the sinusoidal; we introduce the three-level NPC structure in SAF structure [16].

4.1.Control of SAPF

The PQ theory is based on the αβ transition, often referred to as Clark Transformation [7], which converts three-phase voltages and currents into the steady frame of αβ. The generic three-phase line instantaneous currents (ia, ib, ic) may also be translated to αβ axis. The general control scheme is given in Fig.4.

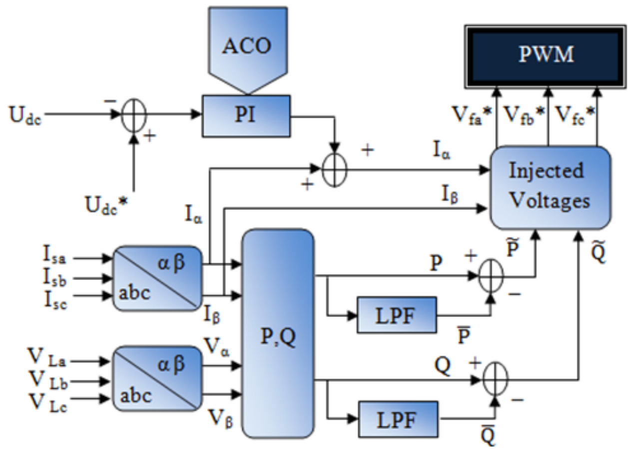

Fig.4. PQ method

4.2. Ant colony optimization of PI controller gains

From the real ants, the conduct of the artificial ants was inspired. Using the transition probability, they cause pheromone tracks and choose their direction by moving to nodes that are related by short boards with great pheromone existence.

A pseudo-random-proportional action choice probability rule pushes the ants to choose their solution to the problem among two nodes i and j.

$$P_{ij}^{k}(t) = \frac{(\tau_{ij}(t))^{\alpha} \cdot (\eta_{ij})^{\beta}}{\sum_{l \in N} (\tau_{il}(t))^{\alpha} \cdot (\eta_{il})^{\beta}} \quad (1)$$

The visibility or the heuristic coefficient ηij is related to the specific problem as the inverse of the cost function. It remains fixed during the execution of the algorithm; on the other hand, the metaheuristic coefficient ζij (linked to the pheromone which has started by ζ0) is updated after each iteration [17].

The factors α and β are dedicated to each edge between two nodes and weigh the graph of solution they allow to change the search of the algorithm in the benefit of the heuristic or the pheromone parameter.

The pheromones are updated after ants have taken a tour, based on the quality of their tour, which is related to the cost function, then by the pheromones which are linked to an evaporation coefficient ρ.

$$\tau_{ij} \rightarrow (1-\rho)\cdot\tau_{ij}, \forall(i,j)\in L$$

$$\tau_{ij} \rightarrow \tau_0 + \sum_{k=1}^{m} \Delta\tau_{ij}; \forall (i, j) \in L$$

(2) $$\Delta\tau_{ij} = \frac{1}{C^k}$$

L: indicates the edges of the solution curve,

m: defines the ants used, and the cost function is mentioned by Ck of the turn Tk, performed by the kth ant.

To have the desired performance of a system, controlled by a PI regulator, it is necessary to determine these gains: Kp

and Ki through certain characters such as maximum overshoot, rise time, and error which are adopted to define the following objective function [18]:

(3) $$F = f_{os} + f_{rt} + f_{ias}$$

The maximum overshoot is given by:

(4) $$f_{os} = y_{\max} - y_{ss}$$

where: $y_{\max}$: presents the maximum value of y; y_{ss}: indiate the steady-state value of y.

The rise time is mentionned as the time requested from a step response. On the other hand, the integral of command error is set as:

$$f_{ias} = \int_0^\infty |e(t)|\, dt$$

(5)

5. Fuel cell model

The FC stack can be defined as a controllable voltage source related with a resistance as shown in Fig. 5 [19].

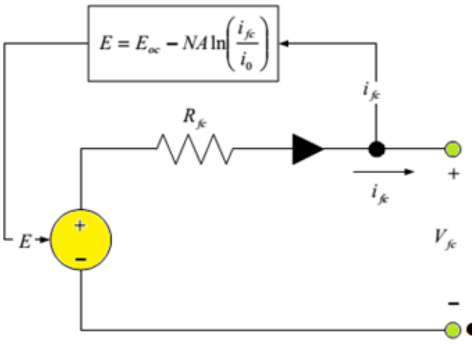

Fig.5. Fuel cell model

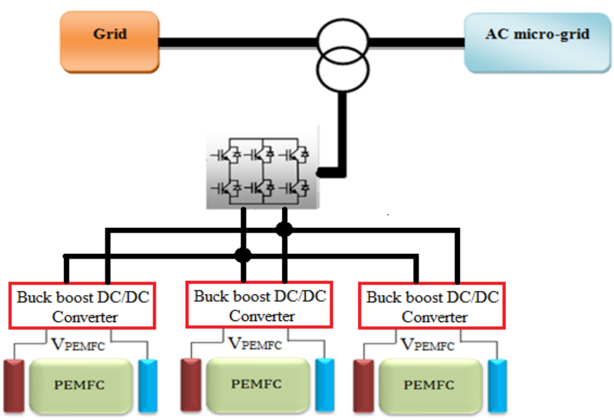

Fig.6. Studied system

The parameters of fuel and air pressure, temperature, compositions, and flow rates can be expressed [20-26].

Fig. 6 presents the studied system, as a 350V AC micro-grid connected with a polluting grid; the SAPF is inserted to cancel any pollution propagation, we use three batteries PEMFC 6 kW, 45 V, each one is associated with à DC-DC converter, all three are connected in series to deliver the overall DC voltage of the filer inverter.

. The AC micro-grid is presented as two shunted controllable AC sources of 340V as photovoltaic and wind sources and RLC load.

6.Simulation results

Fig. 7 and 8 shows the utilization of hydrogen and oxygen of fuel cell and stack consumption.

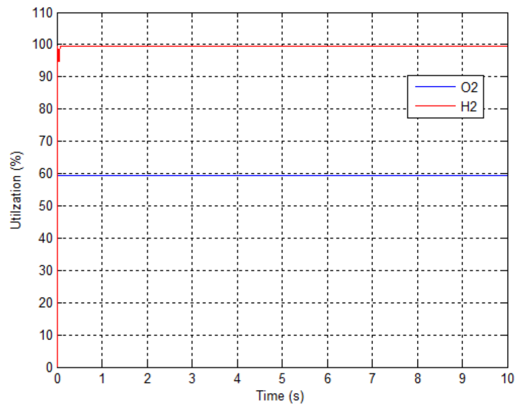

Fig.7. Oxygen and hydrogen utilization

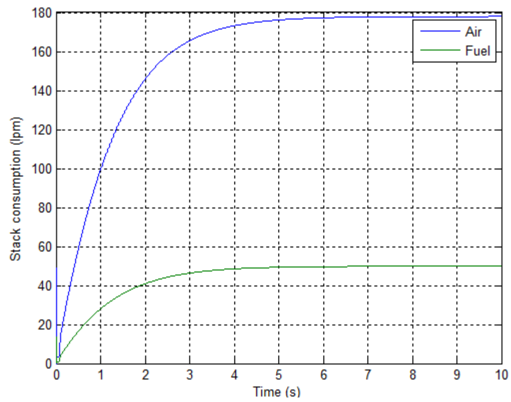

Fig.8. Stack consumption

The voltage of the fuel cell is illustrated in Fig.9.

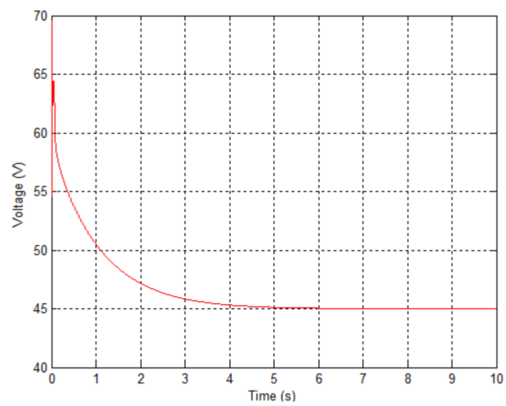

Fig.9. Fuel cell voltage

The uses of buck boost converter allow the stabilization and amplification of DC voltage as shown in Fig.10.

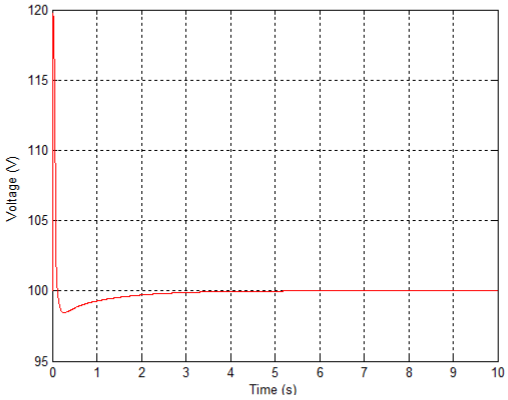

Fig.10. Amplified voltage

The global DC link is formed of three fuel cells, associated in series, Fig. 11 present the DC link of the SAPF inverter.

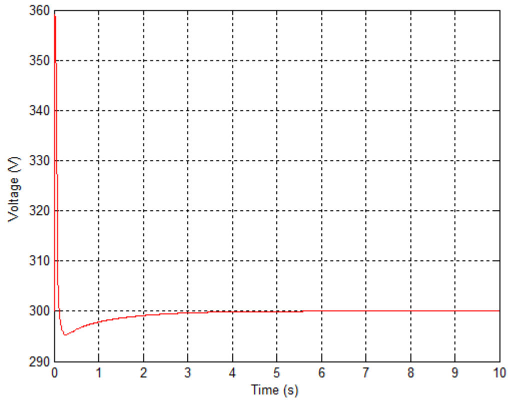

Fig.11. DC link of inverter

The Fig.12 describes the grid polluting voltage.

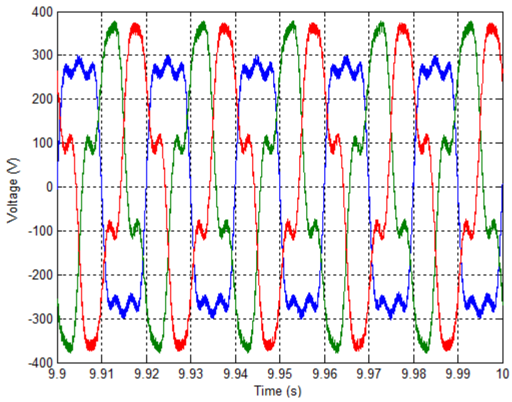

Fig.12. Network disrupted voltage

The spectral analysis show a strong value of harmonics distortion, THD= 27,95%, as shown in fig.13.

The injected voltage of series power filter is mentioned in Fig. 14, this voltage is obtained from classical control and PQ algorithm, and it addressed to a two level PWM inverter.

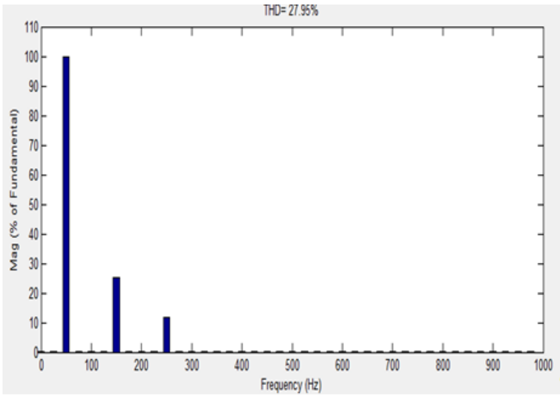

Fig.13. Voltage spectral analysis

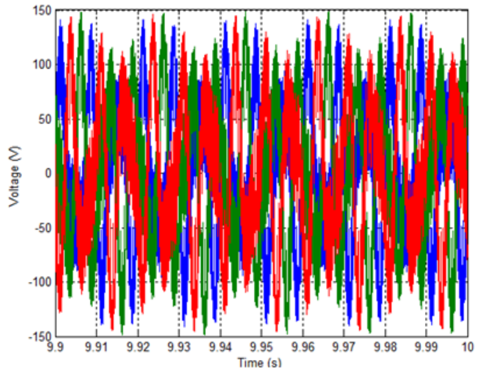

Fig.14. Series active filter voltage

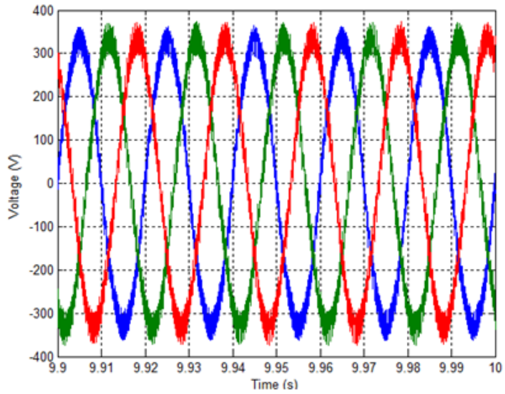

Fig.15. AC microgrid voltage

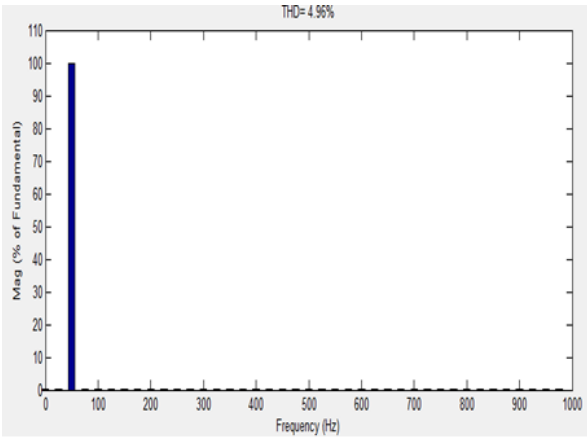

Fig.16. Voltage spectral analysis

Fig.15 presents a sinusoidal form of load voltage.

We can observe that the introduction of SAPF stop the transportation of harmonics to the AC micro-grid side, the harmonic spectrum analysis remains low of 4.96%, as is presented in Fig.16.

6.1 Uses of ACO three level npc sapf based fuel cell

In this case the three-level NPC inverter takes place of the traditional one, and the classical PI controller gains are adapted by ACO algorithm, the optimization of objective function is mentioned in Fig.17.

Fig. 18 shows the two carriers PWM control of PQ injected voltages.

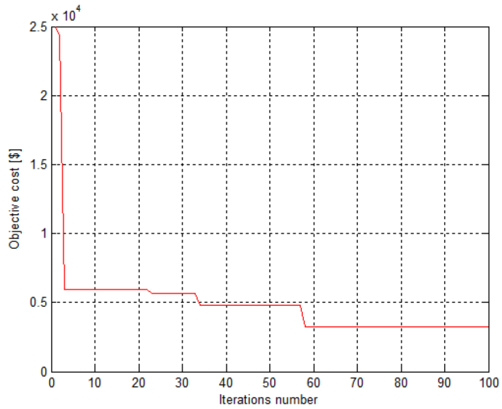

Fig.17. ACO of objective function

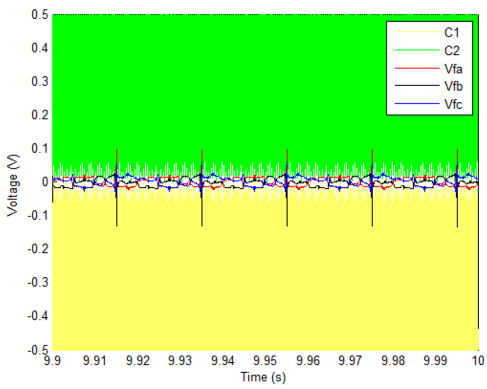

Fig.18. Three-level PWM control

Polluted injected voltages of three-level series active filter are given in Fig. 19.

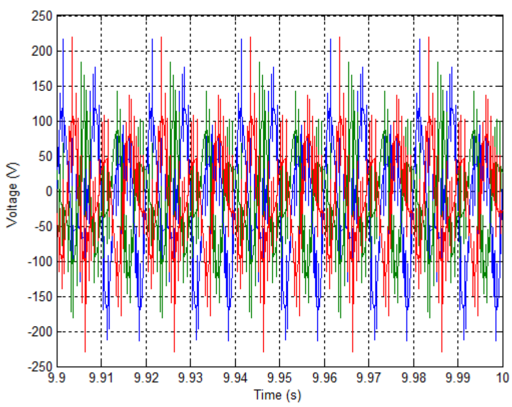

Fig.19. Injected voltage of three-level series active filter

Fig. 20 presents a well-filtrated curve of AC micro-grid voltage

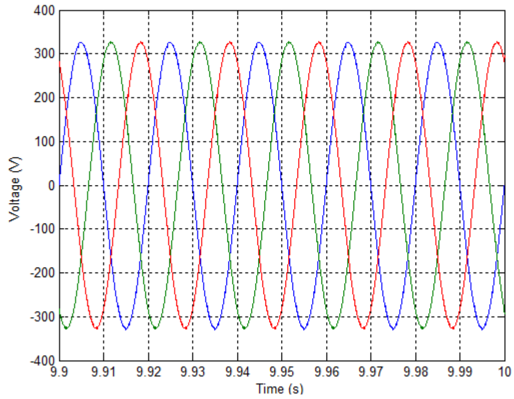

Fig.20. AC micro-grid voltage

The spectral analysis of the voltage shows a very acceptable value of distortion rate as indicated by the Fig. 21.

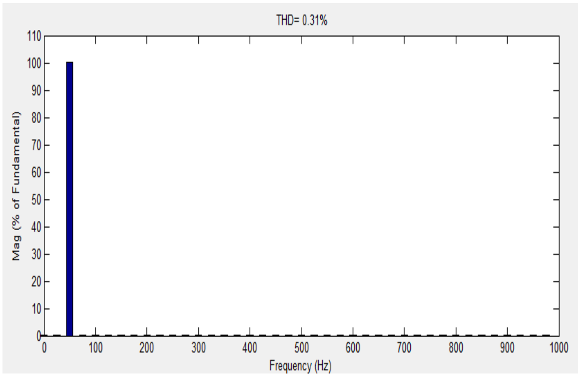

Fig.21. Voltage spectral analysis

7.Conclusion

The propagation of harmonics can cause great problems in power systems such as the malfunction of electrical devices, and the reduction of the effective lifetime. as a solution wepresent the series active power filter based fuel cell to eliminate harmonic and compensate active power of AC micro grid and this filter has demonstrated good efficiency and is capable of decreasing the voltage THD under the limit of 5% and this can stop the propagation of pollution harmonic from the grid to the AC micro-grid.

The uses of Ants Colony Algorithm in software parts and three-level NPC in the hardware side allows to increase the performances of the active filter resulting in a very low value of the AC micro-grid voltage distortion rate.

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