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ANN Identification Technique And Fuzzy PI Control Of A Hybrid Indirect Matrix Converter With A Flying Capacitor Three Level Inverter In Power Active Filtering Application

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Highlights

- This paper focuses on the synthesize of a fuzzy PI controller.
- A hybrid matrix converter in power active filtering.
- Artificiel Neuronal Network identification technique.

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Keywords

Active power filtering,
Artificial neuronal network,
Flying capacitor inverter,
Indirect matrix converter,
RST controller

Abstract

The current paper is concerned with fuzzy controllers employing neural networks to implement control over power electronics systems committed to power quality improvement in a distribution grid. An optimization method technique for tuning fuzzy PI controller gains is introduced to improve a Hybrid Indirect Matrix Converter's control with a flying capacitor three-level inverter (HIMC), and it is connected via an RL filter to the power grid (PG). The harmonics are identified by an Artificial Neural Network (ANN). The effectiveness of this method is shown in the simulation results by MATLAB/Simulink (Simscap, simpower blocks).

1. INTRODUCTION

Disturbance current in electrical power grids has become an interesting point in the power electrical research area in recent years. One of the most proposed solutions is the power active filters, which satisfy the objectives in an accepted way.

These power active filters can be found in shunt type, series type, or combined shunt/series and can be associated with passive filters. These active filters mainly consist of a DC capacitor voltage that supplies a three-legged inverter which is connected to the power grid PG by a passive filter. In this hybrid active filter, the DC capacitor voltage is charged and maintained by a full wave converter connected to the perturbed grid by a third-order RLC filter following a transformer, like Figure 1 shows, to make the active filter act as an indirect matrix converter. The control technique, which presents the main part of power active filters, is implemented to identify the perturbed current (reference) and to insure the generation of this reference by providing the inverter switches pulse.

This research focused on synthesizing a fuzzy PI controller for the Flying Capacitor Inverter (FCI) and its output RL filter. The inverter is connected to the PG via this output passive filter, which is sized to prevent the harmonics produced by the FCI from spreading and so improve the filtering quality. The smooth tracking of the reference current when there is a disturbed DC voltage is the controller's main target.

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The switches dynamic, which is inversely correlated with the supported voltage, reflects the inverter's temporal responsiveness. The FCI topology reduces the applied voltage on the switchesand it enables using the FCI at both intermediate and high PG voltages while selecting quick dynamic shifts. Furthermore, these FCI harmonics are from rang fc×N (fc: carrier frequency; N: cell number) when the carriers are evenly phase shifted implemented [1], which makes a simple RL filter very appropriate.

The phase-locked loop (PLL) is the most commonly used harmonics identification technique [2], but there are several others, including wavelet [3], Kalman filtering (KF) [4], instantaneous power synchronous reference frame [5], fast Fourier transformation [6,7], and ANN [8,9].

In order to extract the harmonic currant, a new ANN of the Adaline type is implemented. This ANN performs exceptionally well in signal estimation [9]. The objectives of this ANN type, which was developed and proposed by [10], are the amplitudes of the Fourier decomposition components of the harmonic currant.

In this application, The Flying Capacitor Multilevel Inverter (FCMI) is a regulated voltage source that is controlled in an open loop with saw-tooth rotation PWM (STRPWM), performing as a first order system with less than one cycle of PWM duration delay. The FCMI and its output RL filter presenting a second order system controlled in a closed loop with the selected Fuzzy PI controller, the harmonics detected by the Adaline identification technique serving as the reference for this final loop.

The paper is strutured as follows: Section II provides a short summary of the active filtering process's components and organizational structure; Section III focuses on the fuzzy PI modelisation and its parameter calculation algorithms; Section IV presents results, a discussion of the filtration process, and a comparison of both optimization methods; and Section V concludes this work.

2. ACTIVE POWER FILTER

2.1. Full Structure

The elements of the current filtering procedure are:

- Element of control composed of the current measurement; neural identification technique; The duty cycle calculation to generate a current equal to the reference; An STRPWM technique that insure the maintain the flying voltages and provides the inverter control signals.
- Element of power presented by the transformer and its filter; FCMI and its output RL filter; three-phase rectifier.

Figure 1 shows the two parts and the perturbed grid

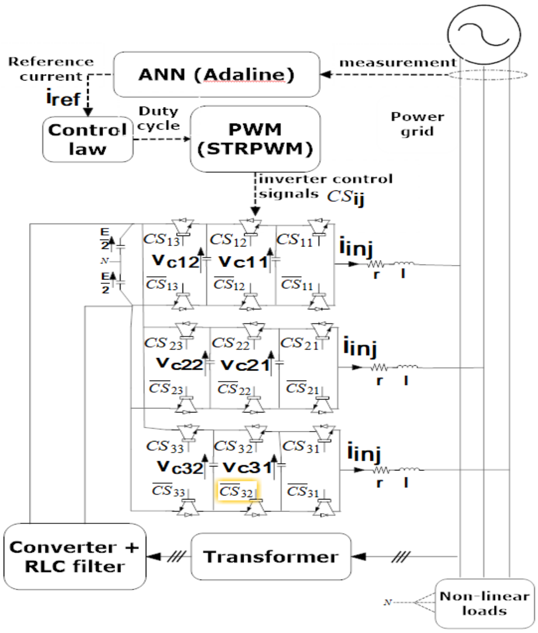

Figure 1. *Control part, Power part and the perturbed grid*

2.2. Perturbation identification

An identification technique based on an Adaline neural network that contains a singel input and output layer, this type of neural network impliment a linear activation function, the elements of the input vector X(t) are the functions that used to estimate the yref(t).

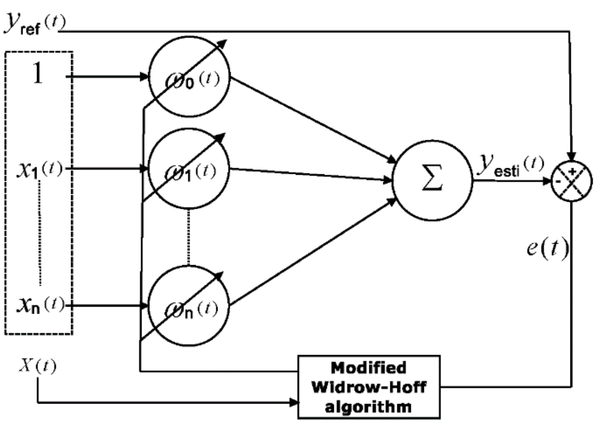

Figure 2. *The identification architecture*

Online adjustment of the inputs weights is done by Widrow-Hoff algorithm modified by [9] to optimize the error as Figure 2 shows. The PG current can be expressed as:

$$i_g(t) = i_f(t) + i_h(t). \quad (1)$$

with:

$$i_f(t) = i_{11}\cos(\omega t) + i_{12}\sin(\omega t). \quad (2)$$

and:

$$i_h(t) = \sum_{k=2..M} [i_{k1}\cos(k\omega t) + i_{k2}\sin(k\omega t)]. \quad (3)$$

The higher range of harmonic is M, and the PG pulsation is ω.

The formulation of the input vector:

$$X(t) = [\cos(\omega t), \sin(\omega t), ..., \cos(M\omega t), \sin(M\omega t)]. \quad (4)$$

The norm of Fourier series components forming the Weights:

$$W(t) = [i_{11}, i_{12}, ..., i_{M1}, i_{M2}] \quad (5)$$

The modified Widrow-Hoff algorithm is:

$$W(t+kT_e) = \begin{cases} W(t) + \dfrac{\mu e(t)Y(t)}{X(t)^T Y(t)} \rightarrow X(t)^T Y(t) \neq 0 \\ W(t) \rightarrow X(t)^T Y(t) = 0 \end{cases} \quad (6)$$

and

$$Y(t) = \frac{1}{2}(sign(X(t)) + X(t)). \quad (7)$$

The learning parameter μ determines the speed of identification but also has an impact on the error e(t). A large value of μ results in an identification that occurs quickly with an observable average value of e(t), while a small value of μ causes the identification to take longer but eliminate e(t). To take advantage of these two benefits, μ can be chosen as a variable during the transitional phase.

2.3. Control Loop

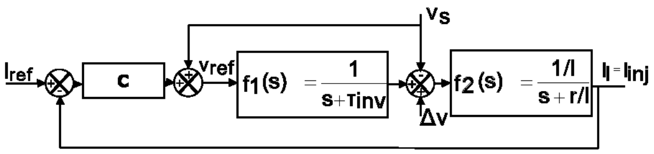

Figure 3. *Current control loop*

The FCMI dynamic makes the closed loop control a wise choice even though it requires complicated calculations. On the other hand, the open loop control is an interesting idea, in addition to its simplicity, it was designed to achieve the appropriate average voltage and balance the flying voltages [11], Figure 3 presents the control loop of the controlled system by presenting of both transfer functions of the FCMI and the RL output filter, inverter transfer function is:

$$f(s) = \frac{1}{s+\tau}. \quad (8)$$

τ is the inverter constant time and represents the delay in the response. The transfer function of RL output filter is:

$$f(s) = \frac{1/l}{s + r/l}. \quad (9)$$

The closed loop control of the inverter:
Many controller as PI [12,13], predictive control [14,15] and sliding mode [16] can satisfy the aims by using the state vector X for a single phase:

$$X(t)=\begin{bmatrix} V_{c1} \\ V_{c2} \\ i_{inj} \end{bmatrix}. \tag{10}$$

But it necessitates intricate and exact calculations.

The open loop control of the inverter:
The PWM technique presents a smart solution in open loop control. It has been studied by many researchers [11] such as carrier redistributed PWM (CRPWM), the phase shifted PWM (PSPWM), The Modified CRPWM (MCRPWM) and the saw tee rotation PWM (STRPWM). These PWMs only offer the maintain function for the flying voltages (FV), not the convergence, therefore the inverter must start operating with balanced voltages. To make up for this shortcoming, a straightforward balancing technique as suggested in [17] is used initially to balance these voltages. According to a research by [11] were STRPWM, MCRPWM, and PSPWM all evaluated, the STRPWM offers the optimum balance between THD and FV ripple, hence it was chosen for this application.

CONTROL METHOD

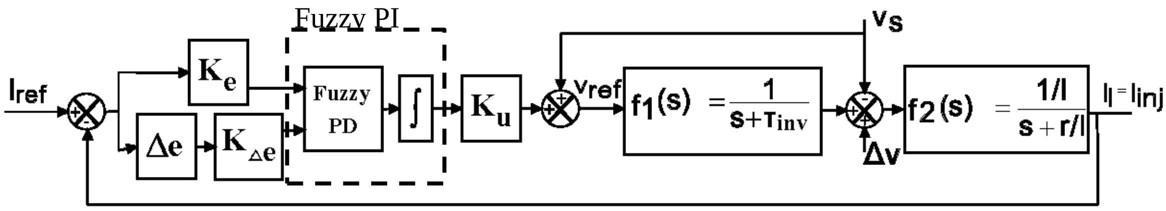

Figure 4. *Fuzzy PI control loop*

A fuzzy PI controller is used to insure that I_{inj}(t) track I_{ref}(t) and reduce as possibal the error (e), the fuzzy PI controller is based on a fuzzy PD controller, then a PI controller is obtained by adding an integral action to the output. The error and the error's derivative are the inputs of the controller, as illustrated in figure 4.

$$e(t)=I_{ref}(t)-I_{inj}(t). \tag{11}$$

$$\Delta e(t)=e_{k+1}(t)-e_k(t). \tag{12}$$

Both inputs are weighted by K_e and $K_{\Delta e}$ respectively, the controller output (u) is weighted by K_u. A three middle triangular input membership functions that overlap their neighbor functions at a membership value of 0.5 and two trapezoidal memberships at the positive and negative ends are chosen as Figure 5 shows.

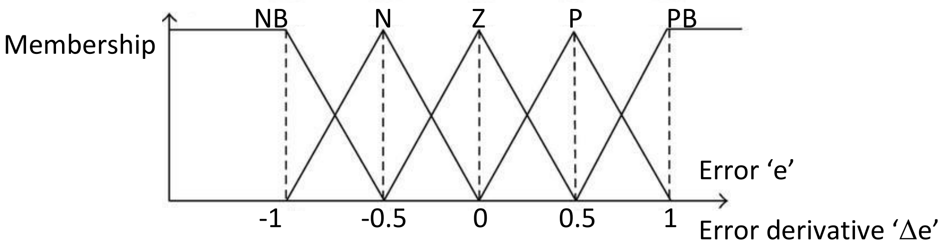

Figure 5. *Membership functions*

A 25 rules (Table 1) treated by the Sugeno inference system, which uses a singleton output membership function, it uses a product operation for implication and sum for aggregation. Because it uses a weighted average or sum (our case) of a few points, the defuzzification for the Sugeno system is more efficient than the Mamdani system, which computes the centroid of a two-dimensional area [18]. A 9 constants membership deffuzzification functions implemented to speed up controller treatment.

Table 1. *Mamdani Rules base*

e \ Δe	PB	PS	ZE	NB	NS
PB	PB	PB	PB	PS	ZE
PS	PB	PB	PS	ZE	NS
ZE	PB	PS	ZE	NS	NB
NB	PS	ZE	NS	NB	NB
NS	ZE	NS	NB	NB	NB

The weight parameters K_e, $K_{\Delta e}$ and K_u are calculated with the Genetic Algorithm (GA) optimization method, from the MATLAB/Optimtool.

The target function 'TF' to be optimized is the square root of the fuzzy PI response error

$$TF = \sqrt{e^2}. \tag{13}$$

Genetic algorithms (GA) are an adaptive algorithm that can find the best solution to an optimization problem. This process is based on the natural selection process, which mimics how evolution works in the real world. The algorithm works on a population of individual solutions, modifying them until it finds one that works. At each step, the genetic algorithm selects individuals from the current population and uses them as parents to produce the children for the next generation. This process continues until the population has reached a desired size. Over time, the population tends to reach an optimal solution..

3. RESULTS AND DISCUSSION

To simulate the power grid, a three-phase voltage generator is used; a nonlinear load is presented by rectifieras; a linear load is presented by a resistor; and the active filter with its output filter. Parameters of simulation are all placed in Table 2.

Table 2. *Simulation parameters*

Parameters	Value
μ	1
f_c	12 khz
Simulation step	1^{-7}s
Sampling time	1^{-5}s
Transformer	10e4VA, 50Hz
Output filter *r,l*	10Ω, 0.5mh
Flying capacitors	470µf
DC capacitor	470µf
Number of cell	N=3

A single phase is presented to explain our results.

Figure 6 shows the results of identification technique, The grid current is shown in the upper plot together with the results of the identification technique's estimates, and the estimated current's fundamental and harmonic components are shown in the lower plot.

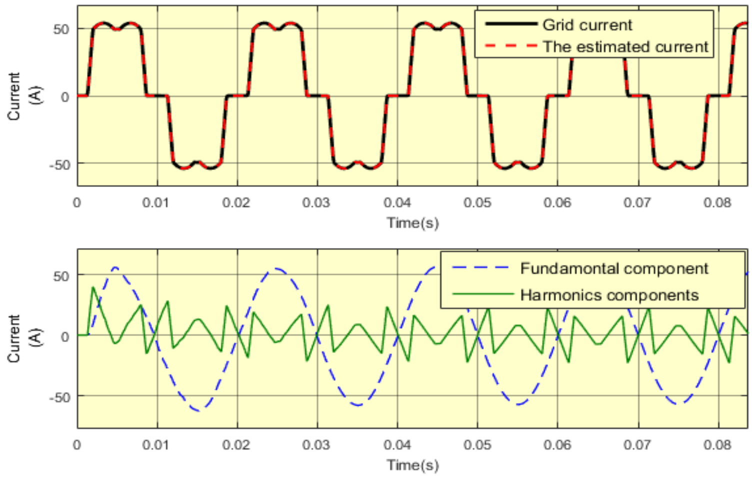

Figure 6. *Harmonics identification result*

This study was highly acceptable since it concentrated on the harmonics identification time, This is achieved in the first half of the basic period.

Table 3. *Summarizes the GA parameter setting*

Population size	50
Maximum generation	0.25
Selection	uniform stochastic
Crossover probability	80%
Mutation function	Constraint dependent

Table 3 presents the set parameters of the GA optimization in MATLAB/optimtool, the three optimized gains obtained after 22 iterations.

The fuzzy PI controller response is presented in Figure 7, a remarkable no delay tracking with an accepted rippling as the both zoomed upper graphs demonstrates.

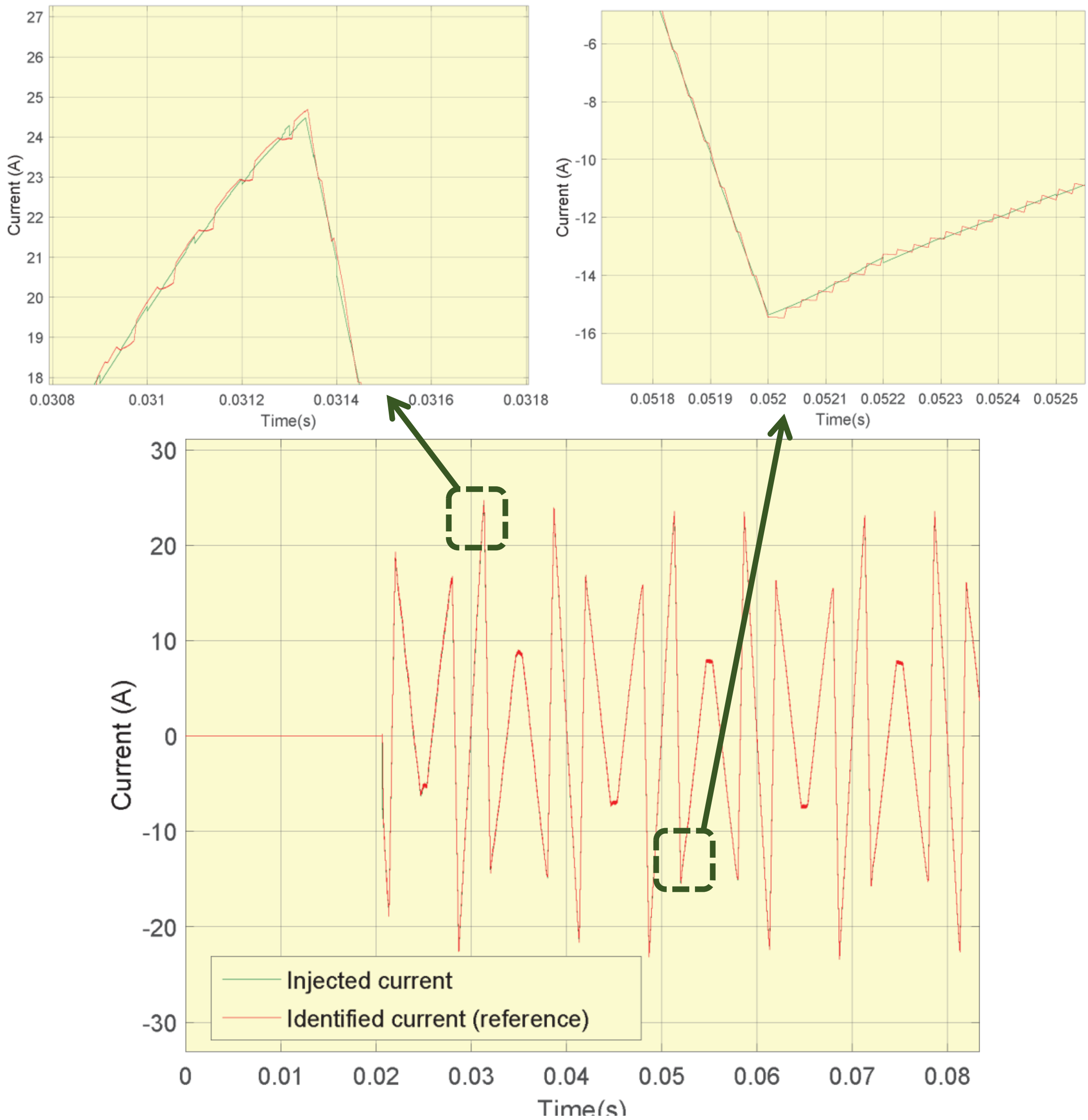

Figure 7. *Reference tracking*

Figure 8 shows the results of the grid current filtering operation; filtration begins at t=0.02s. According to Figure 9, the THD (time harmonic distortion) value decreased from about 26% before filtration to less than 1% after filtration. This is also evident from the grid current's sinusoidal form and the controller's low frequency rippling, which supports the gains tuning algorithm's effectiveness.

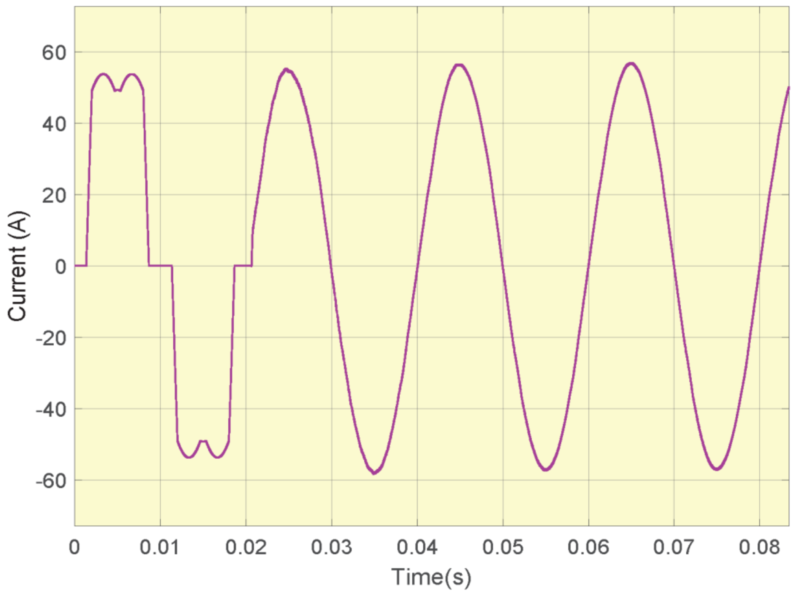

Figure 8. *Full filtering process*

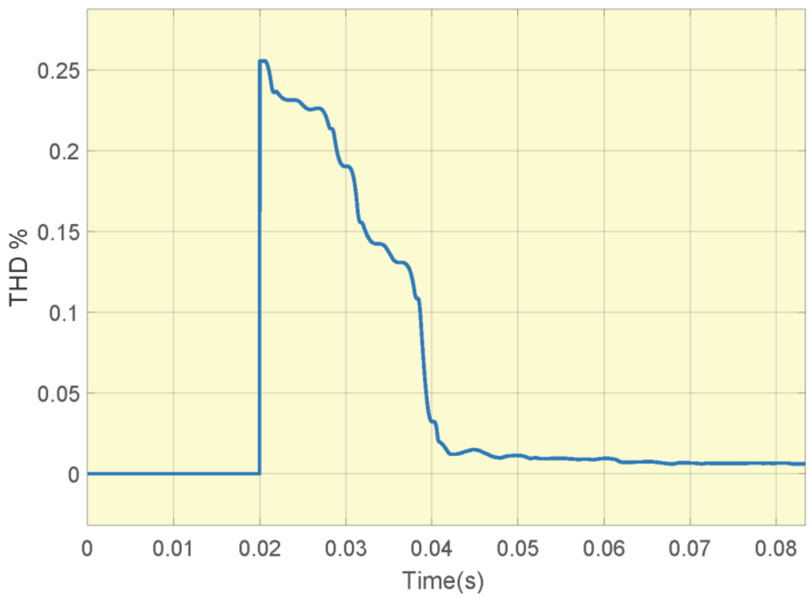

Figure 9. *THD during filtering*

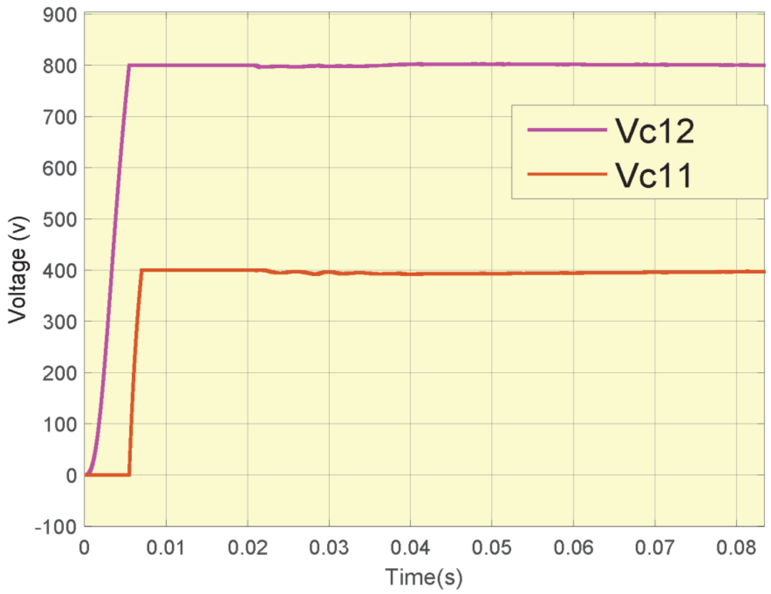

Figure 10. *Flying capacitance voltages*

As it seems in Figure 10, a small fluctuation after the start of filtration at t=0.02s then stabilized back again.

5. CONCLUSION

The fuzzy PI controller tuning approach given in this research is based on the GA optimization method, and the results are robust and quick harmonic tracking. Additionally, the Adaline ANN integration demonstrates a precise and quick reaction to supply reference current for the controller. By utilizing the STRPWM and taking use of the active power filter's inherent stability, the voltages of the flapping capacitors are kept constant. The effectiveness of these techniques to make sure the filtering application's reference finite time tracking is demonstrated by simulation results produced in MATLAB/Simulink (Simscap/Sim Power System).

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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