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# Neural network controller for five phases shunt active power filter applied for five phase embarked electrical network

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## ABSTRACT

This paper discusses neural network ANN controller applied for five phase shunt active power filter. Three-phase shunt active power filters are widely studied, however in this paper we investigate to extend their application to five phase embarked electrical network. Two-level five phase inverter is used as a shunt active power filter to reduce harmonics and compensate reactive power injected by a five-phase diode rectifier. An artificial neural network controller has been used to regulate the DC side of the inverter, thereby contributing to the calculation of the reference harmonic currents on the one side and controlling the injected harmonic currents on the other. Self-tuning filter (STF) is used to calculate the reference current. By using STF allow to extract the voltage and current fundamental components in the α-β-axis directly without the use of a phase-locked loop (PLL). Simulation results shows that the ANN controller presents appreciable performances in references tracking and the proposed five-phase shunt active power filter provides a sinusoidal supply current in phase with the line voltage with low harmonic distortion.

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## 1. INTRODUCTION

Multi-phase generators have been studied in embarked electrical network applications due to their appealing properties. Their high level of freedom, enables them to function in fault mode [1]. Their advantages over three-phase electrical networks such as reduction of torque pulsation, reduction of harmonic currents in the rotor, lowering phase current without increasing phase voltage, reduction current harmonics of DC link and more efficiency and more power in the same frame make them more attractive [2].

Five phase generators permanent magnet synchronous generator PMSG are used to generate power in such application as wind power generation, electric vehicles and embarked electrical network [3]–[6]. In order to obtain a desired output power (power quality and power factor), a series of power converters are required. The use of this converters increase harmonic injection in the system [7], [8]. The injection of this harmonics creates several problems, including increased generator losses and low power factor, therefore generating more heat [9]. Different mitigation solution passive filters; active power filters (APF) have been proposed and used [10].

In three-phase networks to reduce harmonics and compensate reactive power [11]–[13], active power filters (APFs) are widely used. Many studies and applications in this field have been performed in various research [14]–[17]. In the applications of active power filters (APFs) in three-phase electrical networks in order to reduce harmonics and to compensate the reactive power. However, the extrapolation of their studies and application in five phase electrical systems remains minimal. This paper presented an investigation on the application of an APF in five-phase embarked electrical network.

The instantaneous power (p-q) theory and synchronous reference frame (SRF) are two famous methods that have been employed in [10], [18]–[20]. When mathematical models of systems are not available, NNs can design controllers if we have information about the behavior of the system in the form of input-output data. In order to optimize the processing of harmonic current detection time, several artificial intelligence-based algorithms have recently been employed. Artificial neural networks (ANNs), which have high speed recognition and learning abilities but a simple structure, have attracted a lot of interest over the past years. These networks have been used extensively in the power electronic components of both machinery and filters devices, where they have demonstrated their efficacy.

Artificial neural network ANN has used in different application for the active power filter such as the identification and calculate the reference courants [21]–[23]. However, this paper presented an investigation of a five-phase shunt APF to compensate the reactive power and to enhance the quality of the power in a five-phase embarked electrical network. Also, we employed in this work p-q theory and the self-tuning filter (STF) using an artificial neural network controller to regulate the DC bus voltage and to control the injected harmonic currents. Through computer simulations, the performance of the reference current generation techniques (STF) and the artificial neural network controller in the five-phase network has been evaluated. Simulation results shows that the ANN controller presents appreciable performances in references tracking and the proposed five-phase shunt active power filter provides a sinusoidal supply current in phase with the line voltage with low harmonic distortion.

The paper is organized as follows: section 2 deals with the research methods. Reference current calculation is treated in subsection 2.2. In subsection 2.3 neural networks ANN for the control of the shunt APF is presented. In section 3, the simulation results are shown and discussed. Finally, section 4 presents the conclusion of the work.

## 2. RESEARCH METHOD

### 2.1. System configuration

Figure 1, shown the configuration of the study system where five-phase diode rectifier is connected to the five-phase PMSG feeding an inductive load (Rd, Ld). The five-phase two-level VSI forms the five-phase shunt active power filter connected to the five-phase network as shown in Figure 1. Self-tuning filter (STF) is used to extract harmonics and provide reference currents. An artificial neural network ANN controller is used to regulate the DC bus voltage and to control the injected current. Reactive power is compensated and harmonic currents are reduced using the proposed five-phase shunt APF.

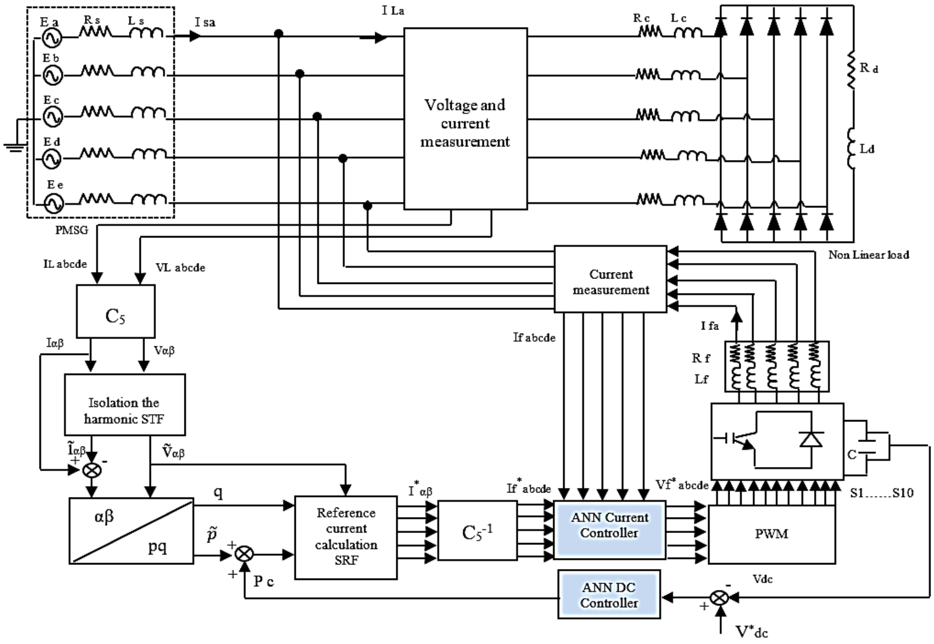


Figure 1. Configuration of the study system

Figure 2 shows the global Simulink model used, as shown it is composed of the PMSG model, the nonlinear load model and the model of the five-phase shunt active power filter APF. The detailed model of the APF five-phase shunt active power filter is shown in Figure 3. As shown, it is composed of a power calculation block, a reference current calculation block and an inverter control pulse generation block.

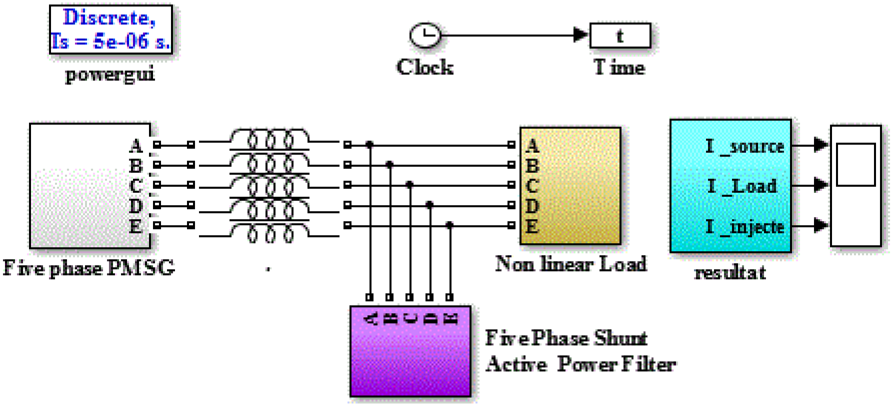


Figure 2. Model Simulink of the five phase APF

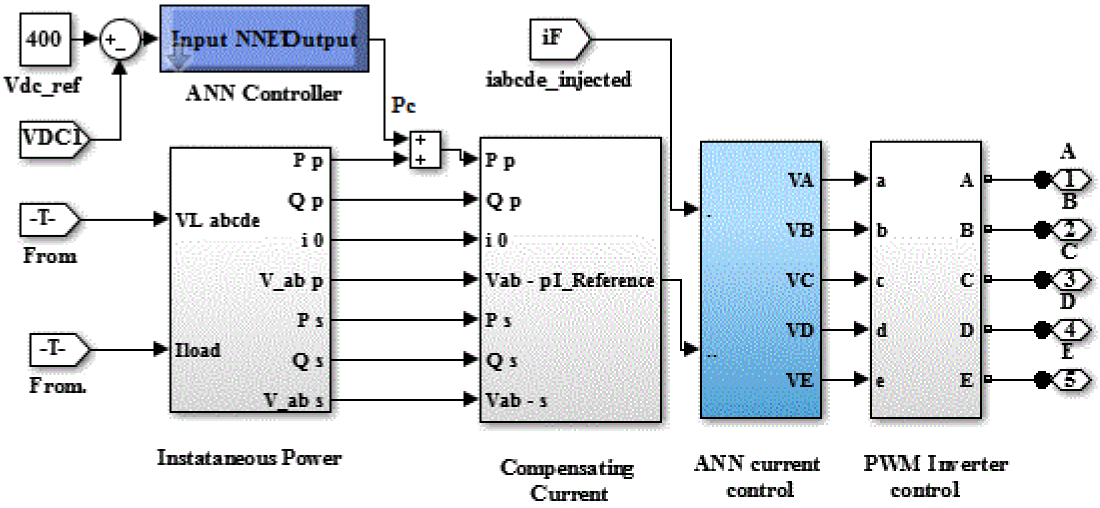


Figure 3. Detailed of the model Simulink

## 2.2. Reference current calculation

### 2.2.1. Equation in Concordia frames

The five-phase machines (original frame) can be projected into principal and secondary Concordia frames by applying the five-phase Concordia transformation [24].

$$[X]_{ps0} = [C_5][X]_{abcde} \tag{1}$$

$$[X]_{ps0} = \left[X_{\alpha p} X_{\beta p} X_{\alpha s} X_{\beta s} X_0\right]^T,\ [X]_{abcde} = [X_a X_b X_c X_d X_e]^T$$

Here *[X]abcde* are the phase voltage and the electromagnetic force (EMFs) of the PMSG generator. Were:

$$[C_5]=\sqrt{\frac{2}{5}}\begin{bmatrix}1 & cos(\frac{2\pi}{5}) & cos(\frac{4\pi}{5}) & cos(\frac{6\pi}{5}) & cos(\frac{8\pi}{5})\\ 0 & sin(\frac{2\pi}{5}) & sin(\frac{4\pi}{5}) & sin(\frac{6\pi}{5}) & sin(\frac{8\pi}{5})\\ 1 & cos(\frac{4\pi}{5}) & cos(\frac{8\pi}{5}) & cos(\frac{2\pi}{5}) & cos(\frac{6\pi}{5})\\ 0 & sin(\frac{4\pi}{5}) & sin(\frac{8\pi}{5}) & sin(\frac{2\pi}{5}) & sin(\frac{6\pi}{5})\\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}}\end{bmatrix}.....and...[C_5{}^{-1}]=$$

$$\sqrt{\frac{2}{5}}\begin{bmatrix}1 & 0 & 1 & 0 & \frac{1}{\sqrt{2}}\\ cos(\frac{2\pi}{5}) & sin(\frac{2\pi}{5}) & cos(\frac{4\pi}{5}) & sin(\frac{4\pi}{5}) & \frac{1}{\sqrt{2}}\\ cos(\frac{4\pi}{5}) & sin(\frac{4\pi}{5}) & cos(\frac{8\pi}{5}) & sin(\frac{8\pi}{5}) & \frac{1}{\sqrt{2}}\\ cos(\frac{6\pi}{5}) & sin(\frac{6\pi}{5}) & cos(\frac{2\pi}{5}) & sin(\frac{2\pi}{5}) & \frac{1}{\sqrt{2}}\\ cos(\frac{8\pi}{5}) & sin(\frac{8\pi}{5}) & cos(\frac{6\pi}{5}) & sin(\frac{6\pi}{5}) & \frac{1}{\sqrt{2}}\end{bmatrix} \quad (2)$$

### 2.2.2. Self-tuning filter

The work of Song Hong-Sock has allowed to establish a new form of extraction filter named STF. The fundamental components is extracted directly in the frame (α – β) as illustrated in Figure 4 [25]. The expressions relating the components ( $\hat{x}_{\alpha\beta}$) at the STF's output to the input components (xαβ) are as follows, according to the axe (α-β).

$$\hat{x}_\alpha(s)=\frac{k}{s}[x_\alpha(s)-\hat{x}_\alpha(s)]-\frac{w_c}{s}\hat{x}_\beta(s) \quad (3)$$

$$\hat{x}_\beta(s)=\frac{k}{s}[x_\beta(s)-\hat{x}_\beta(s)]-\frac{w_c}{s}\hat{x}_\alpha(s) \quad (4)$$

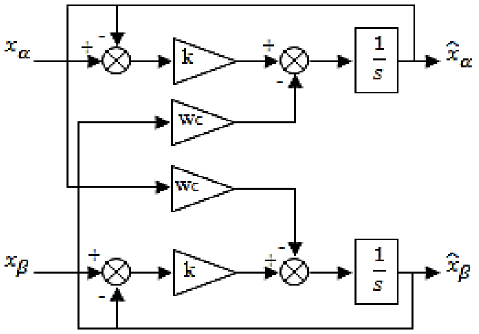


Figure 4. STF principle

### 2.2.3. Harmonic isolator

In the case of five phase system the loads currents and loads voltages are transformed into principal and secondary Concordia frames (αp, βp – αs, βs) as (5):.

$$\begin{bmatrix}I_{\alpha p}\\ I_{\beta p}\\ I_{\alpha s}\\ I_{\beta s}\\ I_0\end{bmatrix}=[C_5]\begin{bmatrix}I_{La}\\ I_{Lb}\\ I_{Lc}\\ I_{Ld}\\ I_{Le}\end{bmatrix}\begin{bmatrix}V_{\alpha p}\\ V_{\beta p}\\ V_{\alpha s}\\ V_{\beta s}\\ V_0\end{bmatrix}=[C_5]\begin{bmatrix}V_{La}\\ V_{Lb}\\ V_{Lc}\\ V_{Ld}\\ V_{Le}\end{bmatrix} \quad (5)$$

The load currents in the reference (α, β) are formed of two components a fundamental component and a harmonic component as (6)-(9).

$$i_{\alpha p}=\tilde{i}_{\alpha p}+\hat{i}_{\alpha p} \quad (6)$$

$$i_{\beta p}=\tilde{i}_{\beta p}+\hat{i}_{\beta p} \quad (7)$$

$$i_{\alpha s}=\tilde{i}_{\alpha s}+\hat{i}_{\alpha s} \tag{8}$$

$$i_{\beta p}=\tilde{i}_{\beta p}+\hat{i}_{\beta p} \tag{9}$$

Using the instantaneous power method (p, q) with STF, the detailed model of reference currents identification is shown in Figure 5. As shown, it is mainly based on the extraction of the fundamental components using the famous STF filter.

The following formulas can be used to represent the power components:

$$\begin{bmatrix}\tilde{p}_p\\ \tilde{q}_p\end{bmatrix}=\begin{bmatrix}\hat{V}\alpha\text{p} & \hat{V}\beta\text{p}\\ \text{-}\hat{V}\beta\text{p} & \hat{V}\alpha\text{p}\end{bmatrix}\begin{bmatrix}\tilde{\imath}\alpha\text{p}\\ \tilde{\imath}\beta\text{p}\end{bmatrix} \tag{10}$$

$$\begin{bmatrix}\tilde{p}_s\\ \tilde{q}_s\end{bmatrix}=\begin{bmatrix}\hat{V}\alpha\text{s} & \hat{V}\beta\text{s}\\ \text{-}\hat{V}\beta\text{s} & \hat{V}\alpha\text{s}\end{bmatrix}\begin{bmatrix}\tilde{\imath}\alpha\text{s}\\ \tilde{\imath}\beta\text{s}\end{bmatrix} \tag{11}$$

The reference currents in the (α, β)-axis is determined using the (12)-(15).

$$i_{\alpha p}{}^{*}=\frac{\hat{v}_{\alpha p}}{\hat{v}^{2}{}_{\alpha p}+\hat{v}^{2}{}_{\beta p}}(\tilde{p}_p+\text{p}_c)-\frac{\hat{v}_{\beta p}}{\hat{v}^{2}{}_{\alpha p}+\hat{v}^{2}{}_{\beta p}}\tilde{q}_p \tag{12}$$

$$i_{\beta p}{}^{*}=\frac{\hat{v}_{\beta p}}{\hat{v}^{2}{}_{\alpha p}+\hat{v}^{2}{}_{\beta p}}(\tilde{p}_p+\text{p}_c)+\frac{\hat{v}_{\alpha p}}{\hat{v}^{2}{}_{\alpha p}+\hat{v}^{2}{}_{\beta p}}\tilde{q}_p \tag{13}$$

$$i_{\alpha s}{}^{*}=\frac{\hat{v}_{\alpha s}}{\hat{v}^{2}{}_{\alpha s}+\hat{v}^{2}{}_{\beta s}}\tilde{p}_s-\frac{\hat{v}_{\beta s}}{\hat{v}^{2}{}_{\alpha s}+\hat{v}^{2}{}_{\beta s}}\tilde{q}_s \tag{14}$$

$$i_{\beta s}{}^{*}=\frac{\hat{v}_{\beta s}}{\hat{v}^{2}{}_{\alpha s}+\hat{v}^{2}{}_{\beta s}}\tilde{p}_s+\frac{\hat{v}_{\alpha s}}{\hat{v}^{2}{}_{\alpha s}+\hat{v}^{2}{}_{\beta s}}\tilde{q}_s \tag{15}$$

In the a-b-c-d-e coordinates, the filter reference current is defined as (16).

$$\begin{bmatrix}i_{\text{fa}}{}^{*}\\ i_{\text{fb}}{}^{*}\\ i_{\text{fc}}{}^{*}\\ i_{\text{fd}}{}^{*}\\ i_{\text{fe}}{}^{*}\end{bmatrix}=\begin{bmatrix}C_5{}^{-1}\end{bmatrix}\begin{bmatrix}i_{\alpha p}{}^{*}\\ i_{\beta p}{}^{*}\\ i_{\alpha s}{}^{*}\\ i_{\beta s}{}^{*}\\ i_h{}^{*}\end{bmatrix} \tag{16}$$

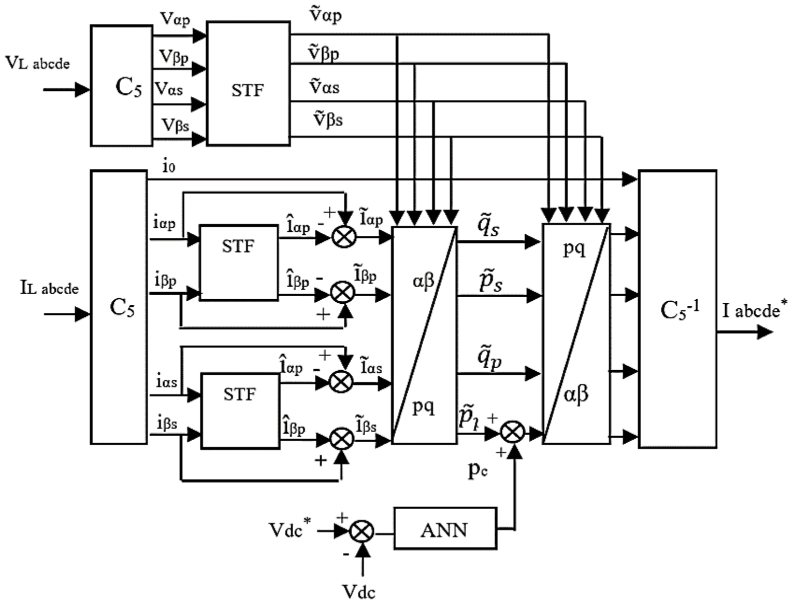


Figure 5. Block diagram for instantaneous power (p, q) with STF

### 2.2. Neural networks ANN for the control of the shunt APF

In addition to producing currents to reduce undesirable harmonics or compensate for reactive power, the (SAPF) control strategy also requires recharging the capacitor to the value specified by the VDC voltage in order to assure proper power transmission to the inverter. Power fluctuations produced by harmonics, active power regulation, reactive power compensation, and converter losses are all absorbed by the storage capacity C. It is necessary to keep a steady average voltage across the terminals of the capacitor.

The aim here is to replace the conventional PI controller with an ANN controller. The ANN for controlling the dc bus voltage is illustrate in Figure 6. The input to the ANN block is the difference between the measured and reference DC bus voltages Vdc and Vdc*. The proposed controller allows an appreciable dynamic, by absorbing or supplying active power on the electrical network, this voltage (Vdc) may beregulated.

Figure 7 shows the neural network-based injected-current controller. The input to the ANN block is the difference between the measured and reference compensation currents. The proposed regulator allows an excellent dynamic response, and the measured currents perfectly follow the reference currents as illustrated in the simulation results. Figure 8 shows the ANN controller structure for the DC bus voltage and injected current.

The following is a description of the ANN controller structure: i) Two hidden layers with six neurons that can activate in the Logsig and Tansig modes and ii) An output layer with a linear activation function. Scaled conjugate gradient backpropagation training is the method we used to train the ANN.

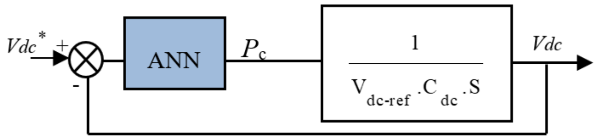


Figure 6. The use of the ANN to regulate the dc bus voltage

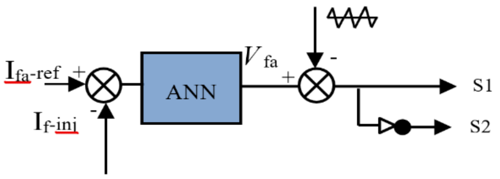


Figure 7. Injected currents control using ANN

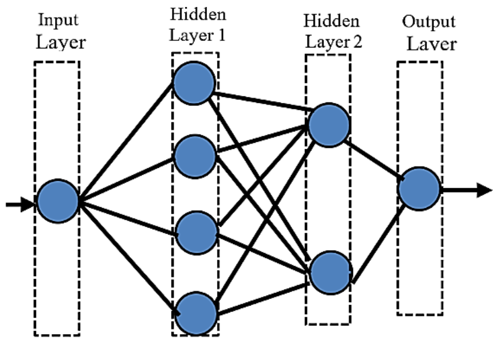


Figure 8. Structure of the ANN controller

## 3. RESULTS DISCUSIONS

The configuration system parameters used in the simulation are detailed in the following Table 1. Figure 9 presents the five phase EMF supply voltage Eabcde of the five phase PMSG. According to Figure 10, the load current $I_{La}$ (supply current Isa without filtering) has a total harmonic distortion (THD) of 48.15%. In contrast, Figure 11 shows that under these conditions, the THD of the supply current Isa after filtering is equal to 0.93%. The proposed neural network ANN control techniques enable simultaneous harmonic currents and reactive power compensation. The current injected by the five-phase shunt APF is shown in Figure 12(a). According to Figure 12(b), the obtained current and voltage waveforms are in phase.

A constant and ripple-free DC voltage has been imposed by the neural network ANN controller schemes that have been proposed. The system using an ANN controller under a step-change reference voltage Vdc-ref has been shown to have excellent transient and constant-state responses, as illustrated in Figure 13. According to the results, the technique based on neural networks has proven its effectiveness in achieving the objectives of controlling and tracking references.

Table 1. Simulation values

| Parameters | Value | Parameters | Value |
|---|---|---|---|
| Supply frequency (Hz) | 50 | Filter inductor Lf (H) | 0.01 |
| Supply phase voltage Ea (V) | 100 | Filter resistor Rf (Ohm) | 0.01 |
| Stator resistance Rs (Ohm) | 0.902 | Load inductor Ld (H) | 10e-3 |
| Self-inductance $L_0$ (H) | $0.171 \times 10^{-3}$ | Load resistor Rd (Ohm) | 10 |
| Mutual inductances ($M_1$) | $0.021 \times 10^{-3}$ | Switching frequency | 5 KHz |
| Mutual inductances ($M_2$) | $-0.078 \times 10^{-3}$ | Dc link capacitor C.dc (F) | 350 e-6 |
| Inductor Lc (H) | $3.5\ 10^{-3}$ | Vdc (V) | 400 |
| Resistor Rc (Ohm) | 0.005 | | |

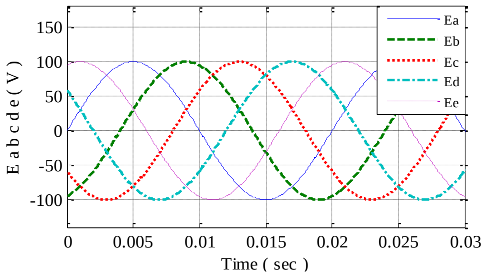


Figure 9. Five phase EMF supply voltage

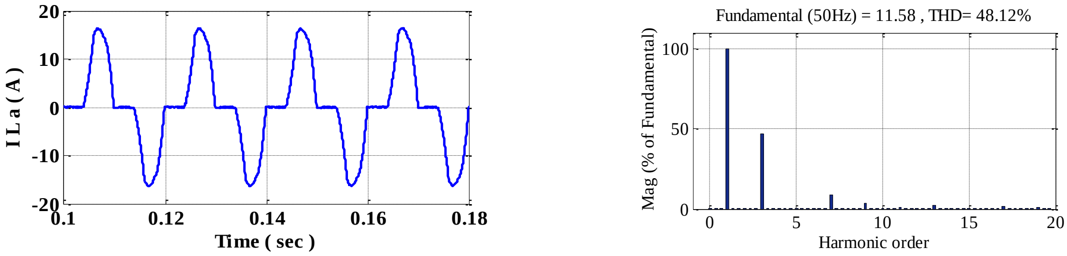


Figure 10. Supply current Isa waveform without filtering

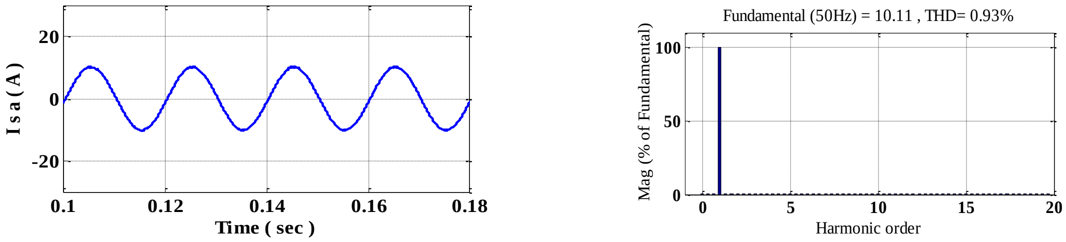
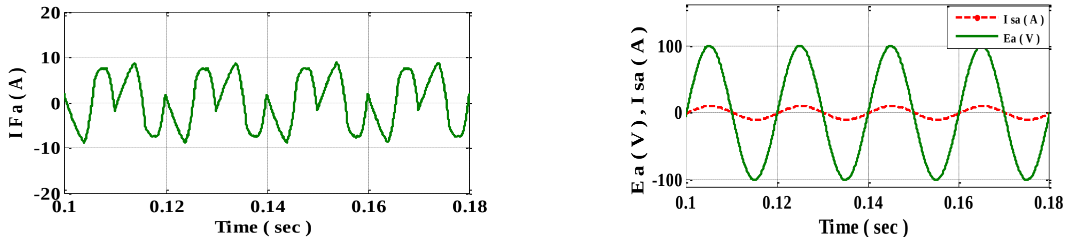


Figure 11. Supply current Isa wave form after filtering



(a) (b)

Figure 12. Injected active filter current *IFa* with ANN controller (a) power factor correction *Ea* and (b) Isa

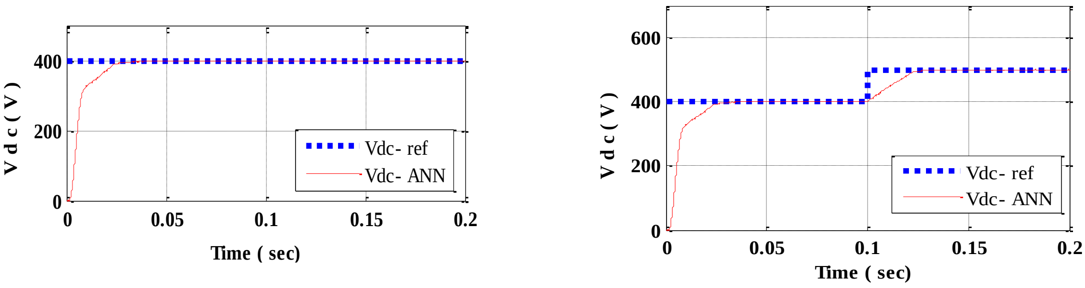


Figure 13. DC bus voltage *Vdc* under step change reference voltage

## 4. CONCLUSION

Five-phase shunt APF with neural network ANN controller under non-linear load and pure sinusoidal curve EMF profile conditions has been presented in this work. Also using five-phase PMSG as a generator allow to take advantage of multiphase embarked network such as fault-tolerant network for energy conversion. Reducing harmonics and compensation reactive power has been improved by using a modified version of the p-q theory to generate switching signals and optimizing the calculation of the reference current. STF filter allow to extract perfectly the fundamental components with no phase delay and with unity gain. The neural network ANN controller is developed to control the DC side voltage of the inverter and the injected reference current. Simulation results shows that the ANN controller presents appreciable performances in references tracking and the proposed five-phase shunt active power filter provides a sinusoidal supply current in phase with the line voltage with low harmonic distortion.

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