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Research Article

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PI-ANN and PI-GA control of a single-phase inverter connected to the grid

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Abstract: Grid-connected photovoltaic systems require a control technique to minimize the Total Harmonic Distortion (THD) in current and voltage. In this work, the Proportional Integral (PI) Controller is proposed. The major problem with this type of controller is the determination of its parameters. The intelligent method, Artificial Neural Network (ANN), and Genetic Algorithm (GA) are used in this paper to optimize the parameters of PI controller in order to reduce the THD of current. The simulation results showed that the system injects a current with 0.23% and 0.20% of the THD into the power grid with PI-GA and PI-ANN respectively. These results are well below the maximum value set by IEEE (THD $THD \leq 5\%$).

Keywords: Photovoltaic, PI- ANN, PI-GA controllers, THD

Introduction

These last decades, renewables energies, especially Solar Photovoltaic (SPV), have become more and more important in the electricity production. In the case of SPV installations connected to the Electricity Distribution Network (EDN), the injection of power leads to current and voltage harmonics. The Total Harmonic Distortion (THD) is one of the indicators of power quality. According to the IEEE Std. 519-2014 standard the THD should not exceed 5%. Several techniques are used by researchers to minimize the value of this indicator. For example, S. Nadweh, et al. in [1] have used the Proportional and the PI controllers optimized and obtained 27 % of current THD. In [2], S. Hassanein et al. have proposed an ANN controller of Dynamic Voltage Restorer. Simulations results gave a THD low than 5 %. E. Heydari, et al. have used the Fast terminal sliding mode control and obtained 3.5 % of current THD [3]. R. Niraimathi has proposed the Grey Wolf Optimization (GWO) algorithm based on PI controller technique [4]. With his method, R. Niraimathi has obtained 6. 51 % of THD of the output voltage. G. Arunkumar et al proposed the Bacterial Foraging Algorithm to optimize the parameters of the PI corrector. They obtained a THD of 3.12% as a result [5]. The digital PI controller applies the offline genetic algorithm to increase the performance of the three-phase inverter in [6]. This method allowed them to reduce the THD to 2.95 %. A PI control algorithm that is based on the regulation of the DC link capacitor voltage is proposed for the purpose of determining the filter reference current in [7]. The authors achieved a THD of less than 5%. The fuzzy logic controller and PI are proposed by C. Kannan et al to reduce the THD in [8]. After simulations, they have 3.23% and 6.89 THD with Fuzzy Logic (FL) and PI respectively. A harmonic filtering scheme based on four-level active filters is used by D. Kidmo et al in their paper [8]. This resulted in a THD of 0.04%. To improve the performance of the PI controller by automatically determining its parameters in order to decrease the error in the control method, M. G. M. Abdolrasol et al have used the Particle Swarm Optimization (PSO) algorithm [9]. The simulation results gave 3.94% THD in both current and voltage [9]. Using the Parallel Feedforward Compensation (PFC) method, D. Khan et al have achieved 2.67% THD [10].

Most of the researchers in the above works have used PI regulators with different optimization methods. These allowed them to obtain THD below 5% which is a value set by IEEE. As THD is a power quality factor. The lower is the THD, the higher is the power quality. Thus, the objective of this paper is to reduce the THD considerably. For this purpose, we use the ANN and genetic algorithm to optimize the parameters of the PI controller.

Materials and Methods

The system studied in this paper is shown in Figure1, which consists of the SPV, the grid inverter and the grid.

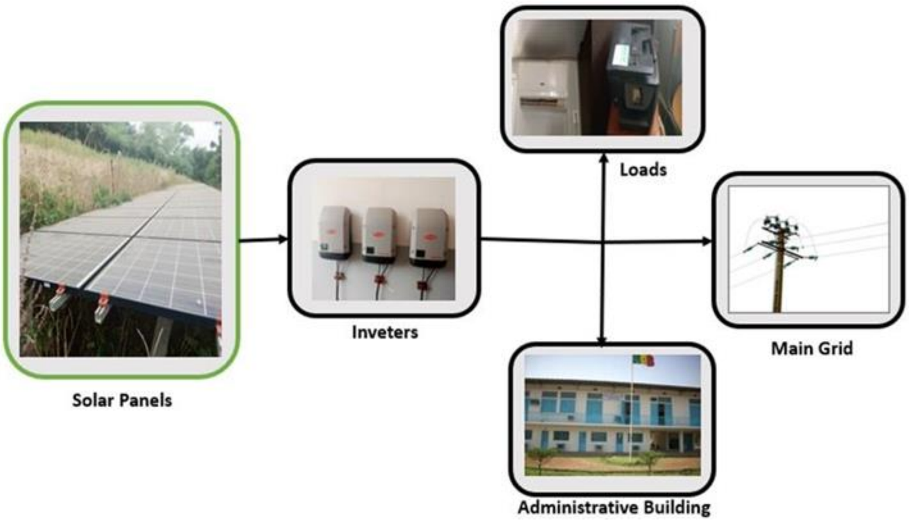


Figure 1: Studied system

PI Neuronal control

An ANN is a model that imitates the information processing and transport functions of a biologic neuron. The structure of an ANN is composed of a set of formal neurons. The latter is a mathematical model in the form of a non-linear algebraic function. An AN has a learning state and an optimal operating state. ANN is used in this paper to determine the optimal parameters of the PI corrector. Figure 2 summarises the principle of parameter determination.

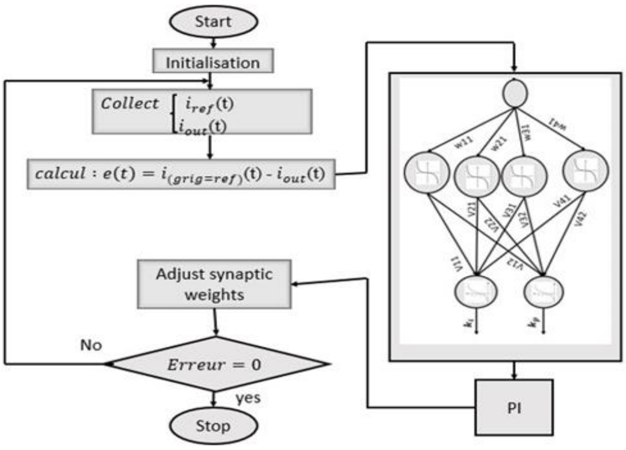


Figure 2: Flowchart of the PI-ANN method.

The backpropagation of the gradient is used here to adjust the connection weights. It is a method that calculates the gradient of the error from the output to the input of each of the neurons in order to minimize the squared error given by the equation.

$$E(k) = \frac{1}{2}\sum_{i=1}^{2}[i_{ref}(k) - i_{out}(k)]$$

The backpropagation steps are described as follows:

- Apply the input vector.
- Calculate the vectors linking the network input with the hidden layer units.
- Move to the output layer. Calculate the input value at each unit.
- Calculate the gradient of the error of the output layer and the hidden layer.
- Adjust the weights of the output layer and the hidden layer.
- Return to step 1.

PI optimized by GA

GA is an evolutionary, stochastic iterative search algorithm based on the mechanisms of natural selection and natural genetics. It includes the following terms: individuals, population, gene, chromosome, genotype, fitness function, new generation, crossover, mutation and selection. The last three terms are the operators used by the GA. The last consists of the following steps (see Figure 3):

- • Initiation, which is the selection of the initial population of chromosomes,
- Fitness assessment of the chromosomes in the population,
- Verification of the stopping criterion,
- Selection of chromosomes,
- Use of genetic operators: crossing, mutation and selection,
- Creation of a new population,
- Presentation of the "best" chromosome.

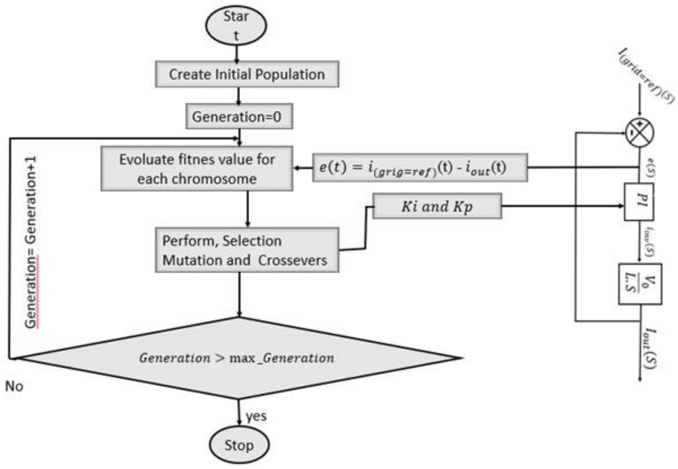


Figure 3: Flowchart of the PI-ANN method.

Results & Discussion

The system studied and the methods developed are implemented in matlab/simulink (see Figure 4). This figure is composed of the PV panel, filter, controller and main grid blocks.

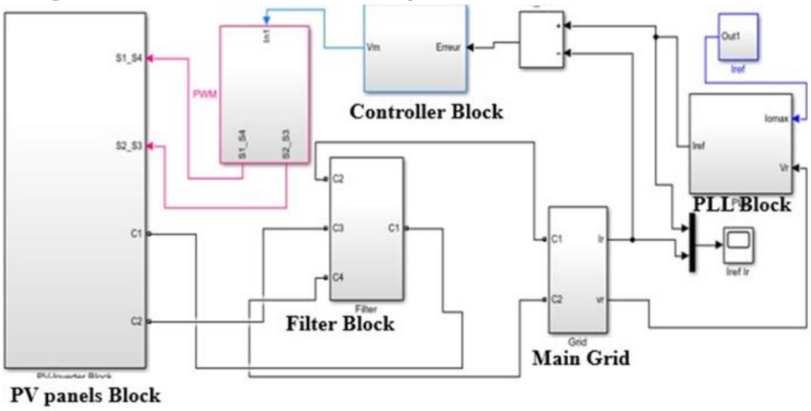


Figure 4: Simulink model of the studied system.

Figure 5 represents the injected current and the grid current. In this case, the currents generated with the methods correctly follow their reference which is the grid current.

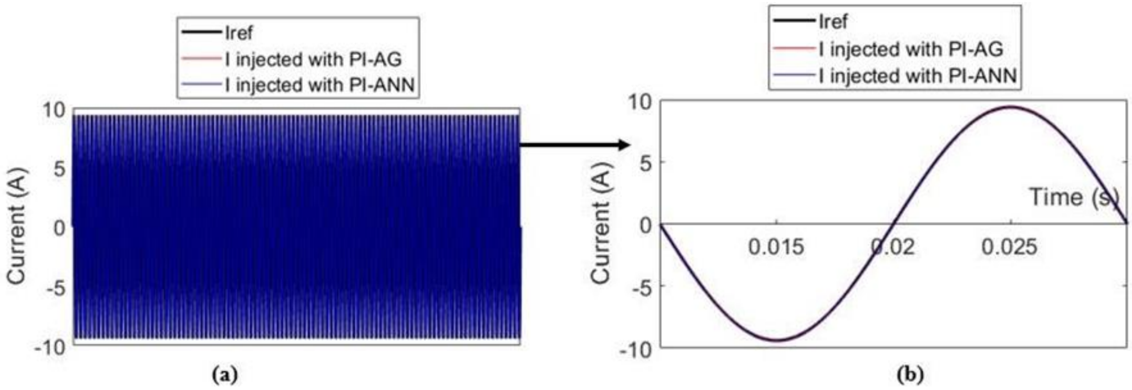
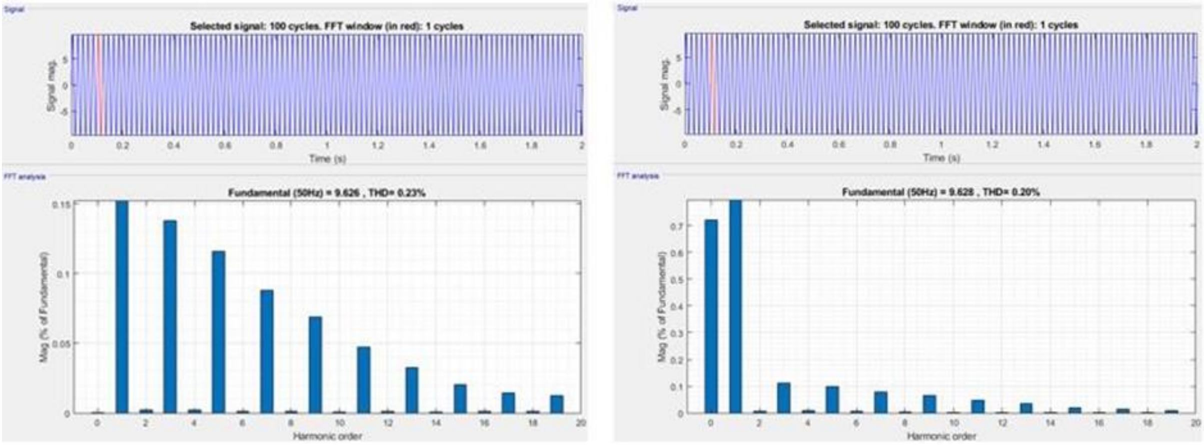


Figure 5: Injected current and its reference regulated by PI-AG and PI-ANN.

Figure 6 illustrate the THD obtained after regulation. The THD are 0.23% and 0.20% for PI-GA and PI-ANN respectively. These values are well below the IEEE Std. 519-2014 standard. This shows that the proposed methods improve the quality of the current produced significantly.



(a) (b)

Figure 6. (a): Total Harmonic Distortion with PI-GA, (b): Total Harmonic Distortion with PI-ANN.

Figure 7 represents the current supplied and the grid voltage (Figure 7(a)) . These two physical quantities are in phase (Figure 7(b)), which means that the reactive power is negligible. So, we have energy efficiency and reduced energy losses.

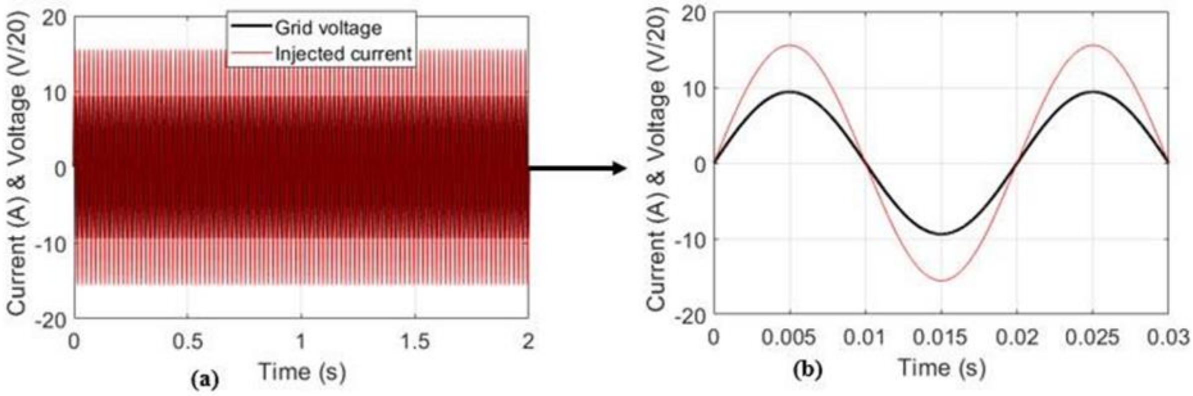


Figure 7: Grid voltage and injected current

To test the robustness of the proposed methods, we carried out several variations of the grid voltage. The grid voltage was increased by 5%, 8% and 10%.

Figure 8(a) shows the results of grid voltage fluctuation using the PI-AG method. It shows that the PI-AG method remains robust regardless of the voltage variation. However, in Figure 8(b), which shows the results using the PI-ANN method, this technique shows its limitations when the variations exceed 8%.

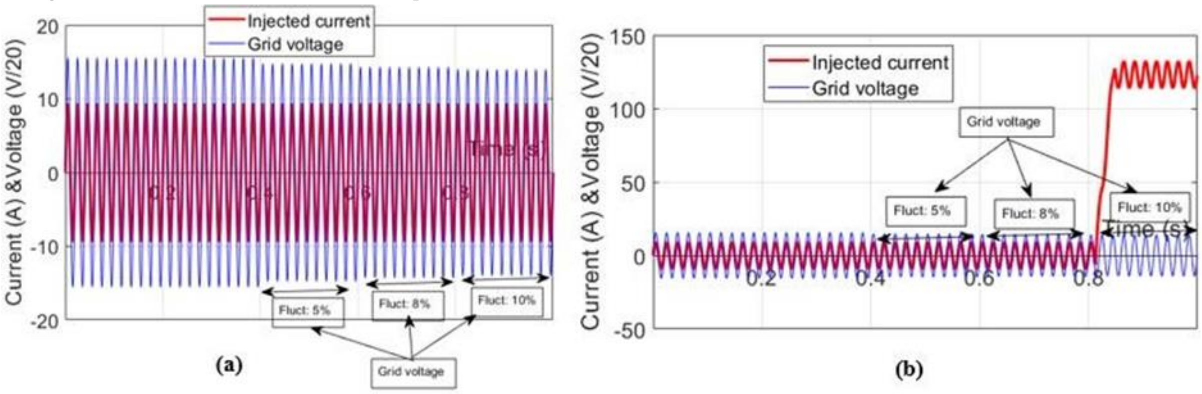


Figure 8(a): Effect of grid voltage variation on the injected current with PI-AG, (b): Effect of grid voltage variation on the injected current with PI-ANN.

Conclusion

In this work, the proportional integral controller is proposed to regulate the current injected by a PV system to the grid in order to improve the THD. Genetic algorithm and artificial neural network are used to optimize the PI parameters. The difference between these two techniques is that the GA method is an evolutionary algorithm while the ANN is a bionic and algorithms. And the PI-GA is easy to implement compared to the PI-ANN method.

The simulation results showed a great improvement in THD. The PI-AG method performs better than the PIANN method.

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