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RESEARCH ARTICLE

COMPARATIVE STUDY OF MPPT BASED ON ARTIFICIAL INTELLIGENCE

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Abstract

An MPPT or " Maximum power point tracking " command, associated with an intermediate adaptation stage, allows a photovoltaic generator (GPV) to operate in such a way as to continuously produce the maximum of its power. We present in this paper a new intelligent approach of a MPPT based on the hybrid and adaptive neuro-fuzzy network of ANFIS model. The latter is applied to a SEPIC* converter in order to extract at any time the maximum power available at the generator terminals and transfer it into the load, regardless of the sunshine variation as well as the temperature. The proposed method for a fixed and simple structure implements a Takagi-sugeno fuzzy system. Its performance will be confirmed by the comparison with the fuzzy logic command which is already known with its speed.

Introduction:-

Photovoltaic panels have a specific electrical characteristic in the form of curves given by the manufacturer. These curves generally represent the evolution of the current and the power compared to the voltage of the panel. The characteristic is non-linear in nature and has a particular point called "Maximum Power Point" (MPP). It is the optimum operating point for which the panel operates at its maximum power.

Photovoltaic energy strongly depends on climatic conditions and the location of the site, which makes the position of the MPP variable over the time and therefore difficult to locate.

The MPPT technique, as its name suggests, tracks the PPM over the time and thus allows extracting the maximum power that the panel is able to provide.

Indeed, this prosecution problem has been the subject of multipleresearches. Some works used the most popular method such as, the conventional P&O and Conductance increment method. Those works have advantages in terms of simplicity and their less expensivecost[2] [4].There are also the artificial intelligent (AI) technique algorithms, best known as fuzzy logic, neural network and fuzzy neuro. Several work proves the efficiency and robustness of

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fuzzy logic or neural network by comparing their results with the classical P&O commands [2] [12] or conductance increment [12]. Otherresearches are focused on comparing ANFIS with other AI methods, and have proved that ANFIS is faster and more efficient than these other two AI methods. [5] [11].

The objective of this work is to make the structure simple as well as to facilitate the implementation of the MPPT, regardless of the complexity and the non-linearity of the system.

This document is organized as follows: In section II, we presentthe model of the GPV. In section III, we are talking about the MPPT commands and the fuzzy-PI controller. The simulation results, as well as the performance evaluation of these MPPT techniques are presented in section IV. Finally, the conclusion and future direction in section V.

Systemoverview

In this work, our system is composed by a GPV as source, a SEPIC converter acting as an adaptation stage, an MPPT control which ensures the pursuit of the optimum operating point, a three-phase inverter and an RL load [4].

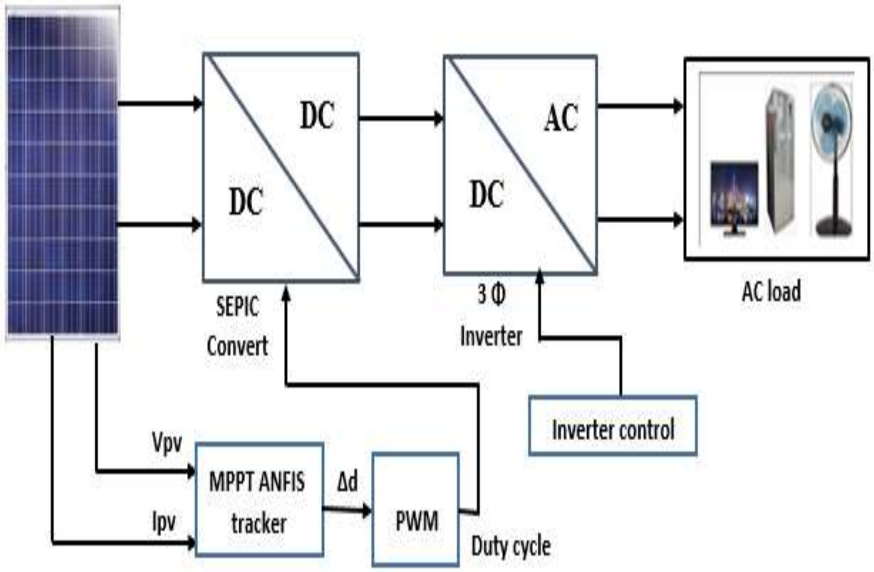


Figure 1:- Block diagram of stand-alone PV system.

Modeling a module

The photovoltaic (PV) cell allows the direct conversion of light energy into an electrical energy. It is often presented as an electric current generator whose behavior is equivalent to a current source shunted by a diode [3]. According to the literature, multiple mathematical models of a PV cell already exist. Those models aim to trick out the current-voltage (IV) characteristic,in order to analyze and evaluate the performance of a PV module. The one-diode model (figure 2) is the most classic and commonly used, because of its simplicity and precision. It is filled by two series of resistors rs and shunt rp in order to take into account the physical phenomena of the cell.

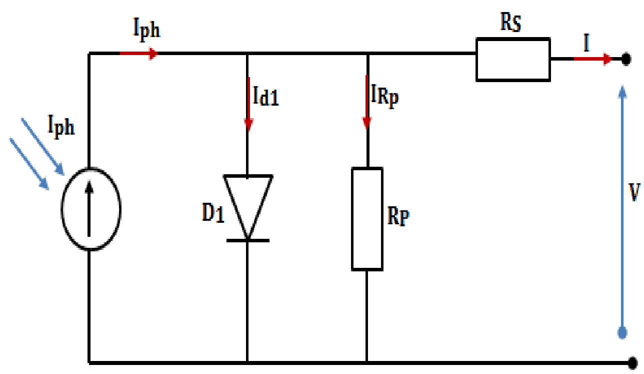


Figure 2:- Equivalent circuit of a PV cell.

The mathematical model of a one-diode PV cell is defined inequation (1):

$$I = I_{ph} - I_{sat}\left[e^{q\left(\frac{V+I*R_S}{V_t}\right)} - 1\right] - \frac{V+I*R_S}{R_p} \quad (1)$$

With: $V_t = \frac{nKT}{q}$

Or, **n**, PN junction ideality coefficient;
k, Boltzmann constant;
T, Temperature in Kelvin;
q, electron charge quantity.

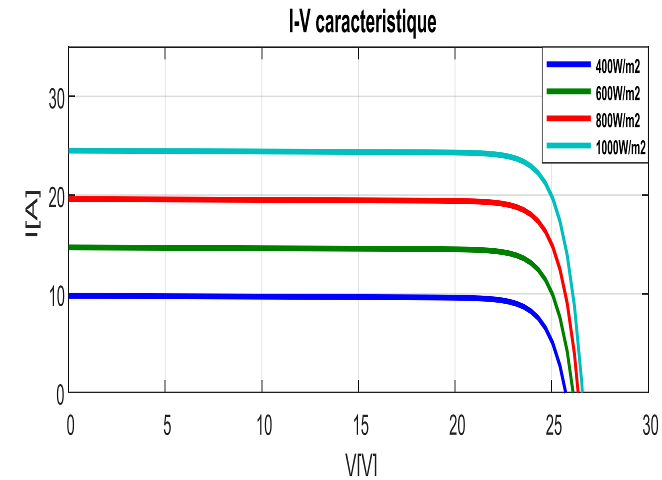
At a given temperature and irradiation, the expressions of the photo-current I_{PH} and the saturation current I_{sat} are defined in equations (2) and (3):

$$I_{ph}(G,T) = (I_{ph-ref} + \beta\Delta T)\times\left(\frac{G}{G_{ref}}\right) \quad (2)$$

$$I_{sat} = I_{sat-ref}\left(\frac{T}{T_{ref}}\right)^3 \exp\left[\frac{-qE_g}{nK}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right] \quad (3)$$

Where:
Iph-ref: current at the reference temperature; β, Temperature coefficient (in the technical sheet); Gref, reference irradiation (1000w / m2);Eg, width of the forbidden band;Isat-ref, saturation current at Tref.

The characteristics IV and PV obtained under the influence of the variation of the sunshineand Temperature are represented, in Figures 3 and 4.



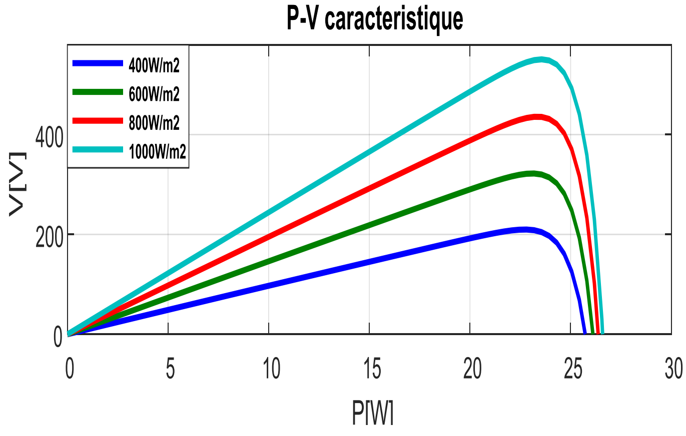


Figure 3:- IV and PV characteristic under the influence of the variation in sunshine.

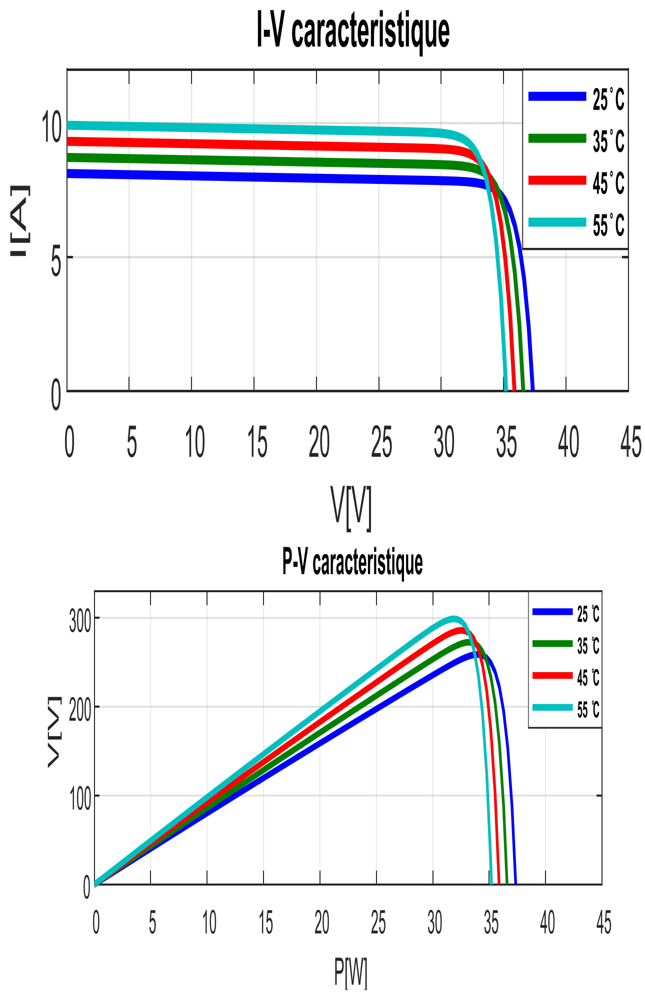


Figure 4:- IV and PV characteristic under the influence of Temperature variation.

SEPIC converter

The SEPIC converter is used as an interface between the output of the GPV and the load, where the source always delivers the maximum energy whatever the values of the Temperature and the sunlight [9]. Synchronous converters (SEPIC or CUK), become more advantageous than other converters due to reduced current ripple and better efficiency [4].

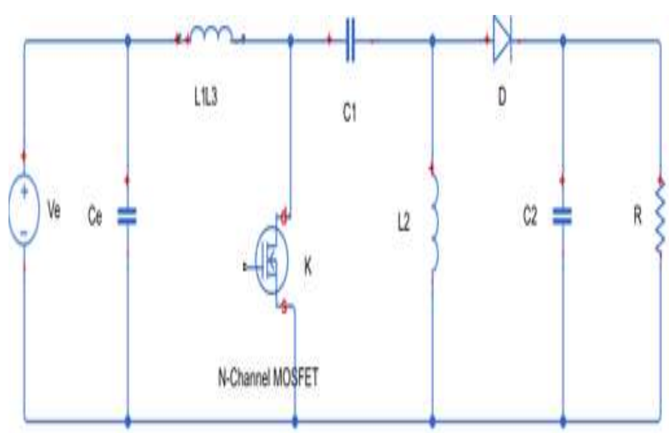


Figure 5:- SEPIC converter.

The converter state model during a switching period is described by the equations (4):

$$\begin{cases} \dfrac{di_{L1}}{dt} = \dfrac{1}{L_1}\left[(d-1)\left(V_{C_1}+V_{C_2}\right)+V_e\right] \\ \dfrac{di_{L2}}{dt} = \dfrac{1}{L_2}\left[(d-1)V_{C_2}-dV_{C_1}\right] \\ \dfrac{di_{V_{C1}}}{dt} = \dfrac{1}{C_1}\left[(d-1)\,i_{L_1}-di_{L_2}\right] \\ \dfrac{di_{V_{C2}}}{dt} = \dfrac{1}{C_2}\left[(d-1)\left(i_{L_1}+i_{L_2}\right)-\dfrac{V_{C_2}}{RC_2}\right] \end{cases} \quad (4)$$

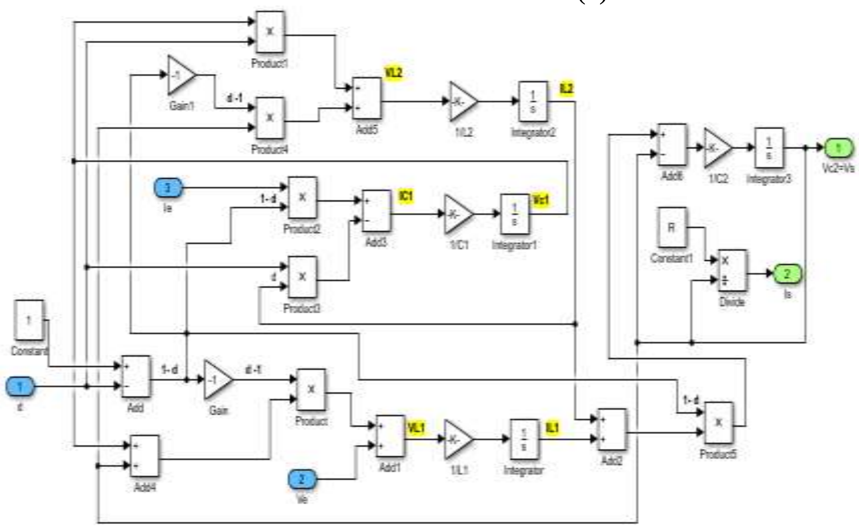


Figure 6:- SEPIC simulation model.

Fuzzy Controller

Fuzzy logic control (FLC), offers the advantage of being robust and relatively easy to build, and having a precise mathematical model and an exact knowledge of the model to be regulated is not required [2]. It allows managing the non-linearity and the complication of the system.

The establishment of an FLC is done in three stages, which are: fuzzification, inference and defuzzification.

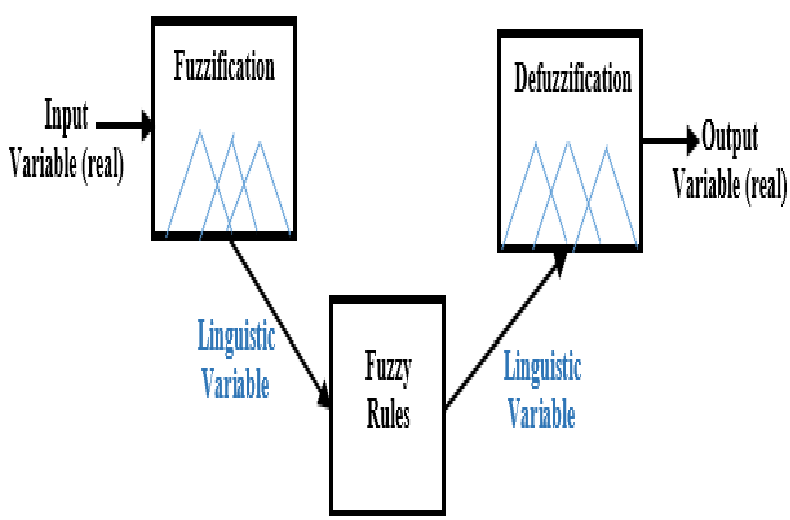


Figure 7:- Fuzzy Logic basic scheme.

In this document, the input variables are the variation of the GPVpower (dP / dV) and its derivative (d^2P / dV^2).The output is the duty cycle Δd of the SEPIC.

Fulfilling the rule base in the table below comes from the operating principle of the P&O algorithm.

For example:if (dP / dV) is NB and (d^2P / dV^2) is NS, then Δd is PB

This example will be described as follows:

When the positive increment of V (dV>0) generates a reduction in the according power (dP <0), it means that the operating point is on the right of the PPM and therefore V must be reduced (P&O algorithm).

In fact, if (dP / dV <0) i.e.the operating point is far on the right of the PPM, and when it continues to move away (d^2P / dV^2<0), then the cyclic ratio Δd will be increased to reduce the voltage V in order to redirect the operating point to the PPM.

Table 1:- Table of Rules base.

d^2P/dV^2 \ dP/dV	NB	NS	Ze	PS	PB
NB	PB	PB	PS	Ze	Ze
NS	PB	PS	PS	Ze	Ze
Ze	Ze	Ze	Ze	Ze	Ze
PS	Ze	Ze	NS	NS	NB
PB	Ze	Ze	NS	NB	NB

The membership functions of the input and output variables used in this model are illustrated in Figure 8,and respectively Figure 9. All membership functions are presented with a triangular function and consist of five fuzzy subsets which are denoted by, NB (Negative Big), NS (Negative Small), Ze (zero), PS (Positive Small) and PB (Positive Big).

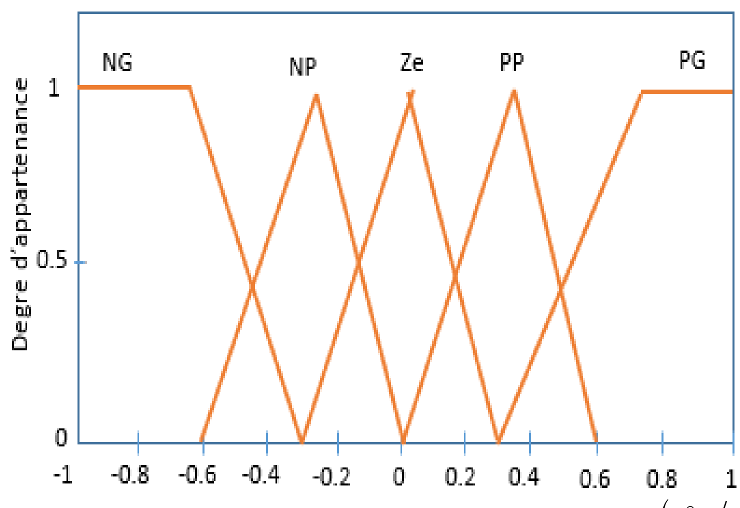


Figure 8:-Membership functions of inputs variable (dP/dV) and (d^2P/dV^2)

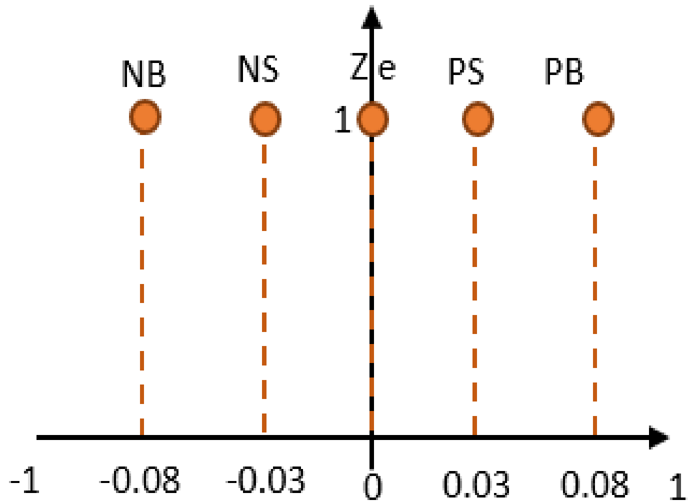


Figure 9:- Membership functions of output variable Δd.

ANFIS Controller

A hybrid neuro-fuzzy system (SNFB) can be interpreted as a special ANN with fuzzy parameters. These two methods are combined in a homogeneous architecture [10].

The joint use of RN and fuzzy logic makes it possible to derive the advantages of both methods: the learning capacities of the first and the readability and flexibility of the second.

The adaptive ANFIS model is one of the most widely used SNFB, especially in complex system optimization problems. It is based on the Takagi Sugeno inference model proposed by J-SR Jang. [3]

The Figure 10 shows the architecture of an ANFIS with two entrances, a single exit and consists of 5 layers.

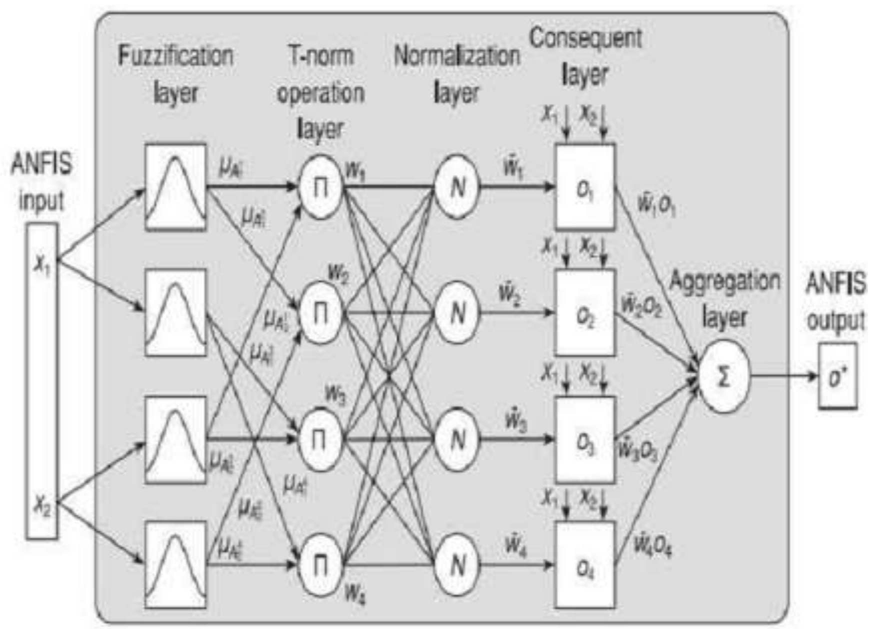


Figure 10:- Five layers ANFIS structure.

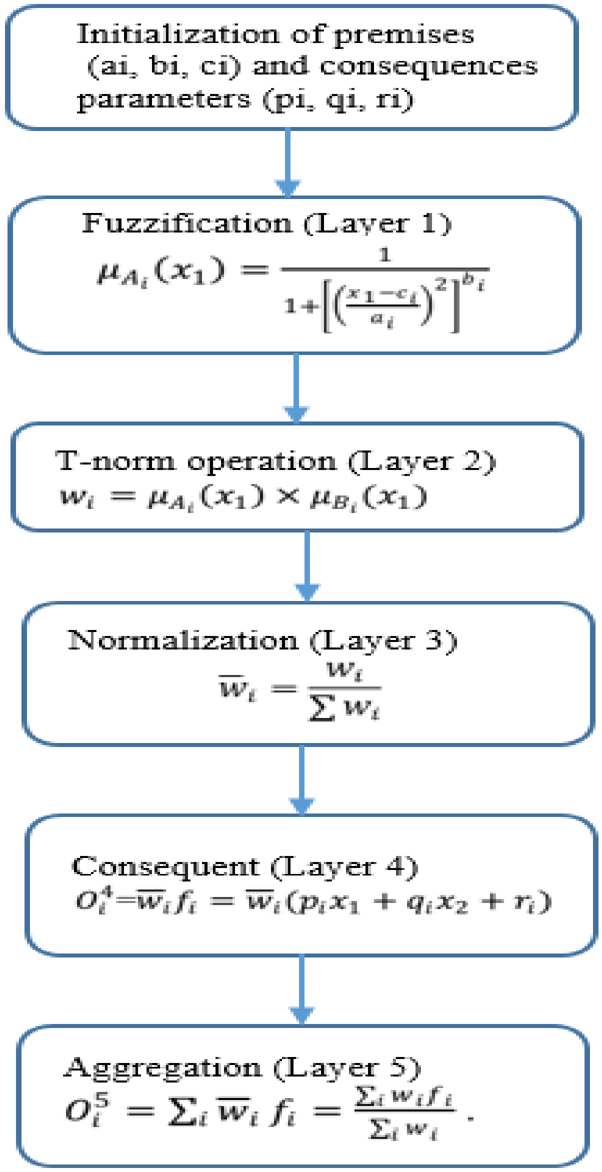


Figure 11:- ANFIS program procedure.

The proposed ANFIS MPPT controller uses two inputs, such as the Vpv voltage and the Ipv current of the GPV, and a single output which is the d command. The two input variables generate the control action d which becomes a reference for the PWM in order to adjust the duty cycle of the SEPIC, to ensure the adaptation of the power supplied by the GPV.

System learning

Learning is done from a set of input and output data. It involves identifying the parameters of the premises and consequences as well as the structure of the network to be fixed [3] [11].

With ANFIS, learning follows Jang's proposal, which is a hybrid learning rule, used on the one hand the method of least squares to estimate the consequent parameters then on the other hand, a descent of gradient to identify the premise parameters.

To do this, we start by identifying the linear equations of the desired outputs as a function of the consequent parameters starting from P pairs of collected training data.

$$\begin{cases} y_d(1) = \bar{w}_1(1) f_1(1) + \bar{w}_2(1) f_2(1) + \ldots + \bar{w}_n(1) f_n(1) \\ y_d(2) = \bar{w}_1(2) f_1(2) + \bar{w}_2(2) f_2(2) + \ldots + \bar{w}_n(2) f_n(2) \\ \vdots \\ y_d(P) = \bar{w}_1(P) f_1(P) + \bar{w}_2(P) f_2(P) + \ldots + \bar{w}_n(P) f_n(P) \end{cases} \quad (5)$$

With $\bar{W}_i f_i = \bar{W}_i (p_i x_1 + q_i x_2 + r_i), i = 1 \ldots P$

Where p_i, q_i, r_i are consequent parameters to identify.
The equation (5) shows that by fixing the parameters "premises", the output is linear compared to the consequent parameters. We can then use the estimated value of the least squares to establish the optimal consequent parameters, then, applying the expression in equation (6), to optimize the premise parameters also called lattice weight:

$$\alpha_{k+1} - \alpha_k = -\eta \frac{\partial E_S}{\partial \alpha} \quad (6)$$

Where η denotes the learning step and α, the parameter to be modified. The gradient of the error is evaluated by the gradient backpropagation algorithm $\frac{\partial E}{\partial \alpha}$.
In this work, the training data were extracted from the simulation data of the previous fuzzy MPPT controller.

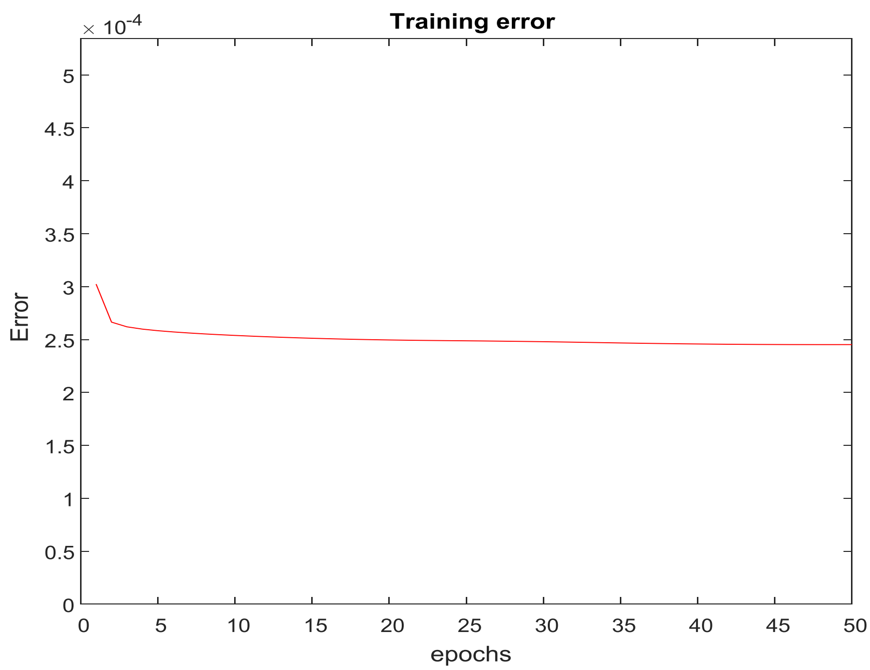


Figure 12:- Performance of ANFIS.

System simulation

The system consists of a GPV, a SEPIC converter controlled by the proposed MPPT commands, a three-phase inverter with an LC filter and an alternating current load (AC load). The DC voltage at the output of SEPIC is used to supply a three-phase inverter of 210V, controlled by a command using the SPWM.

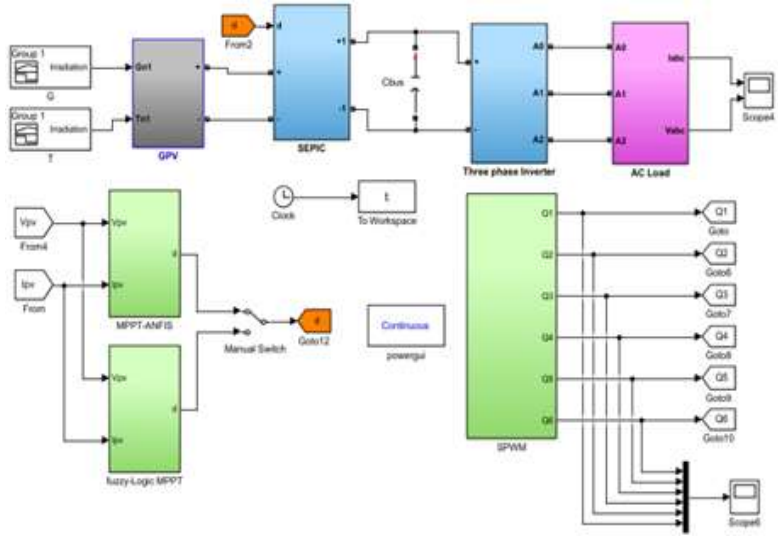


Figure 13:- System presentation.

The figures 14 and 15 show the contents of the command blocks as well as the load. Each command contains three blocks: the first compute the input parameters, the second contains the program according to the chosen method and the last is the PWM.

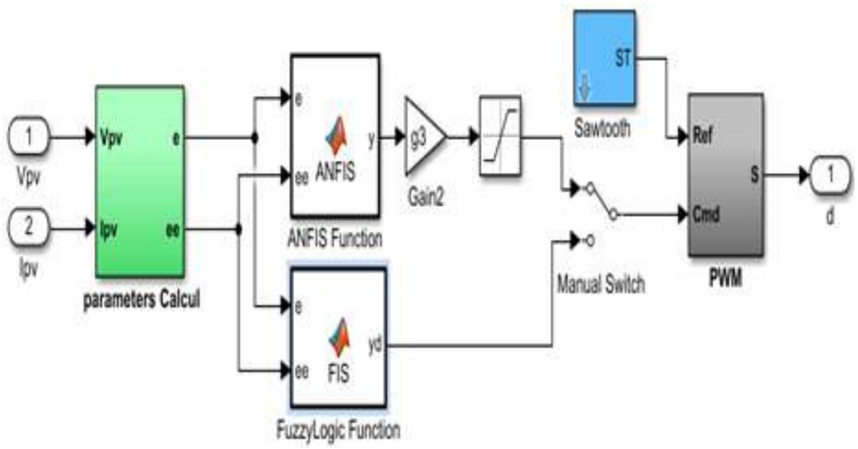


Figure 14:- Fuctions blocks of ANFIS and Fuzzy logic control.

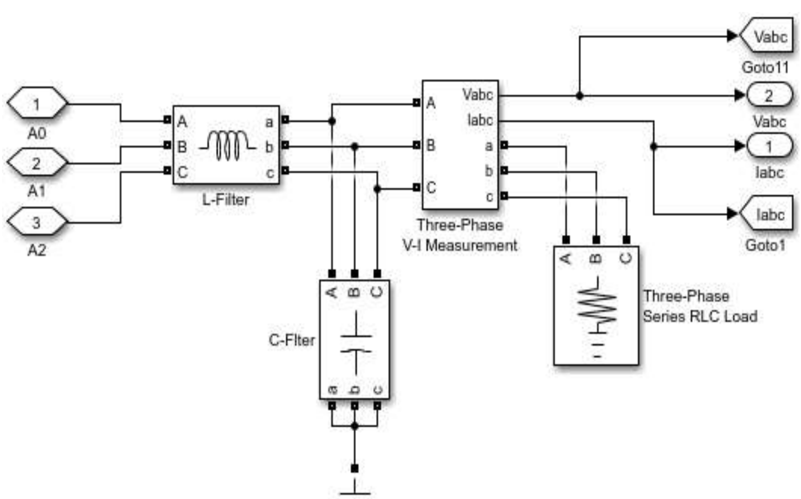


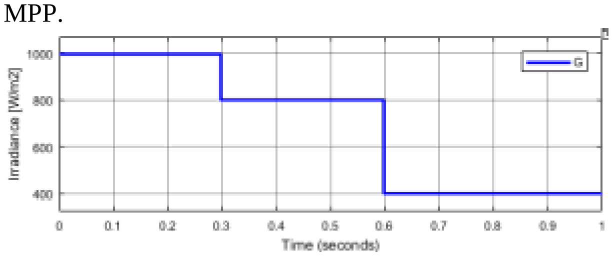
Figure 15:- AC load.

Results Analyzes and Interpretations

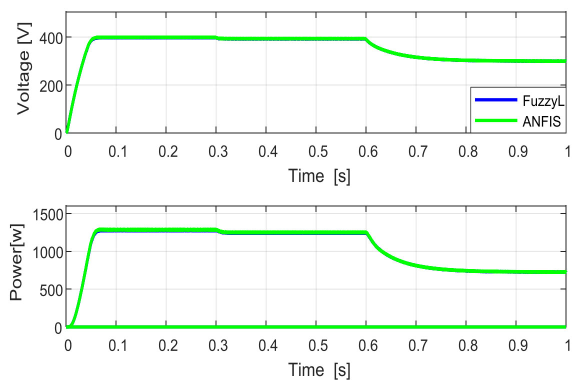
The behavior of the system is evaluated by comparing reached results under various conditions. We first use the standard condition, then applying variations in temperature and sunlight.

Sunlight variation Influence

Figures 16 shows the behavior of the system under some variations of the sunlight with a constant Temperature equal to 25 ˚C. In figure 16 (a), the standard condition (G = 1000 [w / m2] and Temperature = 25 ˚C) occurs in the interval from 0 [s] to 0.3 [s], then the sunshine decreases by 800 [w / m2]. Thus, we can notice that with these two intelligent controls, the output power of the SEPIC converter varies simultaneously with the sunlight. Indeed, increasing or decreasing itraise or decrease the power. Yet regardless of its changes, it regains quickly and always follows its maximum value or MPP.



(a)



(b)

Figure 16:- (a) sunlight variation, (b) Voltage and Power of theSEPIC output

Figures 17 shows the difference between the two methods in terms of speed and value improvement. Note that with ANFIS, the response time is much better than in fuzzy logic.

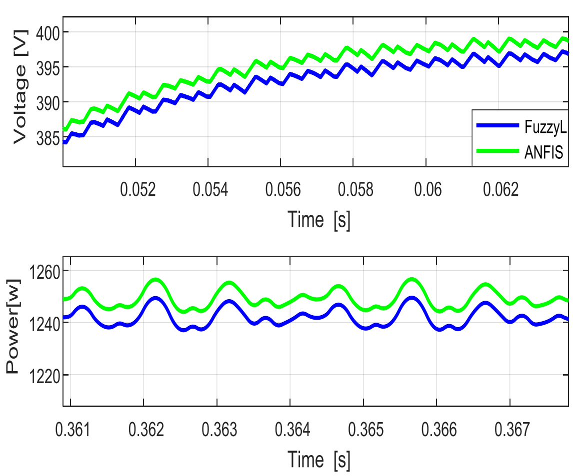
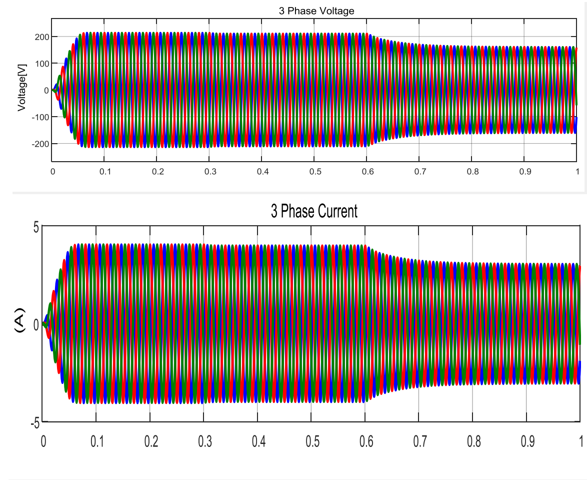
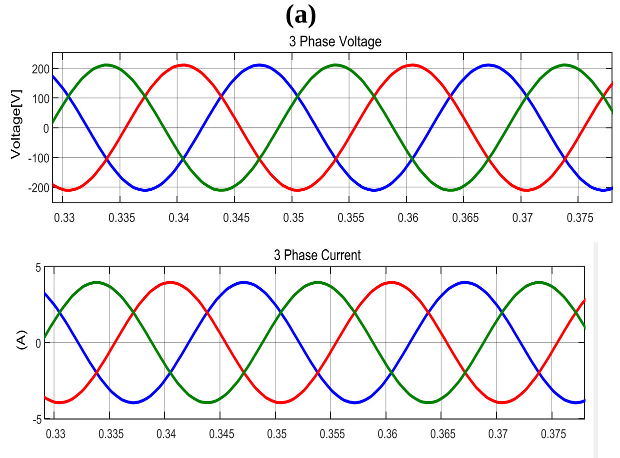


Figure 17:- Zoom of figure 16 (b).

Figure 18 shows the voltages and currents at the output of the inverter. With these results, we had a THD equal to 4.91%.



(a)



(b)

Figure 18:- (a) Three-phase voltage and current at the output of the inverter, (b) Zoom of (a)

Tempertureand Sunshinevariation Influence

The figure 20 shows the performance of the two methods when faced with the simultaneous variation of sunshine and temperature.

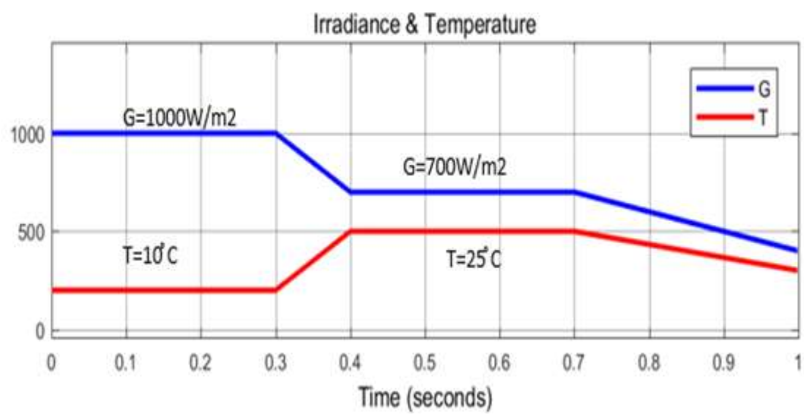


Figure 19:- Temperature and Sunshine Variation.

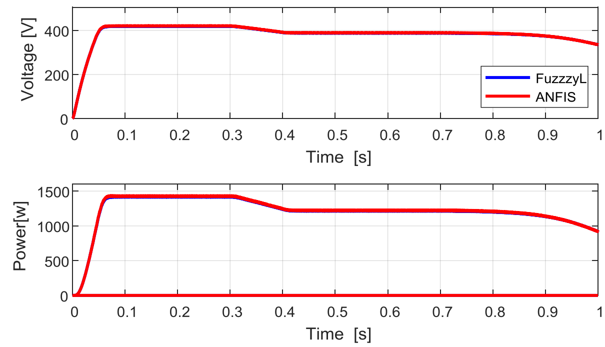


Figure 20:- SEPIC output voltage and Reactive power at the output of the inverter

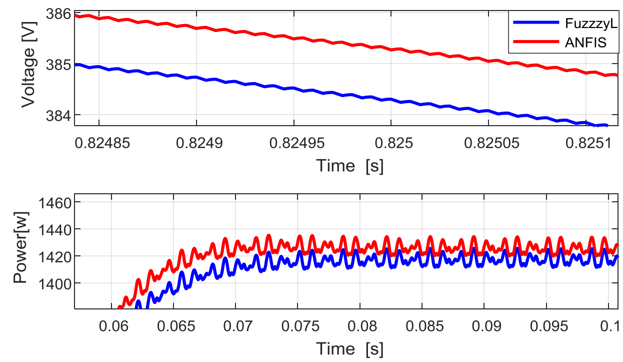
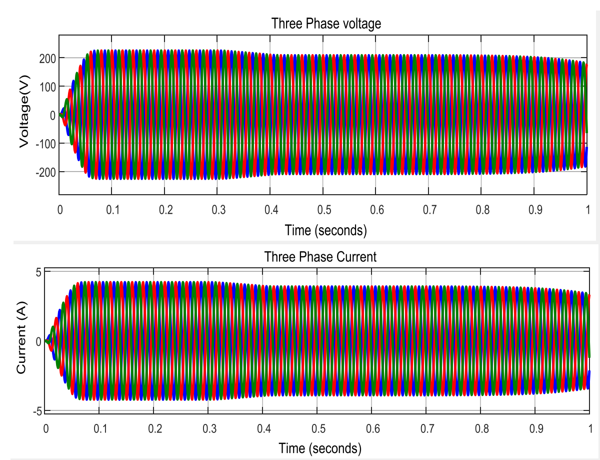
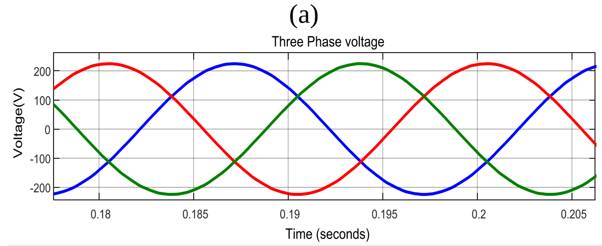


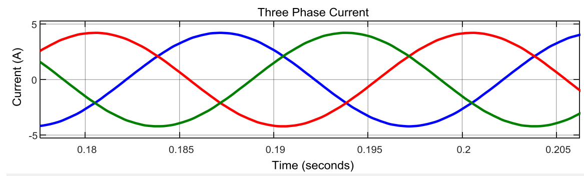
Figure 21:- Zooms of the figure (19).

Figure 19 shows the variations in Temperature and irradiation simulate.Under the influence of these variations, we notice in figure 20 that despite the sudden change of these two external parameters, the system stabilizes and always reaches the PPM, only after a lapse of time.The shape of the power in the figure 21 clearly shows its stability, as well as its speed with a response time equal to 0.07 [s].



(a)





(b)

Figure 22:- (a) Voltage and output current of the inverter, (b) Zooms of (b)

In the same figure (Fig. 20), there is also a difference with the obtained values of the voltage andpower. Indeed, with the ANFIS, these parameters have muchgreater values than in FL one. However, the oscillation presentsno difference with these two intelligent techniques.

The comparison of the results obtained with the two proposed MPPT commands allows us to conclude that the system with the ANFIS command is very satisfactory. It converges faster and more efficient than those with the FL, despite the presence of small oscillations, due to the capacitive and inductive facts.

Figure 22, shows the three-phase voltage of 215 [V] and current of 4.8 [A] produced by the inverter to supply the AC load. These simulations show that our controller generates good results. It ensured the load demand, despite sudden or slow variations in climatic conditions.

Conclusion:-

We have presented in this work the application of MPPT control based on fuzzy logic and Neuro-Fuzzy to adapt the medium power GPV (1.5KW). This system was simulated, with different variations of the external parameters.

Some research works showedalready the performance and efficiency of the FL method. However, in this paper, the results obtained with ANFIS present more robustness and a very encouraging effectiveness of this method compared to the FL one. The simulation results obtained and discussed prove that this system can adapted to uncertainties. It gives better performance, becomes faster, robust and more precise.

The two commands offered are also adaptive. Infact, they were designed with scripts therefore, using them with a new type of system no longer requires the generation of pre-defined blocks. In short, they are easy to implement, and adapt well to any type of SPVA recess with impedance matching.

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