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OPTIMIZED VOLTAGE BOOSTING SYSTEM FOR ENHANCED PHOTOVOLTAIC ENERGY HARVESTING USING AI CONTROLLER

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Abstract : Solar energy is considered one of the most promising renewable sources due to the availability of sunlight and its cleaner performance compared to fossil fuels. The transferred energy from the sun to the earth changes during the day. So, absorbing the maximum energy from the solar panel and transferring it to the load is essential. Consequently, maximum power point tracking (MPPT) techniques are proposed in numerous research papers. The artificial intelligence (AI) based MPPT (AI-MPPT) methods are faster, reliable in performance and improve the efficiency of SPPGS. In this paper different AI based MPPT techniques are review and compare different techniques on the bases of tracking speed or time, oscillation, efficiency and limitation. To transfer maximum power to the load, the duty cycle of the high-gain dc-dc converter, which has been connected between the solar panel and the load, is used. The AI controller can very quickly and accurately detect momentary irregularity of equipment and feed back to control in real time.

***Index Terms* – SPV Module, Driver, Converter, Maximum power point tracking, artificial intelligence, Particle swarm optimization, Ant- colony optimization, artificial neural network, Fuzzy logic control.**

I. INTRODUCTION

The solar photovoltaic modules depend on irradiance and temperature for power generation, but these two factors vary with varying atmospheric conditions like weather, climate, and seasons. This introduces the need for power optimization in solar photovoltaic power generation, which will keep track of the maximum power point and optimize the power accordingly. A maximum power point tracker can be defined as a technique employed in renewable energy-based power generation units like solar photovoltaic or wind turbines to extract maximum power output under uncertain conditions. The efficiency of PV modules in various situations is already known across industries and trades. However, since sunlight, as the source for generating electricity from PV modules, depends on weather conditions, PV modules may have lower efficiency. This results in low electricity generation from solar power. Three factors affect the effectiveness of electricity generation from solar power: solar exposure of the module, module temperature, and PV system properties. The first two factors are beyond human control and are highly unstable because they change from one second to another, depending on the weather conditions and season. Consequently, these properties result in PV systems being an unreliable source of electricity. This paper addresses the above problem and presents the AI method used as the MPPT controller, from which many have been presented in previous papers [2]. In this paper, we developed an ANFIS controller for the actual PV system and applied it in practice [4]. AI is proposed as the MPPT controller and modeled. Therefore, none of them have results compared against those collected from the PV plant. Numerous articles have demonstrated the flexibility of the AI method, although not directly related to PV systems, but were instead compared against the neural network in laboratory conditions [7], used in the role of an expert system for steel grading [8], and integrated bidirectional subsystem MPPT [17]. The articles that have focused on the comparison of artificial intelligence (AI) methods, such as neural networks (NN) and genetic algorithms (GA), proved that AI is the most suitable for use in uncertain systems [17] and without a doubt presented AI as the most suitable algorithm for MPP tracking. In the past four years, numerous articles and reports have addressed the simulations of PV cells and, consequently, of PV modules and served as the basis for developing authentic models for further research. Type-2 fuzzy logic controller [10], PV MPPT controller with I-V and P-V curve results [12], comparison with fuzzy logic controller [13], standalone complex PV system with MPPT controller [14], trained AI, and fuzzy logic controller according to DC-DC converter The papers that dealt with AI in detail, considering all layers and training methods, opened the path to using AI as the method to resolve all insufficiently defined problems with a high rate of uncertainty in conclusions [2-4], [21]. Many researchers have embedded the AI algorithm in the field-programmable gate array (FPGA) [2], [6]. This paper deals with AI as an MPPT algorithm in an actual 35 kW PV system used for electricity generation, which has the role of a distributed generation (DG) source of energy, i.e., it feeds all generated energy into the distribution system operator [1]. The specifications of the actual PV system installed on the roof are presented in Section 2. The AI structure, its block diagram, and modeling of the actual system are presented in Section 3. The basics of AI architecture, the data from the actual measurements, the comparison of the obtained results, and the discussion are contained in Section 4. Section 5 contains the conclusion and results.

II. SAMPLING AND SYSTEM MODELLING

2.1 Photo Voltaic System

The most commonly used renewable energy source is solar energy. Increasing the number of solar cells in a panel can increase its voltage output .A photovoltaic, or PV, system is used to convert the solar light energy into electrical energy. The basic component of a PV system is known as a solar cell. A single solar cell has the capacity to produce about 0.5 volts of electricity. A solar panel, or solar module, is a combination of several solar cells connected in series to generate usable voltage. The solar panel voltage can be increased by increasing the number of solar cells. For example, 30 solar cells connected in series will produce an output of 15 volts. A combination of solar panels connected together is known as a solar array and can be used to achieve the required current and voltage. It works by generating electricity when exposed to sunlight, known as the photovoltaic effect. This principle is used by solar cells to produce electricity. The solar cells are made of semiconductors. Mostly, silicon comprises three layers; the top layer, called the N-type layer, is comparatively thin and contains a high concentration of electrons. The bottom layer, called the P-type layer, contains a high concentration of holes. When the p-type and n-type semiconductors join together and form a p-n junction. On forming a p-n junction, the electrons of the n-type material try to reach the p-region, creating a negatively charged layer. Similarly, the holes in the p-type material try to reach the n-region, creating a positively charged layer. This region between the two layers is known as the depletion region of the semiconductor. Sunlight penetrates the top thin layer easily to reach the depletion region. Due to the deficiency of charge in the depletion region, it contains neutral atoms. These neutral atoms are broken, and when the photons from the sun strike the depletion layer, this knocks the electrons from the neutral atoms, leaving behind the holes and using free charge carriers. Then the electrons move towards the n-type layer, and the holes move towards the p-type layer. Due to the electric field present in the depletion region, when connecting an electronic circuit, electrons flow through generating electricity to electrical devices like bulbs, fans, etc.

Fig : PV Module

2.2 AI ALGORITHM

Neuro-fuzzy method is important in the designing of fuzzy expert systems. In any case, the right selection of the number, type, rules and parameters of the fuzzy system Membership Functions (MFs) is vital for acquiring the minimum performance. Trial and error is the method to achieve the minimum performance. This fact emphasizes the weight of settings of the fuzzy systems. ANFIS is a Sugeno network within the adaptive systems facilitating learning and training. That framework makes models more systematic and uses expert knowledge so that user does not have to be an expert. For better understanding the ANFIS architecture, consider the following fuzzy system which has two rules, two inputs, and therefore is a first order Sugeno model:

Rule 1: If (x is A1) and (y is B1) then (f1 = p1x + q1 + r1) (1)

Rule 2: If (x is A2) and (y is B2) then (f2 = p2x + q2 + r2) (2)

Literature proposes several types of reasoning of Sugeno fuzzy systems [11]. Based on type of fuzzy reasoning and if-then rules, there are three types of fuzzy inference systems mostly used:

Depending on rule‟s strength, the overall output is the weighted average of each rule‟s crisp output (the product or minimum of the degrees of match with the premise part) and MFs. The output membership function used in this example is a monotonic function.

The output of fuzzy system is obtained by applying “maximum” operation to the certified fuzzy outputs (each is equal to the minimum of scoring result and the output membership function of each rule). Diverse schemes have been presented to obtain the final (crisp) output based on the main fuzzy output; some of them are centroid of area (CoA), bisector of area (BoA), mean of max (MoM), etc. [11].

Takagi-Sugeno “if-the” rules are used for the purposes of this paper. Linear combination of fuzzy input variables plus a constant term are used for output of each rule, and the ultimate output is the average weight of output from every rule. One of the ANFIS architectures is the implementation of these two rules as shown in Figure 3. A circle represents a fixed node, as presented in Figure 3, a square indicates an adaptive node (the parameters are changing during training with back propagation or hybrid method of learning).

Fig: MPPT ANFIS & AI Architecture

Layer 1: Nodes in this layer are adaptive nodes. The output of each node is the degree of membership of the input of the fuzzy membership functions represented by the node. Expressions for obtaining those outputs are:

$$O_{1,I} = \mu A_i(x) \quad i=1,2 \qquad (3)$$
$$O_{1,I} = \mu B_i(x) \quad i=3,4 \qquad (4)$$

where, Ai and Bi are any suitable fuzzy sets in parametric form, and O1,i is the output of the node in the i-th layer. This paper uses trapezoidal shape MFs.

Layer 2: The nodes in this layer are fixed (not adaptive) and therefore are called a Neural Network layer. They are signed with Π to indicate that they play the role of a multiplier function of inputs. Outputs from this node are presented in expression (5).

$$O_{2,i} = W_i = \mu A_i(x)\mu B_i(y) \quad i=1,2 \qquad (5)$$

Layer 3: The nodes in this layer are also fixed nodes. They are signed with N to indicate that they perform a normalization of the scoring strength from the previous layer. Output from this node is given in (6).

Layer 4: All the nodes in this layer are adaptive nodes, and therefore this layer is a Fuzzy logic layer. The output of each node is simply the product of the normalized scoring strength and a first order polynomial function. Output from each node from this layer is presented in (7)

$$O_{4,I} = f_i = (p_i x + q_i y + r_i) \quad i=1,2 \qquad (7)$$

Layer 5: This layer has one node signed with S to indicate simple summarization in this layer.

The ANFIS architecture is not unique. Combination of some layers can be still produce the same output instead. In ANFIS architecture, there are two adaptive layers (Layers 1 and 4, Fuzzy layers). Layer 1 has three alterable parameters (ai , bi and ci) referring to the input of MFs. These parameters are called premise parameters. Layer 4 also has three alterable parameters (pi , qi and ri) referring to the first order polynomial function. These parameters are consequent parameters. The task of the training or learning algorithm for this architecture is to tune all the alterable parameters to make the ANFIS output match the training data as much as they can.

III. MPPT WITH AI CONTROLLER

The design consists of a PV module, ANFIS controller, DC-DC converter and MOSFET gate driver. The performance of the proposed ANFIS based MPPT controller is evaluated through multimeters physically. The results demonstrated the effectiveness of the proposed technique since the controller can extract the maximum available power for both steady-state and varying weather conditions. Moreover, a comparative study between the proposed ANFIS based MPPT controller is presented. The results that the proposed ANFIS based MPPT controller is more efficient. The below figure shows the block diagram of MPPT with ANFIS controller.

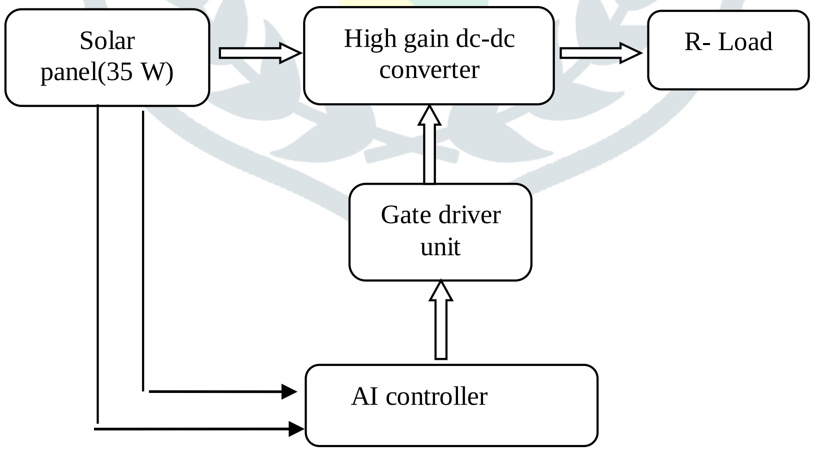


Fig : Block diagram

The below table shows the components list and its specifications:

COMPONENTS	SPECIFICATIONS
Controller	PIC16F877A
Crystal Oscillator	10 MHz
Regulator	7805
Rectifier	W10
Capacitor	470uf, 100uf, 22pf, 47uf
Resistor	330E, 1k, 100E, 470k
Power LED	-
Power supply	12v
PCB Board	-
Driver	IRF2110
MOSFET	IRF840
Inductors	47uH

3.1 MPPT DESCRIPTION

The MPPT solar charge controller is a DC-DC converter for solar power system. It receives voltage from the solar panels and converts it to charge your battery at a more appropriate level. The optimization helps you avoid losing some energy your system captures and generates, maximizing what you can store and use. MPPT stands for Maximum Power Point Tracking. A solar panel has different electric output and different maximum efficiency levels. The efficiency depends on numerous factors, such as the time of day, cloud cover and temperature of the panels. The MPPT identifies the point to get maximum efficiency.

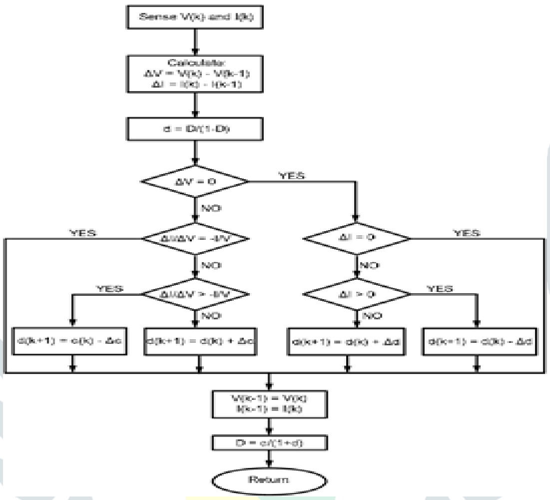


Fig : MPPT FLOWCHART

The operating points of a PV source feeding a resistive load with a solar insolation level varying from 0.2 W/m2 to 1 W/m2 are shown in Figure 3.8. It also shows the peak point trajectory at which the PV source gives maximum power as the product of voltage and current. MPPT is employed in PV systems. To ensure the operation of PV modules for maximum power extraction by shifting the operating points (V, I) (Enrique et al. 2010). A special power conversion circuitry and dedicated algorithms are used to ensure that the maximum amount of generated power in PV is transferred to load. A typical PV panel with MPPT fed DC-DC converter is shown in Figure 3.6. The maximum power is delivered from the source when the source impedance matches the load impedance. Therefore MPPT aims at matching the impedance between the PV module and the load using a DC-DC power converter. But, at the same time, the maximum power in a PV panel is not a fixed one and it varies with the environmental changes. Therefore, the duty cycle or control signal of the converter is so adjusted that the PV panel is made to operate at the Vm or Im, so that the PV panel is operated at its Pm for the given point of time. The choice of converters is made depending on the nature of load and application.

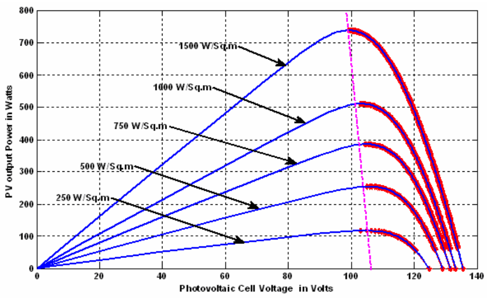


Fig : MPPT description

3.2 DC-DC CONVERTER

The increasing use of electronic devices has drawn more attention to the PV power-producing industry and attempts have been made to develop a dynamic regulation strategy that adapts to the changes in PV source output and load fluctuations. The conventional converters have not been able to handle the changes in operating variables of power systems. Hence, power system engineers and researchers developed isolated and non-isolated converter circuits to provide an integrated solution to the problems of PV systems. These devices are mainly used for regulating the output in terms of stepping up and stepping down the voltage as well as efficiency improvement. The most popular classification of these devices based on topology, number of control elements and the modes of operation are as follows: single-stage converter or DC-DC converter (DC loads), two-stage converter or DC-DC cum AC-AC converter (AC loads), bidirectional converter which feeds the power from source to load and vice versa and its combination, etc. These devices are integrated to improve the PV system performance, which depends on the nature of the load and other related issues.

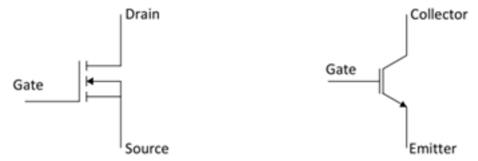
The suitability of the design and execution of a proper control scheme for the proposed PV system is based on the contribution of PV panel parameters due to the proliferation of nonlinear input and variation in load demand. The DC-DC power converter is an essential element within the MPPT since MPP can be achieved if the converter's operating mode is correctly synchronized. Thus, the major concern for a PV system is the creation of an effective regulator for the DC-DC converter.

3.3 DRIVER

A gate driver is a power amplifier that accepts a low-power input from a controller IC and produces the appropriate high current gate drive for a power device. As requirements for power electronics continue to increase, the design and performance of the gate driver circuitry are becoming ever more important.

Power semiconductor devices are the heart of modern power electronics systems. These systems utilize many gated semiconductor devices such as ordinary transistors, FETs, BJTs, MOSFETs, IGBTs, and others as switching elements in switched-mode power supplies (SMPS), universal power supplies (UPS), and motor drives. Modern technology evolution in power electronics has generally followed the evolution of power semiconductor devices.

Power level requirements and switching frequency are increasing in the power electronics industry. The metal oxide semiconductor field effect transistor (MOSFET) and insulated gate bipolar transistor (IGBT) are two of the most popular and efficient semiconductor devices for medium to high power switching power supplies in most applications.



MOSFET Symbol IGBT Symbol

The gate of a MOSFET or IGBT is the electrically isolated control terminal for each device. The other terminals of these devices are source and drain or emitter and collector. To operate a MOSFET/IGBT, typically a voltage has to be applied to the gate that is relative to the source/emitter of the device. In order to drive these switching devices into conduction, the gate terminal must be made positive with respect to its source/emitter.

3.4 CRYSTAL OSCILLATOR

A crystal oscillator is an electric oscillator type circuit that uses a piezoelectric resonator, a crystal, as its frequency-determining element. Crystal is the common term used in electronics for the frequency-determining component, a wafer of quartz crystal or ceramic with electrodes connected to it. A more accurate term for it is piezoelectric resonator. Crystals are also used in other types of electronic circuits, such as crystal filters.

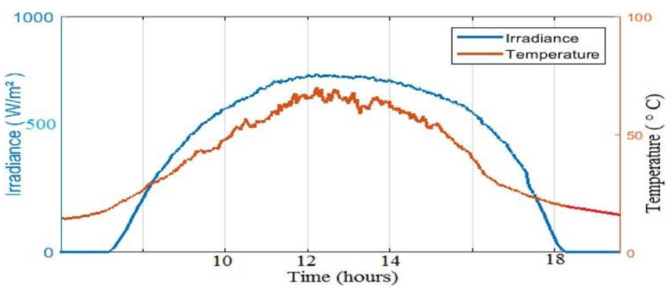
Piezoelectric resonators are sold as separate components for use in crystal oscillator circuits. They are also often incorporated in a single package with the crystal oscillator circuit.

IV RESULTS

TheThis study aims to predict the power of a solar panel at the Polytechnic higher school in Dakar using an artificial neural network. Two intelligence optimization techniques is used and a comparative study is done. To evaluate the performance of our controller we made a comparative study with two MPPT (ANN and ANFIS). To intuitively measure the performance of the proposed models and facilitate comparison of the approaches we compute, the mean absolute error (MAE), the mean-absolute percentage error (MAPE), and the root mean square error (RMSE) were introduced as follows whose expressions are presented respectively .

RMSE measures the average value of the errors, ranging from 0 to infinity, with lower values being better. The mean absolute percentage error MAPE is used for evaluating the optimization accuracy. It indicates how much percent the optimized value deviates from the actual one. The performance of any MPPT depends on its behavior under weather conditions such irradiation and temperature.

Where: P is the electric power of solar panel are the optimal current and the voltage, respectively; the short-circuit current and the open circuit voltage. In climatic variations of one day of each month are presented in Fig. 8. March coincides with the dry season where the sky is clear unlike the month of August which coincides with the rainy season.



the daily weather conditions has not a same repartition, this is characterized by the different profiles of daily weathers (sunny, cloudy). The output power of the PV panel is plotted. As can be seen, both the ANN and the ANFIS methods are identical in all cases of atmospheric variations for each month. In this analysis, we can confirm the two MPPT have a very good solution to track the MPP. This ability to track the MPP for different weather condition is proved from the reached efficiency and a good stability is achieved. Furthermore, the MPPT methods have a high tracking speed capability which allows transferring the PV energy with minimum losses and a test of performance of those controllers is listed in Table 4. And there is a good agreement between the measured and the predicted curves for Month and August. The RMSE, the MAE and the MAPE of an ANFIS are lower than those given with an ANN method for each month.

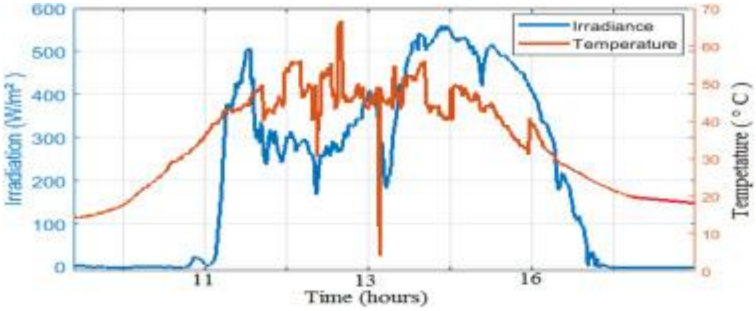


Fig: Solar irradiation in march

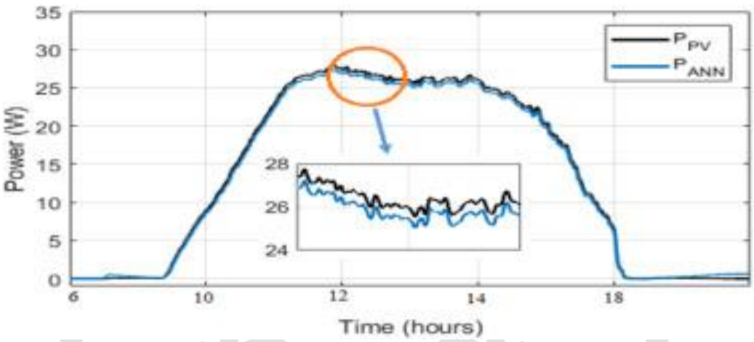


Fig: Solar irradiation in August

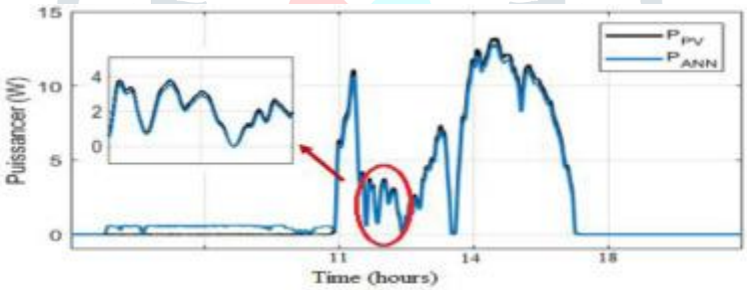


Fig: PVs power and ANN MPPT power optimized for a sunny day in March

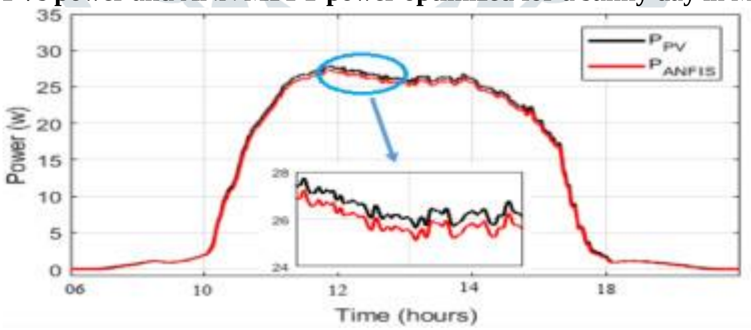


Fig: PVs power and ANN MPPT power optimized for a sunny day in March

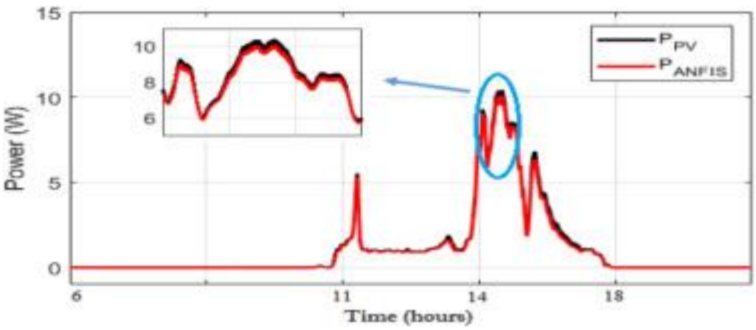


Fig: PVs power and ANN MPPT power optimized for a cloudy day in August

It can be seen from above Table 3 that, in terms of all three error criteria, the proposed ANFIS model obtained better prediction results even in these challenging selected months typified by both weak and strong fluctuation levels. ANFIS model optimizes the prediction accuracy and reduces the two months MAPE to 8.252310−4 % and 4.242910−4 % respectively in March and August. ANN model MAPE equal to 0.0016 % and 0.0039 % respectively in March and August. The evaluation criteria in Table 3 clearly demonstrate the accuracy and validity of the ANFIS. A robustness test of the two intelligent controllers is done in order to confirm the most powerful MPPT controller between ANN and ANFIS. This test is performed in standard conditions (STC) (1000W/m² and at 25°C) and the simulation result.

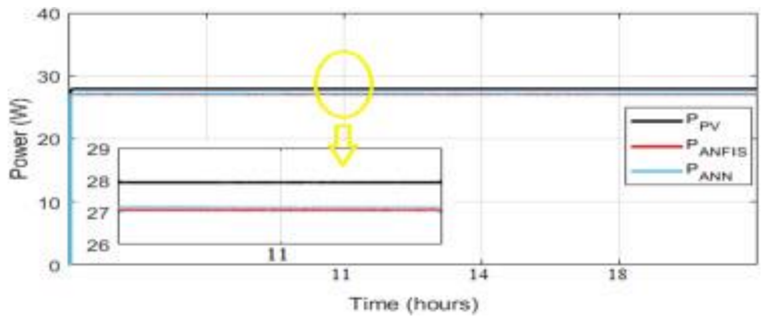


Fig: PVs power and ANN and ANFIS powers optimized under STC (1000W/m² and 25°C)

The simulation results is done under Matlab/Simulink and several tests are done to pronunciation on the most powerful MPPT methods. The statistic evaluators found with ANFIS is lower than the ANN for the performance test Table 4. In robustness test ANN show it good results with low errors Table 5 and the ability to adapt for a new variations of meteorological conditions. Without the evaluators tests the simulation time of the ANN is fast compared to the ANFIS method. At the end of this study we show that ANFIS is more powerful than ANN MPPT controller because of it ability of learning and adaptation to the weather condition. The aim of this study is to confirm the performance of the ANFIS compared to the ANN. Many research listed below have done this comparison and at the difference of our study this comparative study is done by using real weather conditions and the simulation is done in two seasons (dry and rainy). The Table 6 summarized a comparative study of the two intelligent methods. This methods have a fast convergence speed. we show ANFIS structure is more complicate than ANN because it is a hybrid method combined the advantages of the ANN and FL. ANN is less expensive than ANFIS and it hardware implementation is less complicate.

V CONCLUSION

In this work, dc-dc converter along with AI control technique was proposed to enhance the output power in the SSPV generation system under any circumstances. The control design was implemented using an additional PIC controller for generating the two inputs for AI control at the source side. Thus, the improved convergence speed and reduced oscillations around the maximum operating point under varying metrological parameters are obtained. The optimal value of the control signal for the converter was generated by employing AI controllers; there by the regulated output is obtained for the required load. The static and dynamic behavior has been presented and analyzed to validate its performance under different operating conditions. The superiority of the proposed control scheme is validated by doing comprehensive comparison with various control schemes. From the test results, it is proved that the proposed scheme offers simple implementation and ease of control. Also, it is established that the proposed control system can track the maximum power with improved efficiency even under transient and steady state operating conditions with reduced power loss using less switches and cost – effective.

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