A Fuzzy Logic based MPPT for 1MW Standalone Solar Power Plant

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***Abstract* - Solar energy as clean, green and renewable energy is one of the most used resource of energy, but the capture of this energy is subjected to many losses. To overcome the losses in a solar power plant it is imperial to understand principal elements which constitute a solar power plant. In this paper, discussion of various problems affecting the efficiency of photovoltaic solar panels has been done, in addition some techniques for boosting the efficiency are proposed.**

In the interest of reducing pollution and promoting green energy, this paper designs a possible 1MW standalone solar power plant. In order to overcome the losses in solar photovoltaic system, a proposed solution for MPPT (Maximum Power Point Tracking) with an application of a Fuzzy Logic Controller to determine automatically the suitable duty cycle for a buck boost converter has been opted. The simulation is done using MATLAB/Simulink R2016a. This is a case study for feeding Frontier mining camp in D.R. Congo/Africa.

Key words: Photovoltaic Solar Panel; Efficiency; MPPT; Fuzzy Logic; Duty Cycle.

I. INTRODUCTION

The sun is a free source of energy, renewable, no waste, pollution free and can be used as primary source of electricity in remote areas. Solar energy can be used in several ways; to produce thermal energy, photo chemical energy, electrical energy, etc.

Here will concentrate on electrical energy; one of the direct ways to produce electricity from the sun without any intermediate is the photovoltaic system using solar panels [1] [2] [3]. This paper will discuss about the requirements to be taken in consideration for installing a solar power plant, problem affecting solar power plant efficiency and technical solution used to overcome these problems.

For a practical point of view using MATLAB/Simulink R2016a, a simulation of a 1MW standalone solar system is done, by using a Fuzzy Logic based MPPT. Two fuzzy logics are compered and the one having the highest output is used to design the given power plant.

II. MPPT ALGORITHM FOR SOLAR SYSTEM

Fuzzy Logic has been chosen as controller and optimization technique to determine automatically the suitable duty cycle of a Buck-boost converter in any condition, in order to extract the maximum output from a given array of solar panels[9][10]. In addition, in this part an explanation of what is and how works the MPPT system with the different algorithms chosen is done.

Two combinations of variables have been chosen for the design of controller, which should determine the duty cycle of the Buck-boost converter used in the MPPT; (i) variation of power (ΔP) with the variation of voltage (ΔV) and (ii) variation of power (ΔP) with the variation of current (ΔI).

The algorithm designed aims to optimize the output power of the converter, by gradually increasing and decreasing the duty ratio of the converter. [8] [14] The controller will have to automatically adjust the step size of the duty ratio of the converter depending on the output of the solar panel; the adjustment should be done as human rezoning there for fuzzy logic is chosen as artificial intelligent technique. [15]

The block diagram of the MPPT will consist of a solar panel, Buck-boost converter and a MPPT controller her FLC as shown on figure 1.

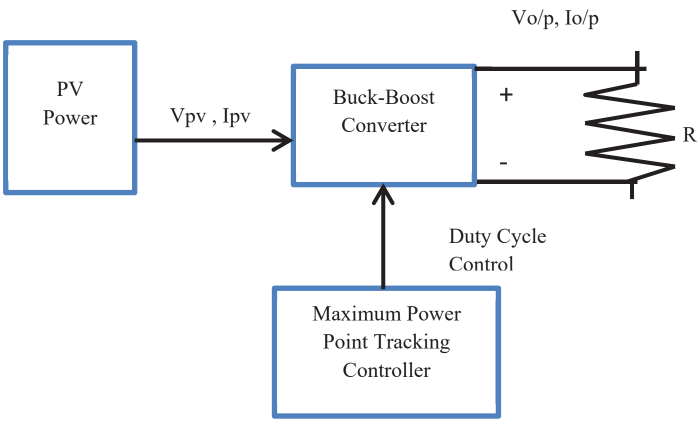

Figure1. MPPT Block Diagram

III. DESIGN OF THE FUZZY LOGIC CONTROLLER

Since time, scientists have been trying to develop an intelligent machine capable of rezoning like a human being. Many points of similarity between computer processing and human thinking are observed, one of the approximate human rezoning logic found to date is the “fuzzy logic”. By its definition “fuzzy” as an adjective is difficulty to perceive, indistinct or vague. [17]

The advantage of Fuzzy logic compared to other computer logics is that, Fuzzy Logic has a human approach of problems as many computers have a crisp set input (0 and 1) fuzzy logic can lead to a human approach where the approximation of all infinite values between 0 and 1.

For better understanding, an example is given; for many logics it can only, either be hot or cold, but using fuzzy logic we can give a degree of belonginess to "hot" or "cold" which can be divided in many members as its needed, some of commonly used degrees of belonginess are: very, less, extremely, etc. [16] The figure below shows the architecture of Fuzzy logic.

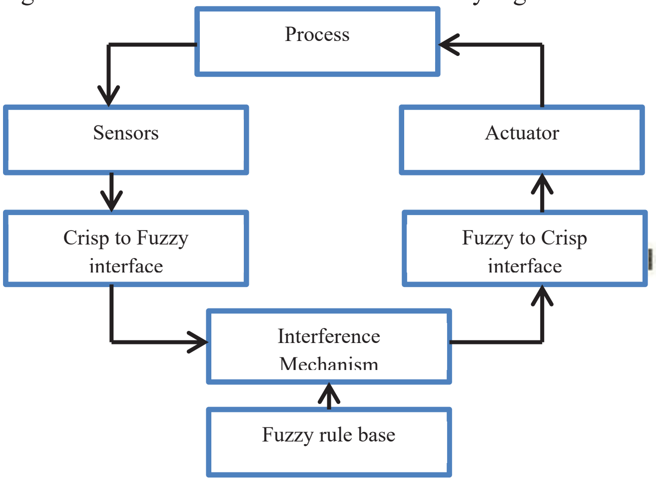

Figure2. Structure of fuzzy logic algorithm

A. *Fuzzy logic algorithm for MPPT controller*

Three variables have been chosen to design three types of controllers for the MPPT, the variables chosen from real datasheet of a solar panel [7] [22] extended into an array are: (i) variation of power(ΔP), (ii)variation of voltage(ΔV) and (iii) variation of current(ΔI). The combinations of these variables are grouped into two to design 2 types of controllers which will be compered and then chose the best output. The combinations are taken as follow:

- Variation of current(ΔI) and variation of power(ΔP),
- Variation of power (ΔP) and variation of voltage (ΔV).

The purpose of building this Fuzzy logic controller is to define the optimum duty cycle for the DC to DC converter to extract the maximize the output of the solar panel array, for this work a Buck-boost converter has been chosen because of its advantage over other converters to be able to step-up or step-down the input voltage depending on the duty cycle. For maximizing the output, the converter is operated in continues conducting mode, the duty cycle of a Buck-boost converter is expressed as follow [12] [20]:

$$D = \frac{V_{out}}{V_{in}+V_{out}} \qquad (1)$$

$$V_{out} = \frac{D\times V_{in}}{1-D} \qquad (2)$$

Where,
D= duty cycle
V_{out} = voltage output
V_{in} = voltage input

By observing the equation (5) we can conclude that when the duty cycle is the rage [0, 0.5[the converter behaves like a buck converter and in the rage of] 0.5, 1[is a boost converter. When the duty cycle D= 0.5 no change is observed at the output, D = 0 the output is 0 and D=1 the output will be infinite (∞).

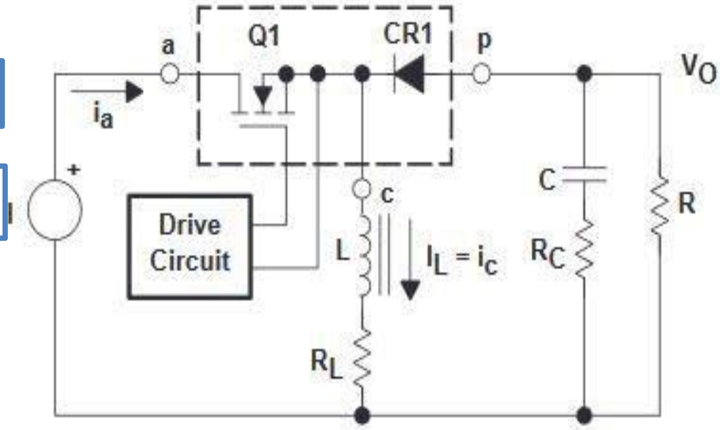

Figure3. Circuit diagram of a buck-boost converter

The operation of a buck-boost is explained as follow; when Q1 (switch) is repeatedly switched on and off, the switching on and off times in a period is decided by the control circuit. The switching actions give rise to a train of pulses at the junction of Q1, CR1, and L. Although L (inductor) is connected to the output C (capacitor), only when CR1 conducts, an effective L/C output filter is formed and filters the train of pulses to make a DC output voltage [20].

With the above details, it will now be able to design the fuzzy logic for our controller; this will be done as follow:

B. *Definition of linguistic terms and variables*

For building our fuzzy logic controller will use the following five linguistic variables; VS (very small), S (small), M (medium), H (high) and VH (very high) and the variables are the same defined previously.

C. *Construction of membership functions for the variables*

Here will define the range of every variable so that we can choose the membership function suitable to be used in the controller. [19]

- Current [0, 6.68]
- Voltage [0,28.5]
- Power [0,183.3]
- Duty cycle [0,1]

These are the rages of one solar panel or for the design of the plant will make a combination of 10 arrays and one array is a combination of 600 panels (20 in series and 30 in parallels) which will give the following rages;

- Current [0, 193.2]
- Voltage [0, 570]
- Power $[0,10^5]$
- Duty cycle [0,1]

The three first are considered as fuzzy input and the forth is the output of the controller. The membership function for this controller is the triangular membership function because of its simplicity and facility in calculation [18] [19]. With triangular membership function it is possible to uses direct; this method consists of giving each element y, a membership grad A (y) depending on the best opinion of the expert and defining linguistic terms represented by the fuzzy set A. for this work the overlapping of fuzzy sets has been decided by using Yager method witch defines that the overlapping of two membership function should be in the rage of 25 to 50% of its base, even though there is no predefined method to determine the overlapping of membership functions [18] [21] [22].

The inference mechanism used is the "*Mamdani*" this method has been chosen because of its min and max operator where the IF AND THEN rule can be used and most suitable for controller systems [18].

D. Constructing knowledge base on rules

The rules have been done by choosing two inputs in the fuzzy controller and having one output. Two rules have been done by the combination decided above, the rules will be defined by the relation in equation (5) which defines the relation between the voltage and the duty cycle of a Buck-boost converter, therefore the relationship between current and power with the duty cycle can be deduced.

Table 1: variation of current (ΔI) and variation of power (ΔP)

ΔP \ ΔI	VS	S	M	H	VH
VS	VS	S	M	H	VH
S	VS	S	M	H	H
M	VS	S	M	M	M
H	VS	S	S	S	S
VH	VS	VS	VS	VS	VS

Table 2: variation of power (ΔP) and variation of voltage (ΔV)

ΔV \ ΔP	VS	S	M	H	VH
VS	VH	H	M	S	VS
S	H	H	M	S	VS
M	M	M	M	S	VS
H	S	S	S	S	VS
VH	VS	VS	VS	VS	VS

E. Converting crisp data into fuzzy data, using membership functions (Fuzzification).

The membership functions of every variable are shown on the figures below; the Fuzzification has been done using MATLAB R2016a.

Current [0, 193.2]

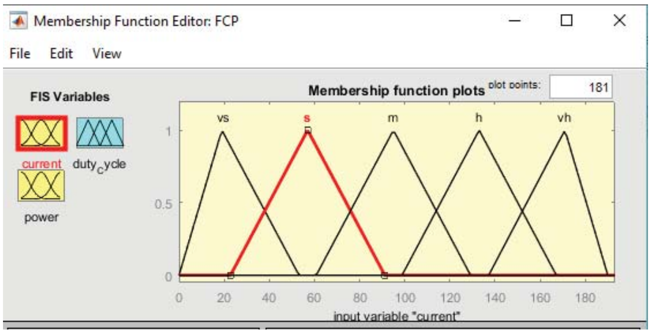

Figure4. Membership functions of current

Voltage [0, 570]

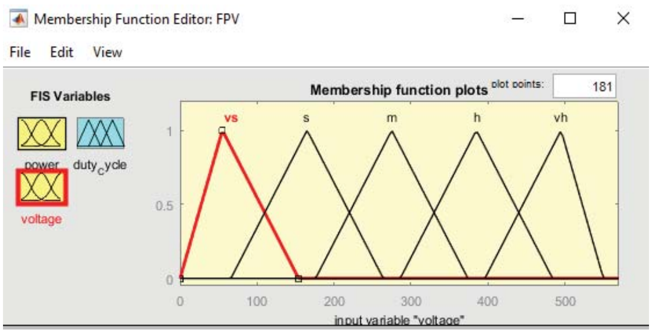

Figure5. Membership functions of voltage

Power $[0,10^5]$

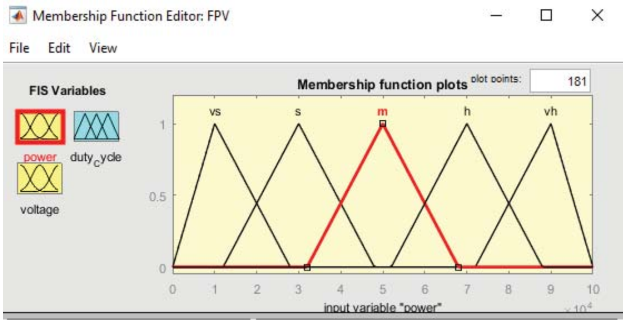

Figure6. Membership functions of Power

Duty cycle [0, 1]

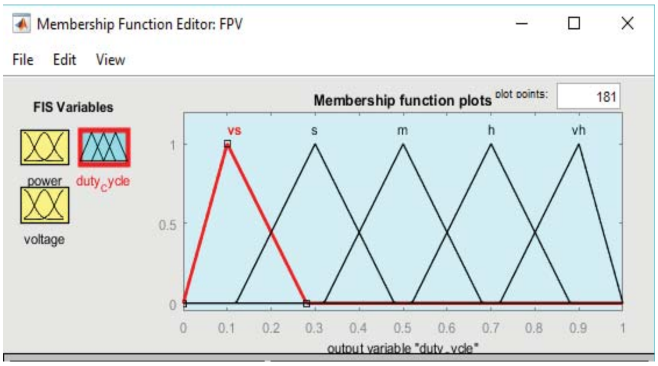

Figure7. Membership functions of duty cycle

F. Evaluating rules in the rule base (interface engine)

The two rules based in the interface engine can be seen in the figures bellow, where the surface and the ruler of rules are shown.

Variation of current (ΔI) and variation of power (ΔP)

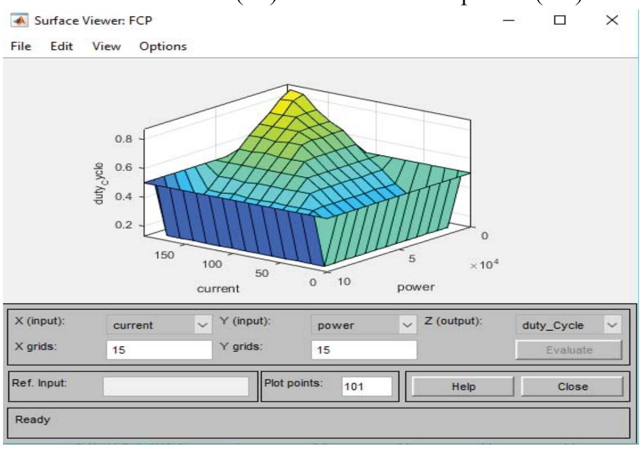

Figure8A. Surface view of Current and Power combination

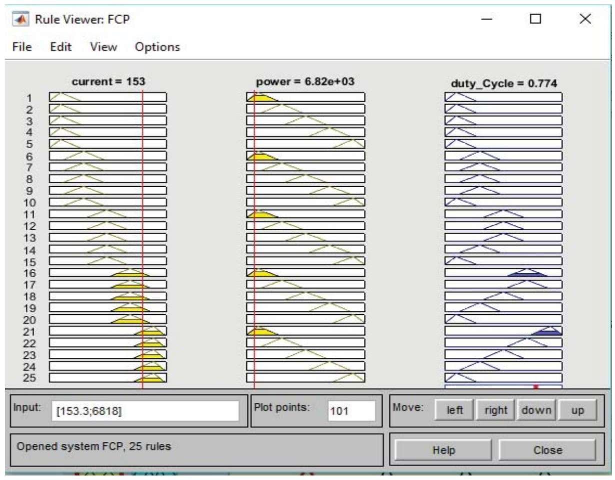

Figure8B. Interface engine of rules view of Current and Power combination

Variation of power (ΔP) and variation of voltage (ΔV)

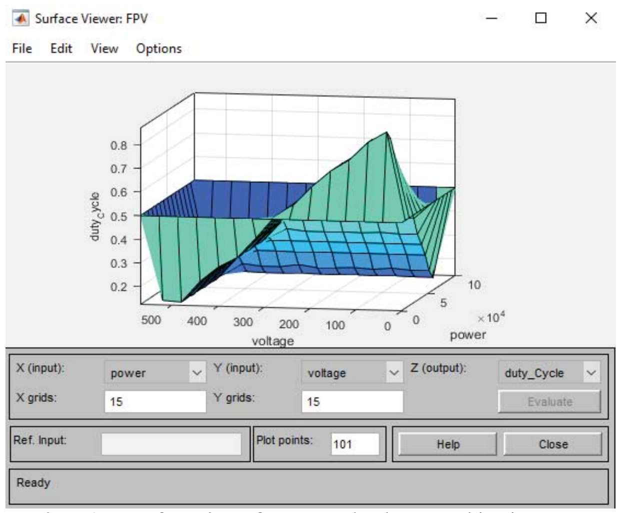

Figure9A. Surface view of Power and voltage combination

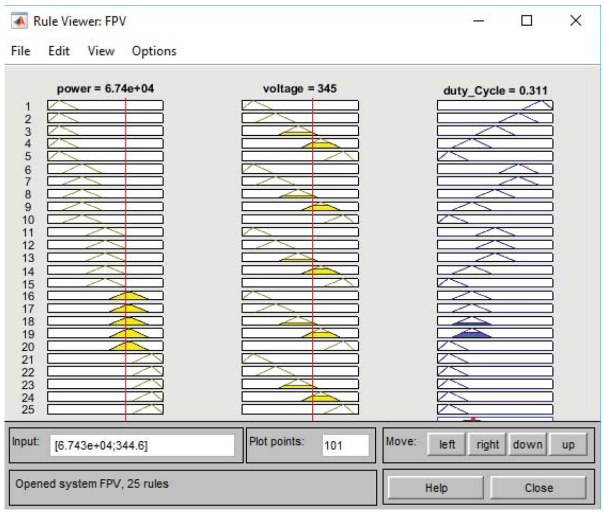

Figure 9B: interface engine of rules view of Power and voltage combination

G. Combining results from each rule (interface engine)

The combination results of each rule are shown in the figures 8B and 9B of each combination taken. This can be seen in the fuzzy engine by varying each input how the output response to the variation.

H. Converting outputs data into non-fuzzy values (Defuzzification).

The defuzzification is done by using the centre of gravity method, the defuzzification value of a given fuzzy set A is said to be its centroid. The process is done by the fuzzy engine.

IV. RESULTS OF MPPT

After comparison of the two fuzzy based MPPT controller designed using the two combinations (i) Variation of current (ΔI) and variation of power (ΔP) and (ii) Variation of power (ΔP) and variation of voltage (ΔV). It has resulted that the combination (ii) is having better results where the voltage is stable at 456.5V DC which represents 80.08% of the maximum output voltage from the array; while in combination (i) voltage is 231.1V DC equivalent to 40.45% of the array voltage. The results of MPPT are taken before the inverter and for an array so in DC; the objective of the MPPT is to fulfil in any condition the requirement imposed to input of the inverter unit.

Considering the output power; (i) gives an average of $4.622\text{x}10^4$ Watt equivalent to 46.2% of maximum power and (ii) gives 9.13 $\text{x}10^4$ Watt about 91.3% of the maximum array power. Figure12 shows the array in MATLAB/Simulink R2016a.
The plot of the array can be seen in figure 10 with the point of maximum power tracking corresponding points;

V. PLANT CHARACTERISTICS

With consideration of rules, safety conditions and land characteristics for implementation of a solar power plant [4] [5] [6]. Each array has a maximum power of 100kWatt that means for a 1MWatt plant a combination in parallel of 10 arrays as seen in figure 13, will be needed to maintain same voltage level but increase in power, this will results to 10x600=6000 panels will be used for the full plant, at a surface of 1.2 hectares.

The actual mounting of a panel is (1.22x1.34)m equivalent to 1.6348m^2 of surface, for 6000 panels the equivalent surface needed will be 6000x1.6348=9,808.8m^2,if including spacing for cabling and array position the surface of 1.2 hectares(12,000 m^2) will be sufficient [11].

For question of reliability the stand alone solar power plant will be divided into two plants of 500kWatt each with its inverter system, where the two inverts are interconnected but feeding individually the its load. The division in two is done to avoid a black out situation in case of failure or any problem in one unite, the load can still be supplied by the other remaining unite after load shading.

- Inverter characteristics

A five level cascaded Multi level inverter is used as invert in the Simulink.

- Load characteristics

The load is a full RL (resistive and inductive) load, practically in our homes we do have small motors like fans, water pumps, air dryer, etc. which are inductive in nature but the main load is resistive, the aim of applying a practical situation a RL load is used.

The THD (total harmonic distortion) in a solar system is usually very high due to switches used in the system both by DC to DC converters and inverter units, the load characteristic and the lack of reactive power in the system. The solar system doesn't produce reactive power and due to this there is a lot of harmonic and voltage drop in the system, to overcome this only solution is to add a capacitor bank in parallel connection with the load, placed at the load end for reactive power compensation and maintain voltage level.

Using FFT (Fast Fourier Transform) analysis in MATLAB/Simulink R2016a with 1000Hz maximum frequency and computation at same frequency, the THD is 6.82% which is an acceptable value in a power system as shown in the figure below and the voltage across the load is about 212.1 V as RMS value.

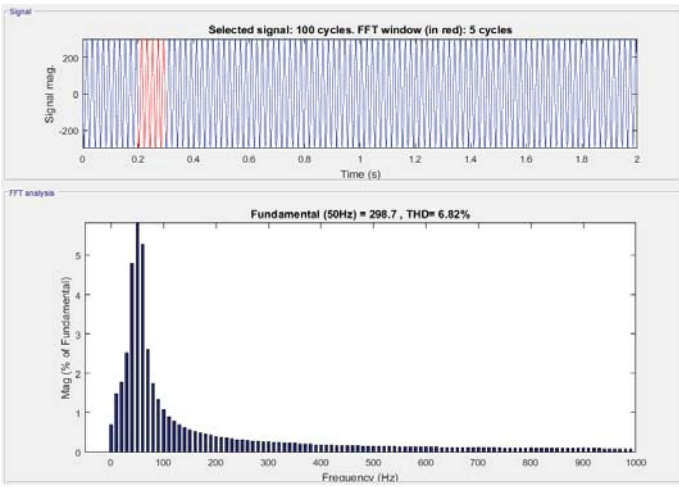

Figure11. View of THD analysis in MATLAB/Simulink R2016a

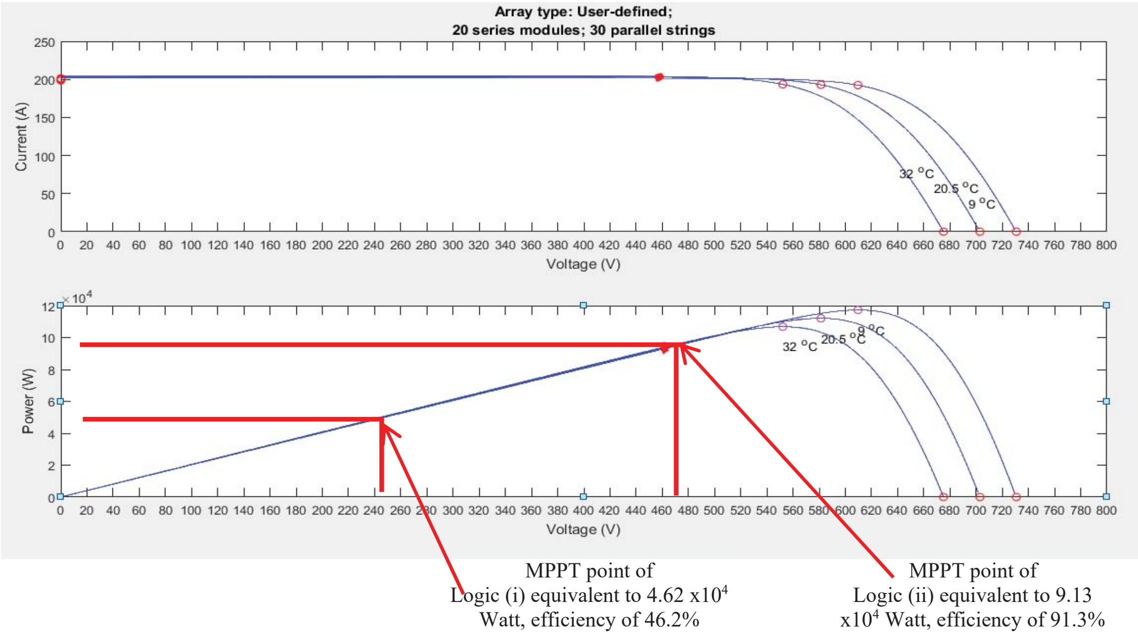

Figure10. Plot of array characteristics and MPPT view

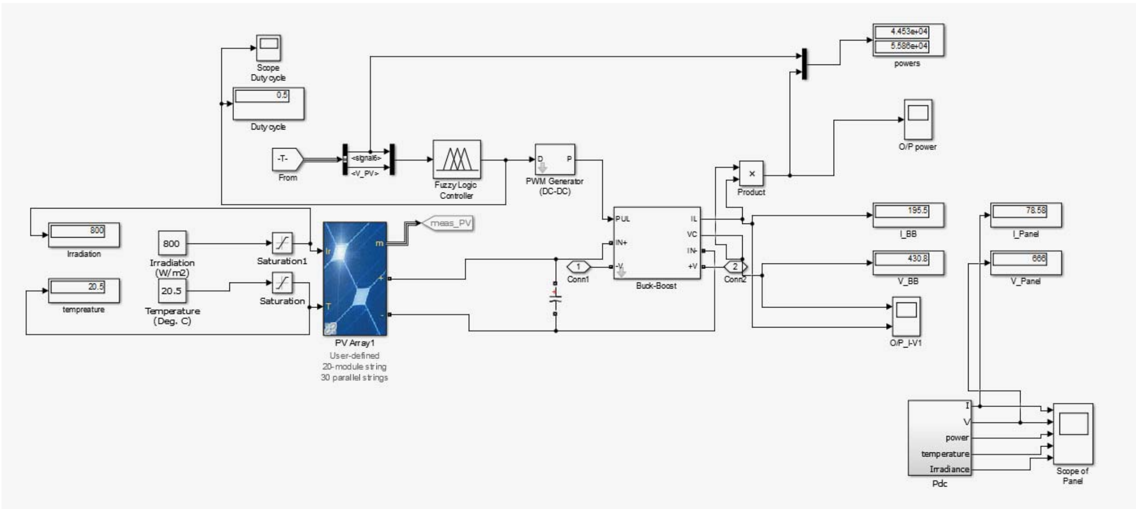

Figure12. View of the Array in MATLAB/Simulink R2016a

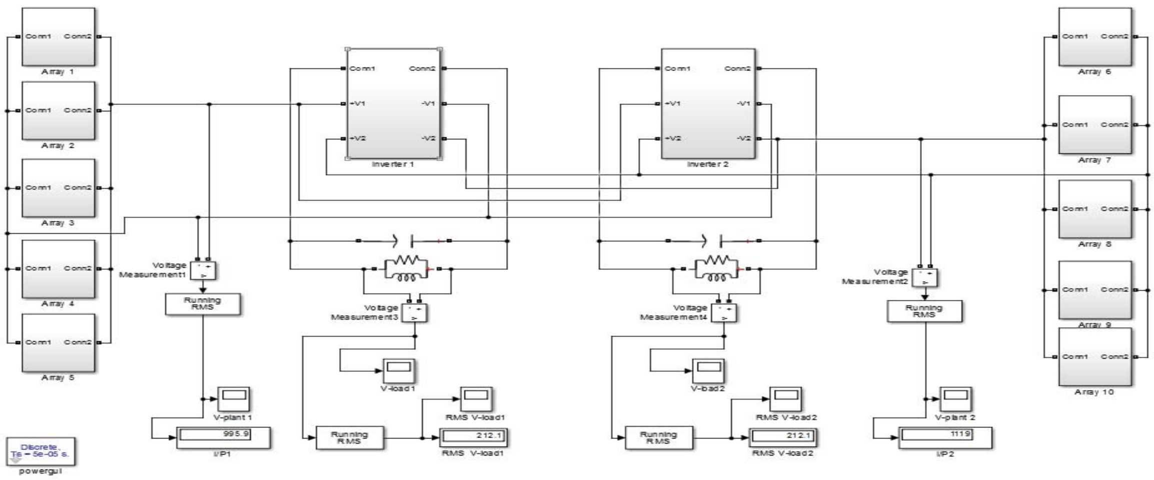

Figure13. View of 1MW solar power plant in MATLAB/Simulink R2016a

VI. CONCLUSION

In this paper, an overview of problems affecting the efficiency of photovoltaic solar panels has been done, a set of method for boosting the efficiency of solar panel has also been proposed. In addition a practical study of a fuzzy logic based MPPT has been done where two Fuzzy logics were compered for this work; one based on the combination of variation in current (ΔI) and variation in power (ΔP) and the other on variation in power (ΔP) and variation in voltage (ΔV). After implementation of both combinations the first gave an efficiency of 46.2% in power output and the second 91.3%, therefore the second combination was opted as controller for the MPPT system.

Studies in the area of boosting the efficiency of solar panel is still under research to find a material a having an efficiency higher than 25% which is known to date in out-laboratory condition.

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