Analysis and Implementation of Fuzzy Logic Controller Based MPPT to Enhance Power Quality in PV System

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Abstract: Maximum power point trackers are so important in photovoltaic systems to increase their efficiency. Many methods have been proposed to achieve the maximum power that the PV modules are capable of producing under different weather conditions.The output power induced in the photovoltaic modules depends on solar radiation and temperature of the solar cells. Therefore, to maximize the efficiency of the renewable energy system, it is necessary to track the maximum power point of the PV array. This paper proposes a new method of maximum power point tracking using fuzzy logic for photovoltaic system. It uses a sampling measure of the PV array power and voltage then determines an optimal increment required to have the optimal operating voltage which permits maximum power tracking. This method carries high accuracy around the optimum point when compared to the conventional perturbation and observation algorithm then it assures fast and fine tracking. The system is composed a solar panel, a Boost converter and Fuzzy Logic Controller (FIS). The simulation results show that the proposed maximum power tracker could track the maximum power accurately and successfully in all condition tested.

Keywords: *Solar (PV), Boost Converter, Fuzzy Logic Controller (FIS), MPPT, MATLAB Simulink.*

I. INTRODUCTION

Energy has become an important and one of the basic structures for economic development of a country [1]. It plays a vital role in the day-to-daylives of the human beings, in the socio-economic development and welfare of a country. Consumption of a large amount of energy in a country indicates increased activities in the domestic, agricultural, transportation and industrial sectors. All this amounts of a better quality of life. Therefore, the per capita energy consumption of a country is an index of the standard of living or prosperity of the people of the country. The gap between supply and demand is continuously increasing. To bridge up this gap, researchers and scientists tried to find out an alternate solution and solar energy has been found to be the best alternative for this problem [1], [2].

Energy sources are divided into two groups namely conventional or non-renewable and non-conventional or renewable energy sources. At present conventional sources are used as the primary source for generation of electricity worldwide. The conventional energysources are derived from ground in the form of solid, liquids and gases. Coal is a solid, Crude oil is the only natural liquid and Natural gas and propane are the gases that are available worldwide. Coal, petroleum, natural gas, and propane are all considered as fossil fuels because they are formed from the buried remains of plants and animals that lived millions of years ago. Uranium ore, a solid, is mined and converted to a fuel. These energy sources are considered as non-renewable because they cannot be replenished in a short period of time. Moreover, excessive use of the fossil fuels, radioactive material, emission of carbon dioxide (CO_2), methane (CH_4) and other greenhouse gases are some of the main threats for the global climate system and our natural living conditions [3].

II. SOLAR ENERGY

Solar Energy is the major source of energy that helps to sustains life on the earth for all plants, animals and human beings. The earth receives this radiant energy from the sun uniformly in all direction in the form of electromagnetic waves. The output of the sun is 2.8 × 1023 kW/year. The energy reaching the earth is 1.5 × 1018 kWh/year. The Sun acts as a perfect emitter of radiation (black body) at a temperature close to 58000K. Solar radiation emitted from the sun covers a continuous spectrum of electromagnetic radiation in a wide range of frequency. Around 99% of the extra-terrestrial radiation has wavelengths in the range from 0.2 to 4μm with peaking at 0.48 μm [1]. The spectrum of the solar radiation at the top of the atmosphere is shown in Fig. 1.1.The intensity of the solar radiation keeps on attenuating as it propagates away from the surface of the sun, although the wavelengths remain unchanged. Solar radiation that falls on the outer surface of the earth is known as Extra-terrestrial Radiation. The solar radiation that reaches the earth surface after passing through the earth's atmosphere is known as Terrestrial Radiation. The energy received from the sun per unit time, on a unit area of surface perpendicular to the direction of propagation of the radiation at the top of the atmosphere and at the earth's mean distance from the sun is defined as the Solar Constant. The World Radiation Centre (WRC) has adopted the value of the solar constant as 1367 W/m2. The measure of power density of sunlight received at a location on the earth is defined as the Irradiance and is measured in W/m2. Irradiation is the measure of energy density of sunlight and is measured in kWh/m2. Irradiance and irradiation apply to all components of the solar radiation.

When the solar radiation enters the earth's atmosphere, a part of the incident energy is lost by absorption by air molecules, clouds and particulate matter usually referred as aerosols and a part by reflection or scattering by dust particles. Solar radiation that is not reflected or scattered and received at the earth surface without change of direction, i.e., in line with the sun is called Beam or Direct Radiation. Solar radiation scattered by aerosols, dust and molecules is known as Diffused Radiation. It does not have a unique direction. Some of the radiation received after reflection from the ground, and is called Albedo. The total radiation consisting of these components is called

Global Radiation. The global irradiance can be as high as 1 KW/m2, but the available irradiance is usually less than this maximum value because of the rotation of the earth and adverse weather conditions [1], [2].

III. METHODOLOGY: MAXIMUM POWER POINT TRACKING

Most extreme Power Point Tracking (MPPT) is helpful apparatus in PV application. Sun oriented radiation and temperature are the primary factor for which the electric power provided by a photovoltaic framework. The voltage at which PV module can create greatest power is called 'most extreme power point (pinnacle control voltage). The primary rule of MPPT is in charge of separating the greatest conceivable power from the photovoltaic and feed it to the heap by means of dc-to-dc converter which steps up/ down the voltage to required size [5]. There are many maximum power point techniques. Among them, two MPPT techniques of ANN, perturb and observe (P&O) have been selected for the purpose of comparison in this paper.

A. DC/DC Boost Converter

The dc-dc converter is used to supply a regulated dc output with the given dc input. These are widely used as an interface between the photovoltaic panel and the load in photovoltaic generating systems. The load must be adjusted to match the current and voltage of the solar panel so as to deliver maximum power. The dc/dc converters are described as power electronic switching circuits. It converts one form of voltage to other. These may be applicable for conversion of different voltage levels. Fig.1 shows the circuit diagram of dc-dc boost convertor [7].

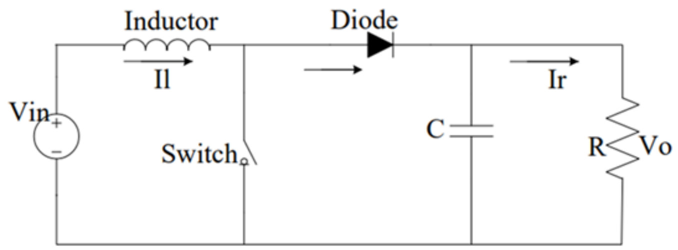


Fig. 1: Circuit Diagram of Boost Converter

The dc-dc boost converter circuit consists of Inductor (L), Diode (D), Capacitor (C), load resistor (RL), the control switch(S). These components are connected in such a way with the input voltage source (Vin) so as to step up the voltage. The output voltage of the boost converter is controlled by the duty cycle of the switch. Hence by varying the ON time of the switch, the output voltage can be varied. The relationships of input voltage, output voltage and duty cycle are as follow:

$$\frac{V_0}{V_{in}} = \frac{1}{1-D} \tag{1}$$

Where, V_{in}, V_o are the input and output voltage of the converter and D is the duty cycle of the control switch.

B. Fuzzy Logic Controller Design and System Simulation

This chapter studies the application of fuzzy logic control as algorithm for a maximum power point tracking of photovoltaic system. Also the design and performance of the fuzzy system was tested in Simulink/MATLAB with PV module and buck-boost converter and the rules of fuzzy logic were formulated and validated. Finally, the results in this section were useful to be implemented in the real fuzzy control system on actual hardware which is presented in next chapter.

1. PV Module with MPPT based Fuzzy Logic Controller

Figure 2 illustrates the basic diagram of a fuzzy logic based maximum power point tracker. It can be seen from the observation that the only two state variables are sensed as inputs of fuzzy controller; output voltage and output current of PV module (Vm) and (Im). The fuzzy logic controller, from measurements, gives a signal proportional to the converter duty cycle (D) which is fed to the converter through a pulse width modulator. This modulator drives the value of D to perform Pulse Width Modulation (PWM) that generates the control signals for the converter switch (s). The fuzzy logic controller scheme is defined a closed loop system.

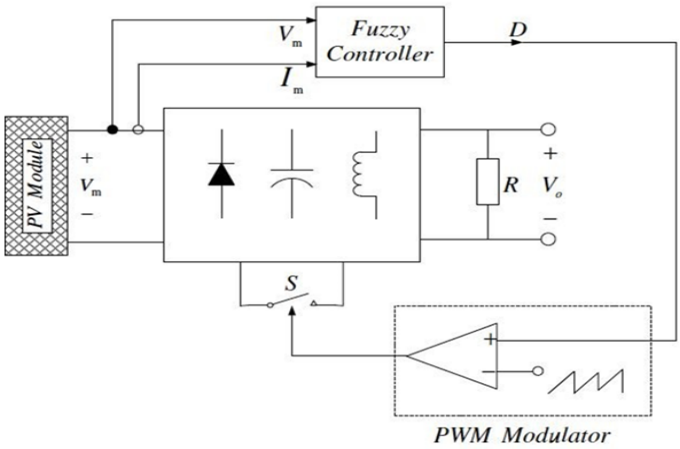


Figure 2: Fuzzy control scheme for a maximum power point tracker.

2. Fuzzy controller structure

Fuzzy logic controller structure is based on fuzzy sets where a variable is a member of one or more sets with a specified degree of membership. Benefits of using Fuzzy logic are; it allows us to emulate the human reasoning process in computers, quantify imprecise information, make decision based on vague information such as resistive load is connected to the PV module through the buck boost dc-dc converter. The block diagram of MPPT based fuzzy logic control is shown in Figure 3.

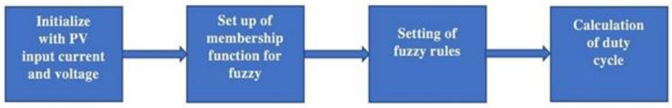


Figure 3: Block diagram of the fuzzy logic algorithm.

Also, Figure 4 illustrates the basic architecture of fuzzy controller which contains of the three following blocks:

2.1 Fuzzification

Each input/output variable in the fuzzy logic controller is required which define the control surface that can be expressed in fuzzy set notations using linguistic levels. Each input and output variables of linguistic values divide its universe of discourse into adjacent intervals to form the membership functions. The member value represents the extent at which a variable belongs to a particular level. The converting of input/output variable process to linguistic levels is named as Fuzzification.

2. 2 Inference

A set of rules are used to governor the behavior of the control surface which relates the input and output variables of the system. A typical rule would be:

If x is A THEN y is B.

Each of the rules that has any degree of truth in its premise, when a set of input variables are read, a rule is fired and contributes to the forming of the control surface by approximately modifying it. Then, when all the rules are fired that resulting control surface. It is expressed as a fuzzy set to represent the constraints output. This process is called inference.

2. 3 Defuzzification

Defuzzification is known as the process of conversion of fuzzy quantity into crisp quantity. There are many methods available for Defuzzification. The most common one is centroid method, which illustrated by the following formula:

$$\frac{\int (\mu(x)x)dx}{\int \mu(x)dx} \quad (2)$$

Where μ is the membership degree of output x.

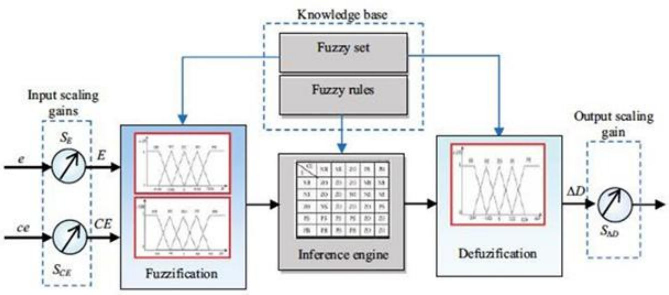
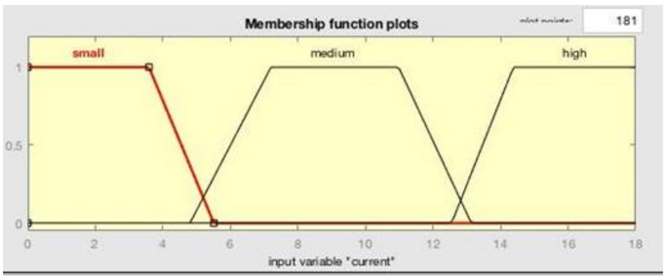


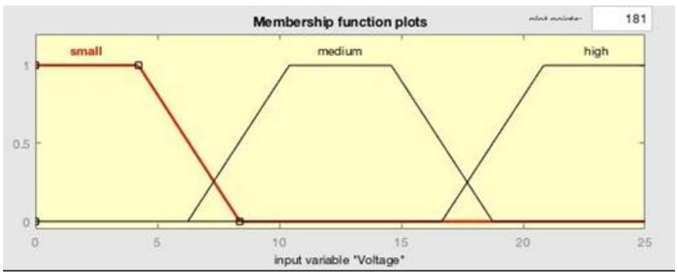
Figure 4: Structure of fuzzy logic controller.

C. Membership functions of the proposed fuzzy system

Fuzzy sets for each input and output variable are defined as shown in Figure 5. Three fuzzy subsets; small, medium, and high were chosen for the inputs and output variables of fuzzy controller. As shown in Figure 5, trapezoidal shapes have been adopted for the membership functions. The range of the inputs memberships which are PV voltage and PV current were modified according to the characteristics of proposed PV module (Voc≅ 22 V, Isc = 15 A) and buck-boost converter that were presented in chapter two and chapter three respectively. Also, the duty cycle which represents the output of fuzzy controller was ranged between zero and one to give more flexibility for switching the buck-boost converter.



(a)



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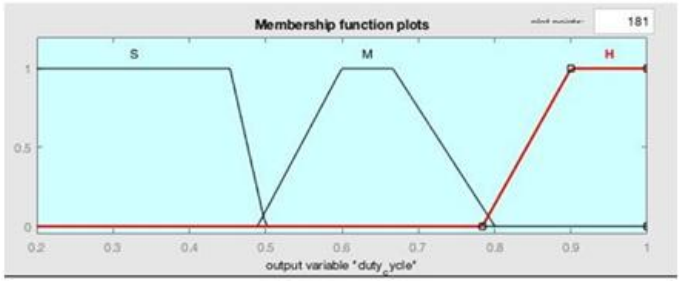

(c)

Figure 5: Membership functions for (a) input current of converter (b) input voltage of converter (c) output duty cycle of fuzzy controller.

1. Derivation of Control Rules

Fuzzy control rules are extracted by analyzing the system behavior. The different operating conditions are considered in order to improve tracking performance in terms of dynamic response and robustness. The algorithm can be explained as follows:

The tracking process is started with an initial duty cycle, D= 0. The converter input current Im, and voltage Vm, are then measured and sense the duty cycle that can give maximum poweroutput of the converter at that time based on predicted values that have already been entered into fuzzy system. This operation repeats itself continuously until the power reaches the maximum value and the system becomes stable.

2. Tuning of Control Rules

The fuzzy rules of the proposed system have been derived from the system behavior and tested in Simulink/MATLAB. Table 1 indicates the rules based on the membership functions that shown in Figure 5.

Table 1: Fuzzy controller rules.

Current/Voltage	small	medium	high
small	H	H	M
medium	H	H	M
high	M	M	M

The rules in the table above are read as:

1- If (current is small) AND (voltage is small) then (MD is high)
2- If (current is small) AND (voltage is medium) then (MD is high)
3- If (current is small) AND (voltage is high) then (MD is medium)
4- If (current is medium) AND (voltage is small) then (MD is high)
5- If (current is medium) AND (voltage is medium) then (MD is high)
6- If (current is medium) AND (voltage is high) then (MD is medium)
7- If (current is high) AND (voltage is small) then (MD is medium)
8- If (current is high) AND (voltage is medium) then (MD is medium)
9- If (current is high) AND (voltage is high) then (MD is medium)

Where MD is duty cycle that represents the output of fuzzy controller.

The fuzzy logic algorithm was simulated in Simulink/MATLAB using the fuzzy logic toolbox and the rules were tuned precisely. The basic window of fuzzy designer is illustrated in Figure 6 where the controller based on Mamdani's fuzzy inference method and centroid method as a defuzzification process is used.

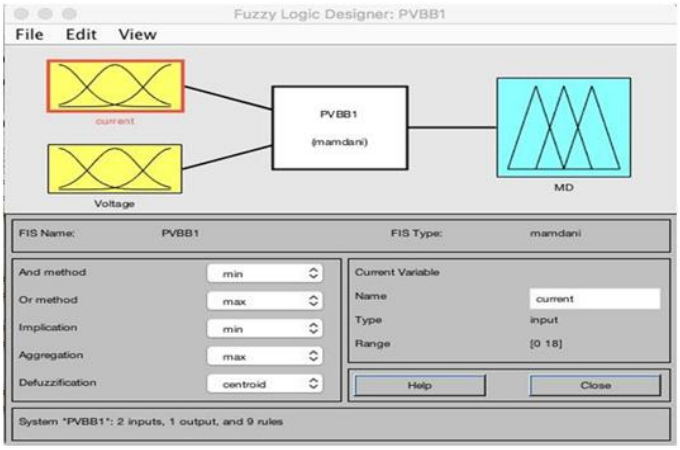

Figure 6: Fuzzy logic designer in Matlab tool box.

Figure 7 demonstrates the fuzzy controller rule surface which is a graphical representation of the rule base. And Figure 8 shows the rule viewer which indicates the operation of the fuzzy controller during the change of inputs.

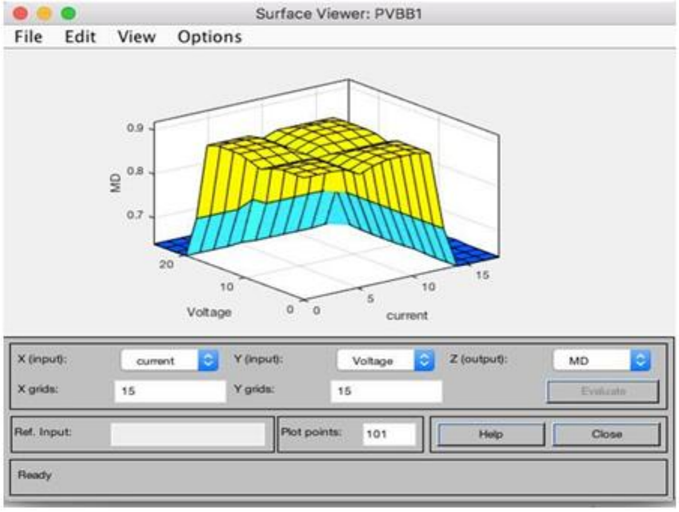

Figure 7: Graphical representation of fuzzy controller rules.

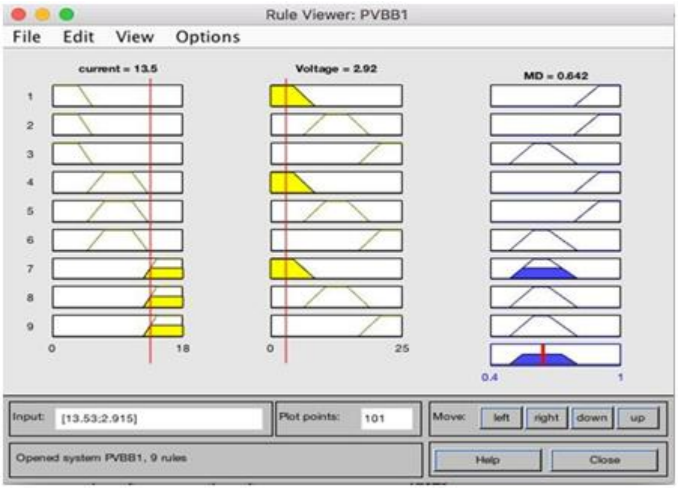

Figure 8: Fuzzy controller rule viewer.

After the fuzzy controller was modified in MATLAB the FIS file was created in order to be called in the Simulink system.

IV. SIMULATION AND RESULTS

The entire system was combined and tested in Simulink/MATLAB for values of solar irradiation and temperature as shown in Figure 4.1.

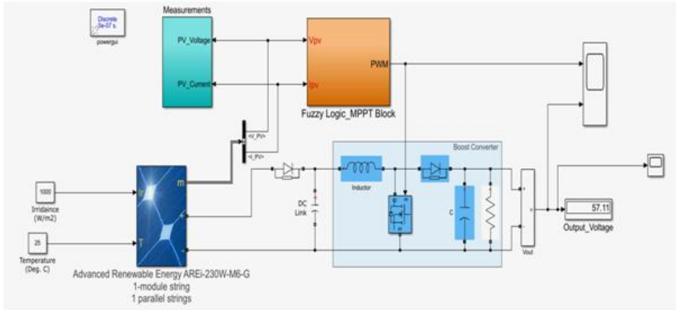

Fig 4.1 MATLAB/ Simulink ANN MPPT Algorithm for Solar PV System

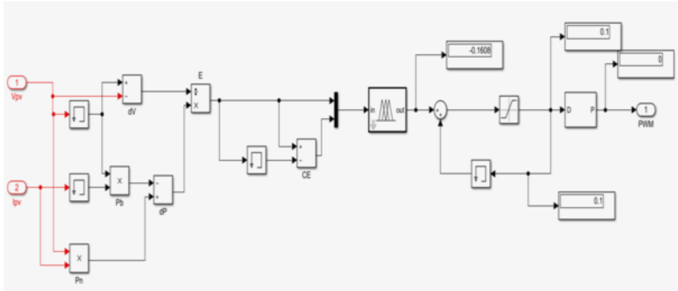

Fig 4.2 Fuzzy Logic MPPT Block

The simulation model shown in Figure 4.1 was implemented in at Simulink/MATLAB. In order to check the fuzzy controller performance and the efficiency of the converter the readings of input power and output power of the MPPT were taken at solar irradiance (1000w/m^2) & temperature $25^{0}C$ and also duty cycle was observed at the same values.

To analyse the performance of the output voltage, the output currents and the output power are measured as shown. The PV parameters of the system are shown in Table 4.1.

Table 4.1 Pv Parameters

Parameters	**Specifications**
Maximum power, P_m	230.4 W
Series-connected modules per string	1nos
Parallel strings	1nos
Cells per module (Ncell)	60
Voltage at maximum power point Vmp (V)	30.72 V
Current at maximum power point Imp (A)	7.5 A
Open circuit voltage, V_{oc}	37.14V
Short circuit current, I_{se}	8:00 AM

The average efficiency of the converter was about 98.49% which means the MPPT based fuzzy controller obtains the maximum power that can be extracted from the PV module at the specification of the proposed system. Figures from 4.3 to 4.7 illustrate the Maximum Power Output of the MPPT based fuzzy controller and boost converter versus pulse width modulation (PWM) at each input and output power.

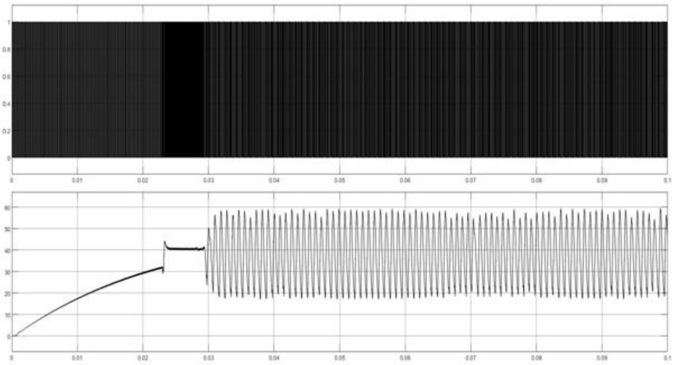

Fig 4.3

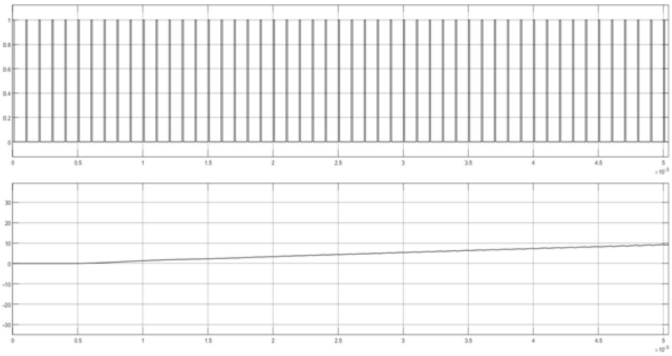

Fig 4.4

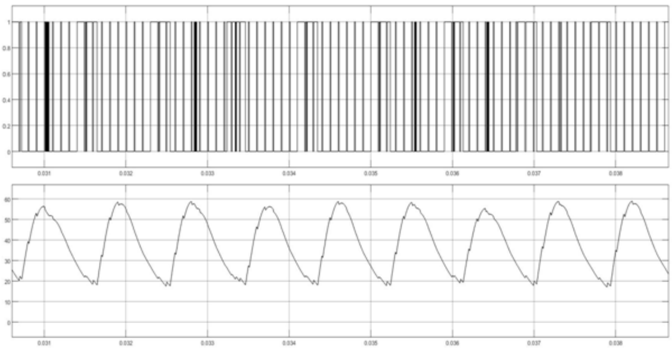

Fig 4.5

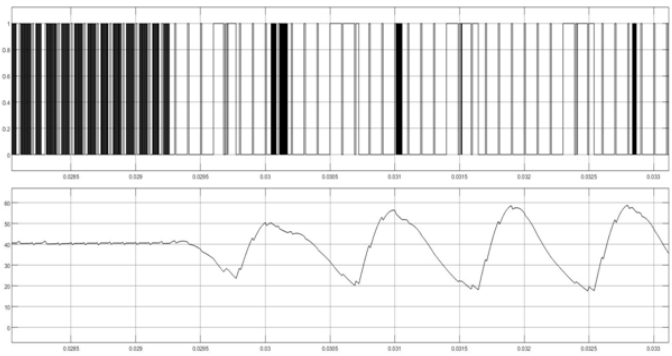

Fig 4.6

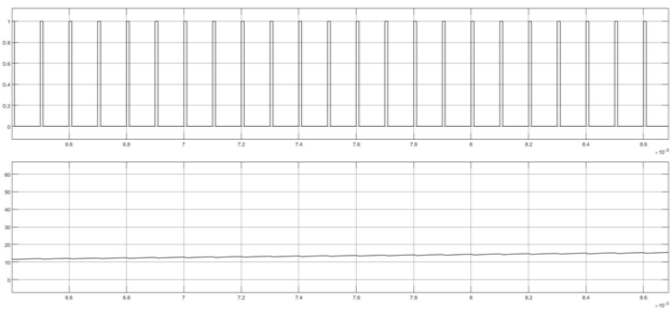

Fig 4.7

A Fuzzy controller for tracking maximum power point of photovoltaic source was proposed in this chapter and simulated in Simulink/MATLAB. The controller was based on the basic blocks of fuzzy system, which are (Fuzzification, Inference, and Defuzzification). These blocks read inputs of fuzzy and program the process of the plant and convert the program into output action respectively. The trapezoidal shapes of inputs and output membership functions were proposed in this controller and Mamdani's fuzzy inference method and centroid method as a Defuzzification process were chosen for this controller as well.The whole system includes PV, boost converter, fuzzy controller, and load was modeled and simulated under fixed irradiance and temperature. The results indicate that the proposed fuzzy controller performed well and valid to be implemented on real time system.

CONCLUSION

This thesis has presented a new fuzzy logic controller (FLC) for controlling MPPT of a stand-alone photovoltaic system. The FLC adjust appropriately the optimal increment's magnitude voltage required for reached the operating voltage and tracking the MPP, whatever solar radiance and temperature. The proposed controller avoids the oscillation problem of the perturbation and observation algorithm in MPPT method to assure fast and fine tracking. The FLC was simulated. The simulation results show the robustness of the FLC for variation in environmental conditions, the PV system is operating at the maximum power point.

The proposed fuzzy logic controller speed-up the procedure of reaching the accurate maximum power point of a photovoltaic array, it is suitable for any DC/DC topology and gives robust performances under variations in environmental operating conditions and load.

FUTURE SCOPE

The possible extensions of the presented work are listed as:

- In this thesis, Mamdani method was used to implement the fuzzy inference system; in future work it may be replaces by Sugeno approach and compare it with Mamdani approach.
- Optimization of membership functions and the rule base of FLC using GA can be done to further improve the efficiency of the SPV system.
- Other optimization techniques such as PSO, DE or other hybrid technique like neuro-fuzzy may be used for the optimization of the proposed FLC.
- The performance of the presented SPV system can be determined for the different types of loads like battery or motors instead of resistive load.
- Experimentation can be performed for the SPV system having inbuilt bypass diodes to depicts its performance under the partial shading condition.

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