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Implementation of Fuzzy Logic Controller Using PIC18F2520 for Maximum Power Point Tracking Control of Photovoltaic System

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ABSTRACT: This work focuses on the implementation of Maximum Power Point Tracking (MPPT) circuit for extracting maximum power from solar panel to improve the efficiency of the PV system by introducing maximum power point tracking techniques. An experimental setup was developed around PIC18F2520 microcontroller which generates high frequency Pulse Width Modulated (PWM) signal in accordance with the output of solar panel and electrical characteristics of the load to operate the panel at maximum power point. Fuzzy Logic Control (FLC) algorithm was developed to implement the incremental conductance technique for MPPT. The codes were written in mikroC, compiled and programmed into the chip using MikroElektronika development kit. The experimental results reveal that the FLC has better performance with higher tracking average efficiency of 71.87% than the Perturb and Observe (P and O) controller which has an average efficiency of 69.87%.

KEYWORDS: PV system, Fuzzy Logic Controller, PIC18F252 Microcontroller, MPPT Control

I.INTRODUCTION

Solar energy is considered as the core of renewable energy in recent times primarily because of the depletion of fossil fuels and its environmental friendliness, inexhaustible nature, free, and clean [1]. Among various renewable energy resources, photovoltaic (PV) systems are gaining popularity in a wide range of applications, from small building integrated systems to large scale utility systems.

A photovoltaic cell is a semiconductor device that converts light to electrical energy by photovoltaic effect. If the energy of photon of light is greater than the band gap then electrons are emitted and the flow of electrons creates current [2]. Cells may be grouped to form panels or modules, and panels can be grouped to form large photovoltaic arrays.

The main hindrance to the wide spread application of PV system is the low efficiency of the PV module due to variations in ambient conditions [3]. To get maximum power delivered by the PV system, it is very necessary to force the PV module to operate at the operating point corresponding to the maximum power point. This is the peak of the P-V curve or the knee of I-V [4].

Several algorithms were employed to track MPP effectively, but notable amongst them include the perturbation and observation (P and O) technique [5], and the incremental conductance method [6]. The problem with the P and O algorithm is that, the operating point is never steady at the maximum power point. Thus, the drastic change in weather conditions severely affects the P and O's efficiency. The main drawback of the IC algorithm is the complexity of its hardware implementation due to the involved computational efforts.

Fuzzy logic controller (FLC) was therefore employed to reduce the complexity of the IC hardware implementation. FLC is a rule-based control method which does not rely on specific model of the controlled object and has good robustness to disturbances. It is particularly suitable for the implementation of complex systems. Fuzzy logic controllers have the advantages of working with imprecise inputs and handling non-linearity [7]. In FLC, basic control action is determined by a set of linguistic rules dictated by the system's operation.

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II. SYSTEM DESCRIPTION

The system consists of a PV module, a Buck-boost DC/DC converter, display and control Unit. A load is connected to the PV module through the Buck-boost DC/DC converter. The PV module generates the DC voltage. The voltage supplied by the PV array does not have constant values, but fluctuates according to the surrounding condition such as intensity of solar rays and temperature. The DC/DC buck-boost converter is used to regulate a chosen level of the solar PV module output voltage and to keep the system at the maximum power point. It is mainly useful for PV maximum power tracking purposes, where the objective is to draw maximum possible power from solar panels at all times, regardless of the load. It also has a capability to regulate the perturbed voltage by increasing or decreasing the voltage reference of the Pulse Width Modulation (PWM) signal. The PIC microcontroller is used to generate high frequency PWM signal in accordance with the output of solar panel and the load to operate the panel at maximum power point. Fuzzy Logic Control (FLC) algorithm is developed to implement the Incremental Conductance technique for MPPT. The current and voltage from the panel, and voltage from the DC/DC converter are sensed by the sensors and are fed to the Microcontroller unit (MCU). The MCU compares feedback values with the reference values to customize the duty cycle of the pulse signal for producing the required output. The MCU is governed by the codes burned in it. The reference values and the boundary limits of duty cycle are defined at the beginning of the program. The block diagram of the proposed solar PV system is shown in Figure 1.

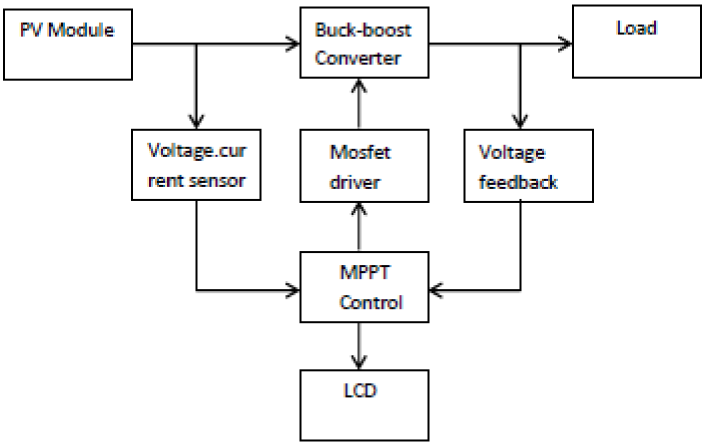

Figure 1: Block diagram of solar PV System [8]

III.FUZZY LOGIC CONTROLLER DESIGN

Fuzzification

This performs the conversion of the crisp value of the process variable into Fuzzy set in order to make it compatible with the Fuzzy set representation of the process state variable in the rule antecedent [9]. This conversion is based on the membership function so assignedand makes use of triangular membership functions for fuzzification purposes [10], and shown in figure 2 and figure 3 respectively. The universe of discourse of the error and change in error are defined between [-15 15] and [-8 8].

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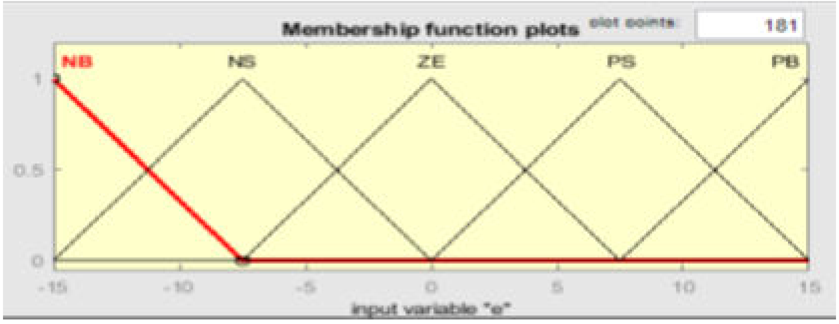

Figure 2: Input Membership Functions of error, e

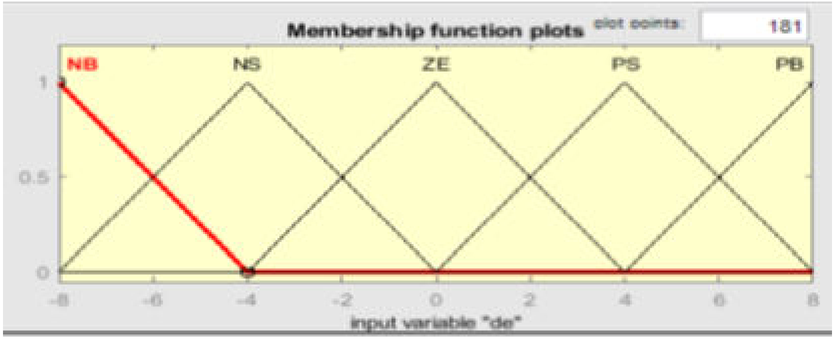

Figure 3: Input Membership Functions of change in error, de

Data Base

The data base provides necessary information for the proper operation of fuzzification module, rule base, and defuzzification module [11].

Based on the knowledge of the PV system, and requirement of the problem at hand, FLC is designed having [-15 15] universe of discourse (to cover the maximum error that could occur in the system) for the input variable partitioned into five fuzzy sets called NB, NS, ZE, PS, and PB with domains [-15 -7.5], [-15 0], [-7.5 7.5], [0 15], and [7.5 15] respectively. For the output variable, [0.3 0.8] universe of discourse is used with five singleton membership functions called NB, NS, ZE, PS, and PB supported at 0.3, 0.4.24, 0.55, 0.675, and 0.8 respectively as shown in figure 4. This way, the output ΔD can only have values between 0.3 and 0.8.

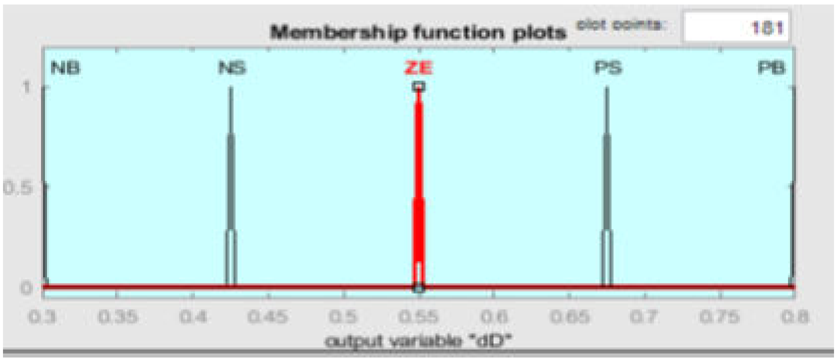

Figure 4: Output Membership Functions for control signal (dD)

Fuzzy Rule Base

Fuzzy logic uses fuzzy rules to make a decision and generate the control action instead of using a mathematical formula [12]. This represents in a structured way the control policy of an experienced control engineer in the form of a set of production rules such as: If <process state > then < control action>

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The ‘if’ of the rule refers to the antecedent and the ‘then’ refers to the consequent. The output of the fuzzy logic is to switch between 0.3 and 0.8 as the error varies between fuzzy sets NB, NS, ZE, PS, and PB respectively. Few among the golden rules are formulated for the Fuzzy Logic as follows:

If (E is NB) and (CE is NB) then (ΔD is PS)
If (E is NB) and (CE is NS) then (ΔD is PB)
If (E is NB) and (CE is ZE) then (ΔD is NB)
If (E is NB) and (CE is PS) then (ΔD is NB)
If (E is NB) and (CE is PB) then (ΔD is NS)
If (E is NS) and (CE is NB) then (ΔD is PS)
If (E is NS) and (CE is NS) then (ΔD is PS)
If (E is NS) and (CE is ZE) then (ΔD is NS)
If (E is NS) and (CE is PS) then (ΔD is NS)
If (E is NS) and (CE is PB) then (ΔD is NS)

Defuzzification Module

Defuzzification is for the aggregation of the duty cycles from each rule. Given a fuzzy set that enclose a range of output values, the defuzzifier returns one number, thereby moving from a fuzzy set to a crisp number [13]. In this work, singleton defuzzification strategy is used.

IV. HARDWARE IMPLEMENTATION

The purpose of this section is to control the operation of the whole hardware. So a microcontroller (PIC18F2520) was used to control and implement fuzzy controller for the system. The microcontroller senses panel voltage, load voltage and current connected to the analogue pins (AN0, AN1 and AN2). This enables the microcontroller determine the power delivered to the load and subsequent execution of the MPPT algorithm for the computation of the buck-boost duty cycle. Interfaced to the microcontroller also is the liquid crystal display (LCD) serving as the human interface to the machine. The circuit diagram of the sub units include: control unit, driver, and display unit as presented in figure 5 and figure 6.

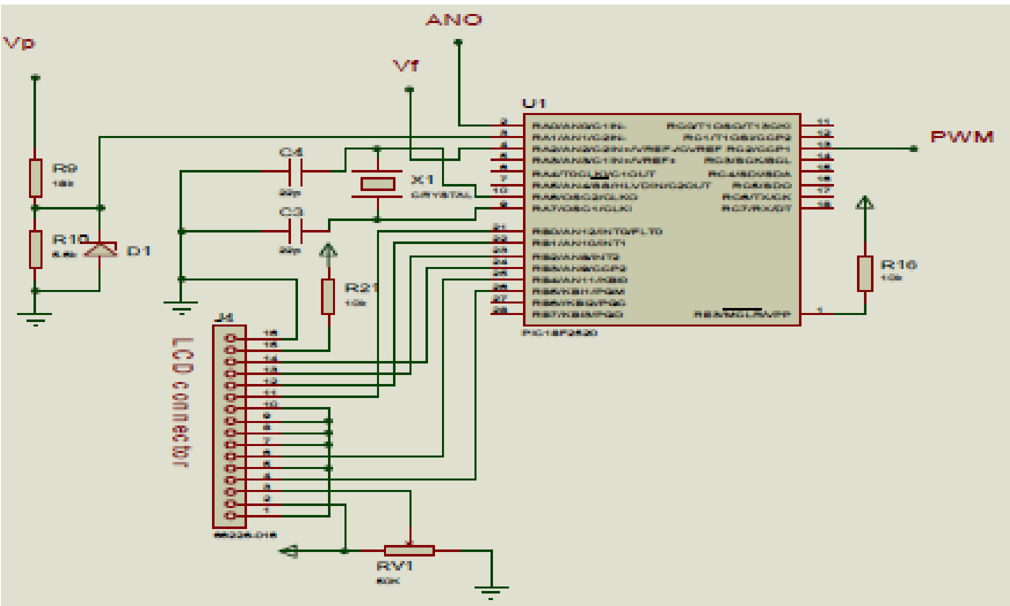

Figure 5: Control unit of the PV System

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Buck-boost converter (Driver unit)

The buck-boost converter is a kind of step-down and step-up DC-DC converter. The output of buck-boost converter is regulated according to the duty cycle of the PWM with input at fixed frequency. When the duty cycle (D) is less than 0.5, the converter output voltage is less than the input voltage. When the duty cycle is more than 0.5, the converter output voltage is more than the input voltage. Then, the input voltage source is VS, output voltage is VO, switching component is SW, D is diode, C is the capacitance, L is the inductance and R is the load resistance. The Buck-Boost converter circuit is shown in Figure 6.

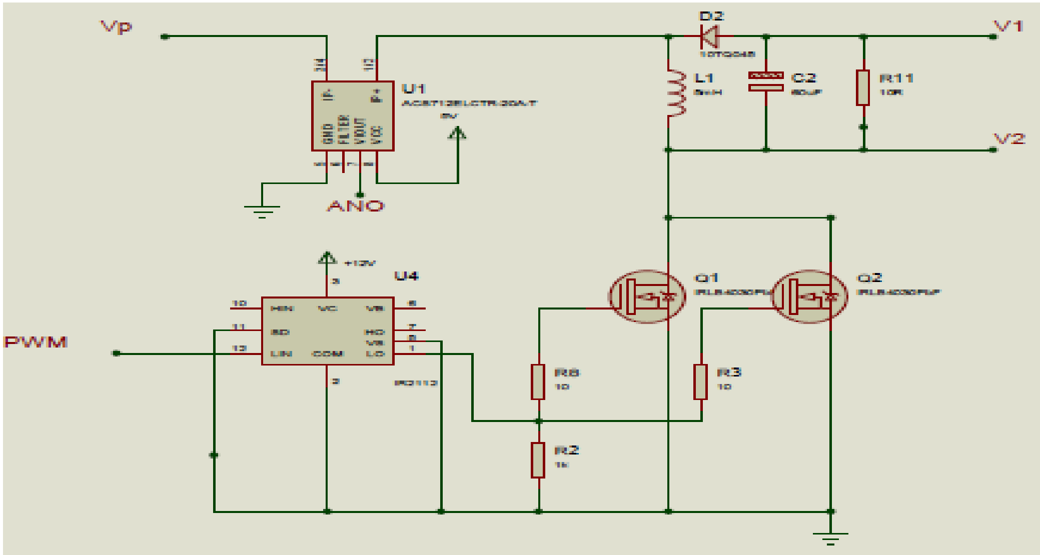

Figure 6: Circuit diagram of a Buck-Boost Converter (Driver unit)

Output feedback

Differential amplifier as shown in figure 7 was used to provide the output feedback for control purpose.

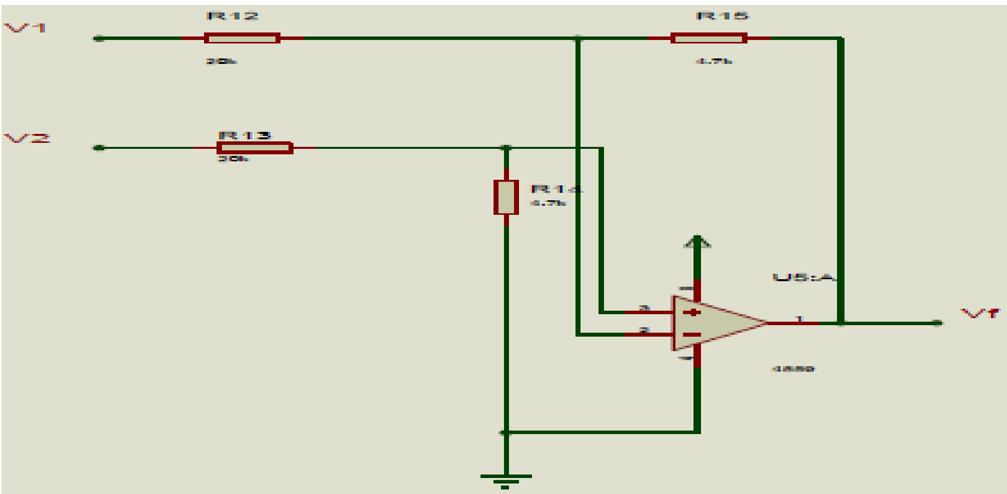

Figure 7: Output feedback circuit

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Voltage Sensing Circuit

To sense the panel voltage, a voltage divider circuit was used to sense the voltage. The output voltage VO (range 0-5 V) of this circuit is fed to the microcontroller ADC1 or pin A1. This input voltage is sensed by microcontroller and sense the Set-points. The voltage divider circuit is shown in figure 8.

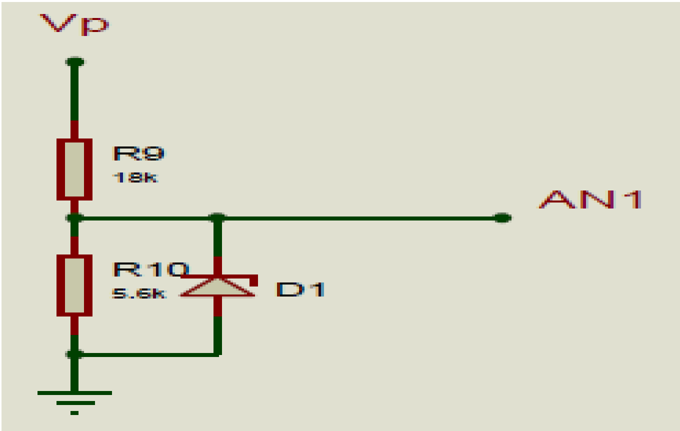

Figure 8: Voltage sensing circuit

Current Sensing Module

To determine the power delivered to the load, it is very necessary to sense the output current from the panel. This is achieved with the aid of Hall Effect sensor (ACS712) connected as shown in figure 9

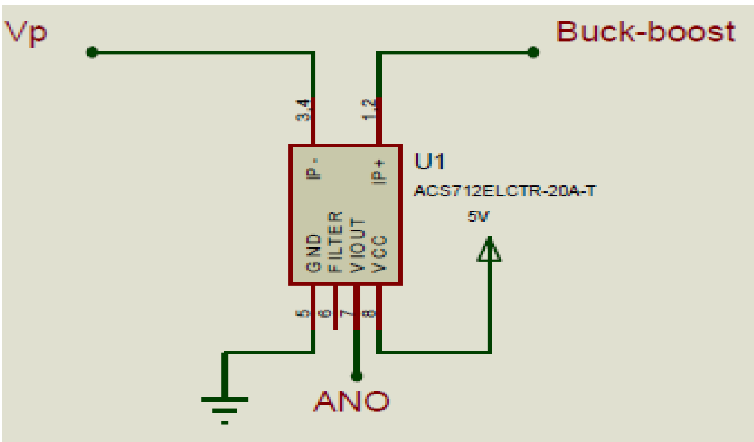

Figure 9: Hall current Sensor (ACS712-20A)

Voltage Regulator Circuit

The microcontroller and the driver require supply voltage of 5V and 12V respectively for proper operation. This is achieved with the help of adjustable voltage regulator (LM317). The LM317 is a monolithic integrated circuit intended for use as positive adjustable voltage regulators. They are designed to supply more than 1.5 A of load current with an output voltage adjustable over a 1.2 to 37 V range. The nominal output voltage is selected by means of a resistive divider, making the device exceptionally easy to use and eliminating the stocking of many fixed regulators. Figure 10 shows the circuit diagram for the voltage regulator.

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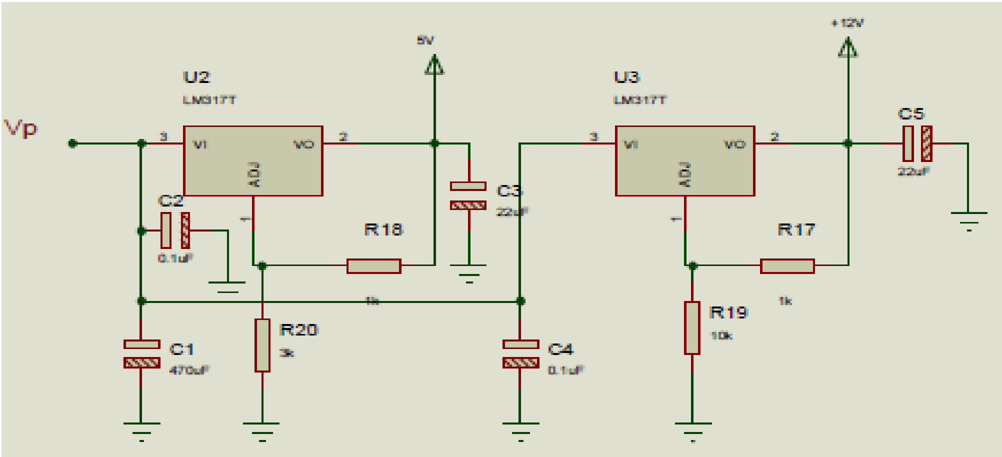

Figure 10: The pin configuration and photography of LM317 [14]

V. RESULT AND DISCUSSION

Experiments were carried out to determine the efficiency (which is a function of input and output power) of the Fuzzy, P and O MPPT algorithms. Moreover, a choke resistor load was used. The results obtained are shown in Figure 11 and figure 12. Overall, the fuzzy logic control technique recorded an average efficiency of 71.30%, while the P and O have 69.87%.

It can be observed on Figure 11 that at 16V, the input power and load power is 22.40W and 18.5W respectively. At that power, efficiency is 82.33%. At 14V, the highest efficiency, 97.06% is recorded where the lowest efficiency is 35.72% at 6V.

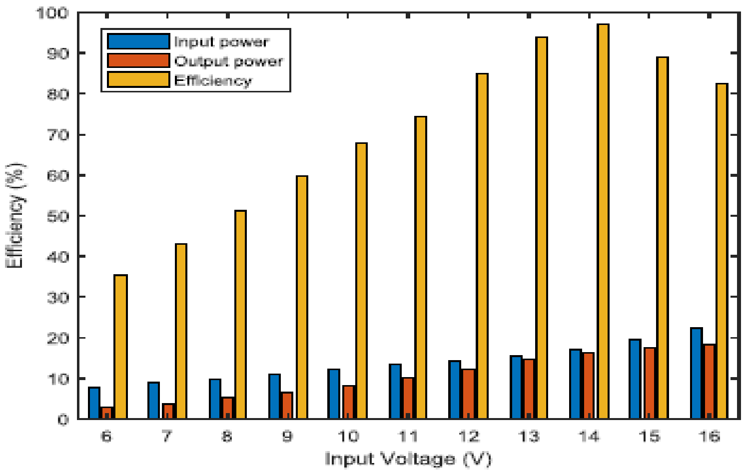

Figure 11: Efficiency of Fuzzy Logic Controller

It can also be observed on Figure 12 that at 16V, the input power and load power is 22.32W and 18.5W respectively. At that power, efficiency is 81.54%. At 14V, the highest efficiency, 96.15% is recorded where the lowest efficiency is 35.36% at 6V.

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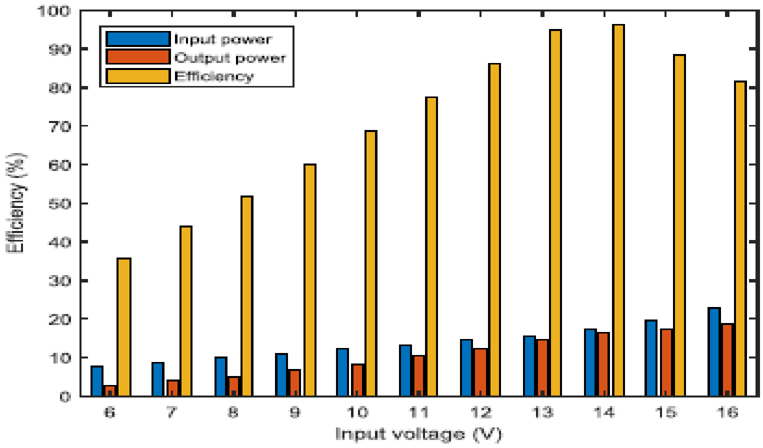

Figure 12: Efficiency of P and O Controller

VI.CONCLUSION

This work has presented the design and implementation of fuzzy logic controller. The fuzzy and 'Perturb and Observe' MPPT algorithm was implemented in microcontroller chip, and experimental evaluation was carried out to determine the efficiency of the system. The results show that fuzzy controller has a higher tracking average efficiency of 71.30% than the Perturb and Observe algorithm which has a tracking average efficiency of 69.87%.

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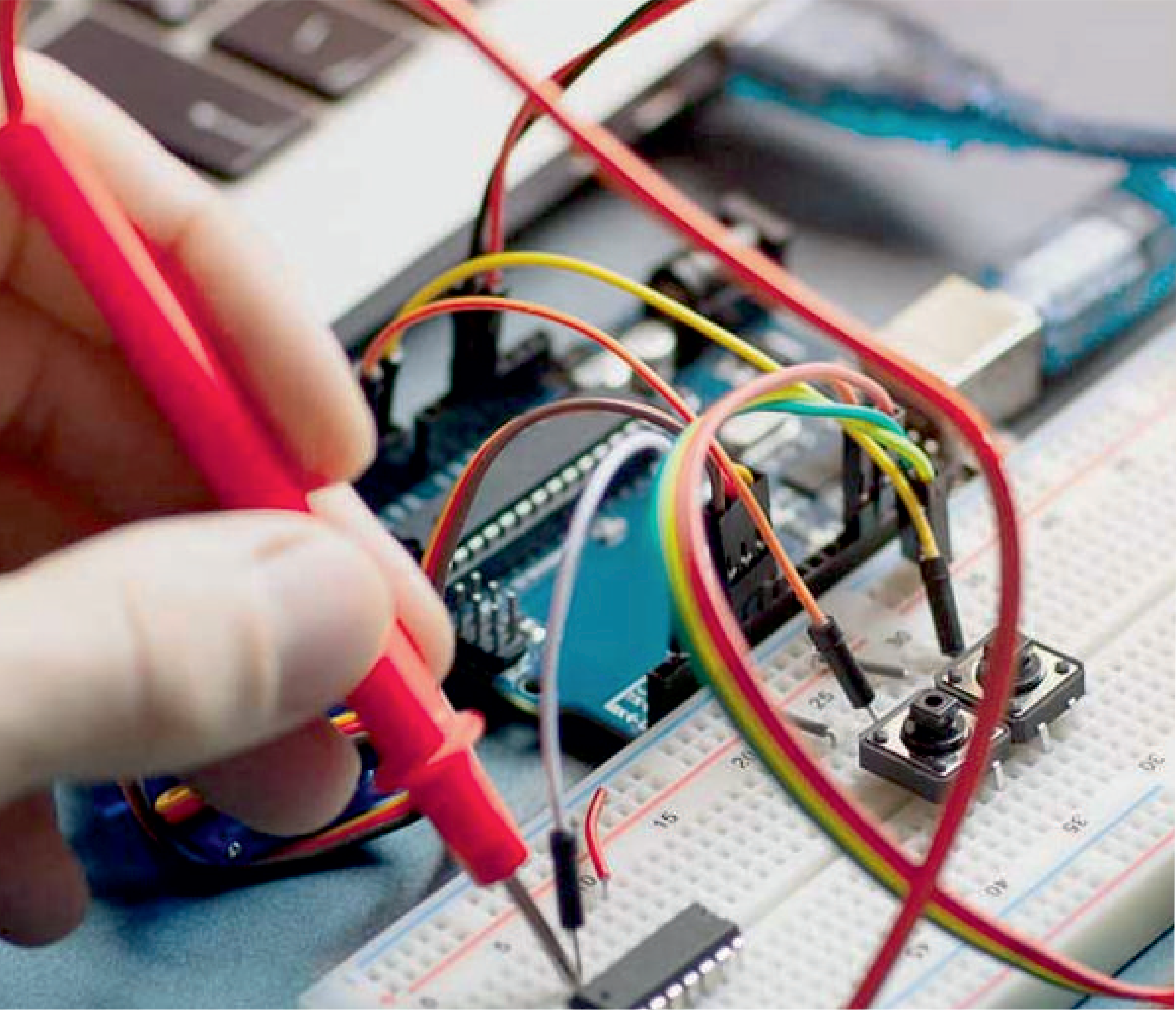

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