Implementation of fuzzy logic MPPT based on Arduino in small scale PV pumping system

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ABSTRACT

The performance of photovoltaic (PV) affected directly by climatic changes. The controller maintain maximum potential energy conversation to operate the pumping system at nominal conditions, fuzzy logic intelligent controllers are successfully suitable and applicable in engineering and applied science. The aim of this paper is present an experimental approach in Implementation of fuzzy logic maximum power point tracking (MPPT) with boost converter based on Arduino Mega micro-controller to maximize energy production in different weather condition applied to small scale pumping system for water and chemical fluid analyses in isolated area. The system is supplied by 20 (W) solar photovoltaic (PV) panel. This paper present a real-time MATLAB/Simulink fuzzy logic method controlling and monitoring MPPT application using an low cost Arduino Mega micro-controller combined with (LV25, LP55) sensors controlling boost converter interconnected with solar panel and plastic pump.

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1. INTRODUCTION

The need for energy is daily increasing in all countries, in the ruler and isolated areas solar energy developing into most economical future renewable energy (RE) source for electricity production applied worldwide [1], photovoltaic systems are built from interconnected components to retch the load requirements in most verity conditions (temperature, solar irradiation, load limits) [2], however to achieve the maximum power production boost converter control the output voltage upgrade stability of power based on software controlling for optimal power point tracking (MPPT) [3].

The successful development of low cost micro-controllers that can be used in varying industrial fields and human life enhancement, moreover computer since played a role in artificial intelligence programming to make systems more protective and reliable, in last three decades several MPPT algorithms tested to the maximum power point of the photovoltaic generator, some MPPT techniques rich better results in specific conditions but with the sudden variation efficiency decrease [4], fuzzy logic controller has improve height performance in optimization of output electric power to supply pumps [5], [6], intended for chemical fluid analysers plastic pumps are made to transport substances that would corrode or harm other kinds of pumps. They are more affordable and lighter than metal pumps, and they offer a wide range of chemical resistance [7].

This paper explains an experimental result of photovoltaic system to feed fluid pump based on Arduino Mega micro-controller occupied with sensors (LV25, LP55) in real time MATLAB/Simulink fuzzy logic
controller proving the efficiency of energy conversation to the pump. The rest of paper is organized as follows: i) Proposed control method in section 2; ii) The experimental tests and discussion of the system results are presented in section 3; and iii) Finally, the concluding remarks stated in section 4.

2. PROPOSED CONTROL METHOD

To produce maximum power from our system, we developed new simple law based on the selection of fuzzy logic trapezoidal membership, which is able to find the voltage value for the PV panel. First we take the measurements of PV panel voltage and current to help us designing the fuzzy logic controller in Arduino Mega drive a boost converter to determine the appropriate voltage to extract maximum power from the PV panel for each irradiation and temperature conditions [8], [9].

The design of fuzzy logic controller Figure 1 require three steps: the first step; fuzzification of input voltage and current with trapezoidal function, the second step: the fuzzy rules as shown in Table 1 which defines the system responses for each condition, then the last step is the defuzzification to go back to real value in this case the duty cycle output for the boost converter insulated gate bipolar transistor (IGBT) switch [10], [11].

![Figure 1. Fuzzy logic designer](image)

<table>
<thead>
<tr>
<th>Figure 1. Fuzzy logic designer</th>
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<table>
<thead>
<tr>
<th>Table 1. Fuzzy rules</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{1}{\Delta V} )</td>
</tr>
<tr>
<td>----------------------</td>
</tr>
<tr>
<td>LOW</td>
</tr>
<tr>
<td>MIDUME</td>
</tr>
<tr>
<td>HIGH</td>
</tr>
</tbody>
</table>

2.1. Boost converter

The variation of sunlight during the day makes output voltage of solar panel not stable, the increase and decrease of system Figure 2 power can’t manage to power the loud as desired [12], to avoid this problem a boost converter electronic circuit Figure 3 is needed to control output voltage [13], [14]. The electronic elements of boost converter are: capacitor, inductor, IGBT, diode, the selected components characteristic are demonstrated in Table 2 [15]. The relation between input and output voltages of the boost converter is given as (1),

\[
V_{out} = \frac{1}{1-D} V_{in}
\]  

with D is the duty cycle which given as (2),

\[
D = \frac{T_{on}}{T_S}
\]  

with \( T_{on} \) is the on-state time of the IGBT and \( T_S \) is the total switching time [16].
2.2. Arduino Mega

The measurement principle adopted in this test bench is to take the current $I_{pv}$ supplied by PVG and voltage $V_{pv}$ between its terminals. These quantities $I_{pv}$ and $V_{pv}$ are delivered by the current and voltage sensors connected to the inputs of the analogue to digital converter integrated into the Arduino board type Mega 2560 [17]. A processing unit, built around the micro-controller of the Arduino Mega board; is programmed to ensure the automation of the pumping station [18]. This unit captures the information delivered by the various sensors and controls the actuators accordingly to a computer via a RS232/USB serial converter cable facilitate the communication and programming with Arduino software or MATLAB, the main characteristic are illustrated in Table 3 [19], [20].

### Table 3. Arduino Mega data

<table>
<thead>
<tr>
<th>Microcontroller</th>
<th>ATmega2560</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Voltage</td>
<td>5 V</td>
</tr>
<tr>
<td>Input Voltage (recommended)</td>
<td>7-12 V</td>
</tr>
<tr>
<td>Input Voltage (limits)</td>
<td>6-20 V</td>
</tr>
<tr>
<td>Digital I/O Pins</td>
<td>54 (14 provide PWM output)</td>
</tr>
<tr>
<td>Analog Input Pins</td>
<td>16</td>
</tr>
<tr>
<td>DC current per I/O Pin</td>
<td>40 mA</td>
</tr>
<tr>
<td>DC current for 3.3 Pin</td>
<td>50 mA</td>
</tr>
<tr>
<td>Flash Memory</td>
<td>256 KB</td>
</tr>
<tr>
<td>SRAM</td>
<td>8 KB</td>
</tr>
<tr>
<td>EEPROM</td>
<td>4 KB</td>
</tr>
<tr>
<td>Clock Speed</td>
<td>16 MHz</td>
</tr>
</tbody>
</table>
2.2.1. Current sensor LA55

Current transducer LA55-P is an electronic component for measuring several types of currents (DC, AC, pulsed,...) with galvanic separation between the primary circuit up to 50 A and the secondary circuit [21], the relationship between primary circuit current and the secondary circuit current is (3), with $I_s$: secondary circuit current, $N$: turns number, $I_p$: primary nominal current, $R_m$: measuring resistance, $V_m$: measuring voltage [22].

$$I_s = \frac{N \cdot I_p}{1000} = I_s \cdot R_m$$  \hspace{1cm} (3)

2.2.2. Voltage sensor LV25

Electronic voltage transducer LV25-P measures currents (DC, AC, pulsed,...) with galvanic separation between the primary circuit and the secondary circuit [23], the relationship between primary circuit voltage with maximum value of 500 V and the secondary circuit voltage is (4), with $V_p$: primary circuit voltage, $R_1$: primary circuit resistance, $V_m$: measuring voltage, $I_s$: secondary circuit current, $R_m$: measuring resistance [24].

$$V_p = I_p \cdot R_1 = I_s \cdot R_m$$  \hspace{1cm} (4)

3. EXPERIMENTAL RESULT AND DISCUSSION

The simulation studies are carried out using MATLAB (R2017a version). Seeking to validate the theoretical concepts and simulation studies, an experimental prototype of the system is developed in the laboratory which is shown in Figure 4. In this section, we present the tests results of our pumping system. (PV panel, sensors, fuzzy logic MPPT controller, Arduino Mega, DC-DC converter, pump unit).

3.1. PV System test site climatic data

Figures 5(a) and 5(b) show ambient temperature and irradiation of testing field clear sky in 7th March 2021 to view the variation form and the amount of ambient power available during the testes, these figures shows maximum solar radiation of 1.1 $kW/m^2$ with 21.2 °C, so PV generation power quality accessible is very approximate to the PV standard conditions. It is clear from graphs that solar radiation intensity increases from 6 AM to 15 PM and decreases from 15 PM to 19 PM in case of clear sky. The temperature values variation depend on climatic conditions of the test area more than the weather, in this test day the temperature between 13 °C at 6 AM and 21.2 °C at 13:30 PM.
3.2. Practical voltage and current sensors output

First for a given insolation, to trited the sensors and upgrade the accuracy of measurement, we regulate the Arduino sensors (voltage, current) output monitor by MATLAB/Simulink 2017a software on Dell computer with Intel core i3, 2.4 GHz processor, 4 GB of RAM memory and windows 7 operating system. The results have the same values measured by amperemeter and voltmeter Figure 6, this figure reveal the steady state performance LV25 and LA55 with high precision. Moreover the outputs of the sensors are given to the analogue inputs converted to digital signal by Arduino Mega board Processor. The Arduino Mega selected pins for sensors are POWER GND pin with ANALOG IN A0 pin For LA 55 current sensor and POWER GND pin with ANALOG IN A2 pin for LV 25 voltage sensor. The dynamic performance and precision of the sensors give the overall system more feasible efficiency in extracting the maximum power.
3.3. Arduino Mega PWM signal

We tested the destined MATLAB/Simulink simulation by the implementation in Arduino Mega PWM signal output, the feedback results shown in Figure 7 match the form and variation values of duty cycle rate with simulated control system, good accuracy. Experimentally obtained rectangular waveform depicted. The obtained practical responses completely verified with high accuracy.

![Figure 7. PWM output signal of Arduino Mega](image)

3.4. Arduino Mega PWM signal amplification

The IGBT gate of boost converter need 15 volt to function for that we managed to amplify Arduino Mega 5 volt PWM signal via electronic driver the result illustrated in Figure 8, as well as it can be seen clearly, the very quickly and efficiently signal pursuit. Therefore the generate PWM signal have required characteristics which provides optimal control of boost converter.

![Figure 8. Amplified Arduino Mega PWM signal](image)

3.5. Experimental power point tracking

The experiment’s results presented below Figures 9 and Figure 10 shows the generated power and the maximum power point tracking. Compared to the theoretical reserves, it is one can see a perfect match reflecting the effectiveness of the proposed control algorithm (strategy). After analysing these figures, we notice that the system pursuit the MPP with stable response and accurate variation form in energy conversation reference to ambient insolation power available, as result system reaches 92% of maximum power from the hardware components tested in ideal conditions.
3.6. Pump unit performance

To evaluate the effectiveness of the pump Figure 11 depicts pump discharge function of pump power. As the energy in pump increases, the pump discharge will also increase \[25\]. Moreover voltage stability and required current supply maintain the nominal pumping unit power delivered. Therefore the high performance of pumping unit during transient and dynamic conditions improve the optimal power conversation and reliable system operation.
4. CONCLUSION

This paper presents experimental study of using Arduino Mega micro-controller equipped by voltage and current sensor in real time MATLAB/Simulink, fuzzy logic control method for pumping. The main problem in PV systems, high cost and low efficiency due the influence of climatic conditions on the PV output, finally after testing the proposed system with variant temperature and irradiance profiles. We found that fuzzy logic controller prove low cost solution in Arduino Mega controller for pumping systems and high efficiency of the last to minimise the oscillations and successfully monitor the maximum power point while the outside environment conditions varies.

REFERENCES


Implementation of fuzzy logic MPPT based on Arduino in small scale ... (Laaoaud Mohamed)
BIOGRAPHIES OF AUTHORS

**Laaouad Mohamed** is Ph.D student in University of Mohamed Khider, Biskra, Algeria. He received the state Master's degree in Electrical Network from the Mohamed Khider University, Biskra, Algeria, in 2017. He is a member of the laboratory Genie Electrique Biskra (LGEB) since 2017. His research interests cover, renewable energy, power electronics, pumping systems, electric drives control, DC motors, AC motors, microcontrollers, artificial intelligence and their applications. He can be contacted at email: mohamed.laaouad@yahoo.com.

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