ENERGETIKA. 2023
T. 69. Nr. 1. P. 1–13

ISSN 0235-7208 eISSN 1822-8836
DOI: https://doi.org/10.6001/energetika.2023.69.1.1

# Design and optimization of automatic solar irrigation-based PLC

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Irrigation is the most important step in agriculture. In order to obtain a good agricultural crop, water must be used wisely and appropriately without waste. This article presents an automatic solar irrigation system developed and designed by the authors. The system consists of two parts: a photovoltaic water pumping system and a unit of control based on programmable logic controller. The programmable logic controller (PLC) uses two sensors: one is placed in the field to measure the moisture in the soil, while the second is used to control the amount of water in the storage unit. The photovoltaic pumping system was designed to be able to irrigate one-hectare area of henna *Lawsonia inermis* L. with daily water need of 33 $m^3$/day and total dynamic head (TDH) of 14 m. The region opted for this study and analysis is 34°41.1' N latitudes and 6°29.6' E longitudes in Zribet el Oued-biskra, Algeria.

**Keywords:** solar pumping system, automatic irrigation, PLC, P&O MPPT algorithm

## INTRODUCTION

Algeria has limited and irregular natural water resources, with water potential of 19 billion $m^3$/year, and the water demand is increasing. Particularly in the south, which represents the most difficult area for water management, agriculture dominates the demand for water. The city of Biskra is considered the gateway to the Algerian desert and is characterised by the culture of henna, (*Lawsonia inermis*). Henna from Zribet El Oued, or *elhanna zribiya*, is a shrub of the Lythraceae family located in arid and semi-arid areas; it is a flat plant that can reach a height of 6 m. By crushing the leaves and kneading them with water, the resulting paste is dried and a dye is obtained, which is used as a cosmetic product (hair, hands and feet) and as a medicine in traditional pharmacology to treat wounds and various illnesses or diseases such as eczema, boils, and abscesses [1]. The irrigation of this plant varies depending on the planting stage, from transplanting to the start of vegetation. Many recent studies show that the correct timing of irrigation and its rationalisation is an important factor of production in order to ensure the continuity of agricultural production and food security [2]. In Algeria, traditional irrigation systems are manual in most cases. This method is not effective as watering can only take place when human beings are present on the farm. It is time-consuming, water wasting, and sometimes not good for the plants because the plants can receive more water than needed, which can lead to soil erosion and nutrient leaching [3]. Therefore, the development of a water-saving irrigation technology is urgently needed [4]. The suggested agricultural irrigation method conserves water by automation [5]. In addition to water scarcity, there is the problem of electricity supply to remote areas. To solve it, a renewable source of energy can be the best choice, particularly because Algeria contains a large amount of solar radiation, which is estimated at 7 kWh/m$^2$/day. Modern automatic irrigation systems work more effectively and benefit the area where they are installed. Once placed in an agricultural land, the distribution of water in the field and the nursery becomes very easy and does not require any human activity support to conduct operations permanently. Solar energy can be employed to enhance this system. In this automatic solar energy-powered irrigation system, soil moisture in the field is sensed. Soil resistivity or volumetric moisture content of the soil is measured by the moisture detector, which then transmits a signal to the controller which will open or close the solenoid valve. Researchers differed in the choice of control technology, with some resorting to using microcontrollers or Arduino such as [6–8], while others giving preference to a programable logic controller (PLC) in [9–11]. In this study, we used a PLC as a control unit, due to its reasonable prices, which allowed it to be used as independent irrigation controllers [12–13]. In addition, the PLC has a faster response and long operating life for programming, which is very easy when compared to microcontrollers. Both the ladder logic method and the structured text method can be used to program any PLC. The program can be written and understood using ladder logic, but as the system expands, the program becomes longer.

## PROPOSED IRRIGATION SYSTEM

In this article we discuss two goals: (1) optimisation of water use by automating the irrigation system and (2) improvement and maximisation of the power of solar panels by introducing a boost converter controlled by maximum power point tracker command (MPPT). The MPPT is a method, which maximises system efficiency by instantly adjusting output voltage and current to reach the maximum power point *d* of a solar panel. The proposed system consists of two major sections: the solar pumping system including a photovoltaic generator (PVG), impedance matching (DC/DC converter + MPPT), moto-pump group and the water storage unit; the second part is the programmable logic controller (PLC) as unit of control. The primary goal of the PLC is to read sensors and provide an output in accordance with the logic set out in the program. Two detectors are used by the system to gather the environmental parameters: soil moisture sensor and level water sensor; hence, the solenoid valve is activated or disabled depending on the level of the moisture sensor, when the soil moisture is high, the soil is wet and the solenoid valve is automatically stopped. On the other hand, the PLC is programmed in such a way that the water pump will automatically turn ON, if the water level in the tank is at the minimum and is stopped when it reaches the maximum level.

### The diagram of the proposed methodology

The entire system, where solar energy operates the entire structure, is presented in the diagram in Fig. 1

As presented in the above diagram, the system is divided into two sections: the first includes a moto- pump and a photovoltaic generator that are inserted through a DC-to-DC converter; the second is composed of sensors that gather data from the field and a tank in order to send signals to the PLC, which acts on the pump and the solenoid valve through electrical relays; A battery is added to ensure the PLC's power supply.

### The flowchart of the irrigation system

The logic table and the flowchart will explain the complete process of the system.

Table 1 and Fig. 2 show the functioning of the system. It obtains information through two sensors: soil moisture and water level sensors.

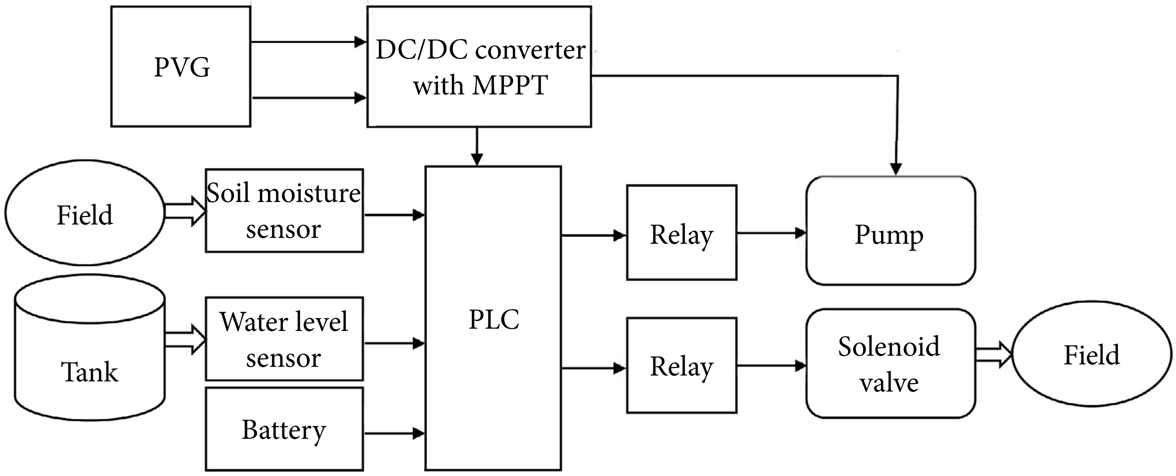


**Fig. 1.** The system designed

Depending on their values, the system is subdivided into two principal ways:

a) Soil moisture <35%: the PLC opens the solenoid valve

Soil moisture >35%: the PLC closes the solenoid valve

b) Water level =0: the PLC turns the pump ON

Water level =1: the PLC turns the pump OFF

Table 1. **Logic table of the diagram**

| Soil moisture sensor | Water level sensor | Solenoid valve | Pump |
|---|---|---|---|
| 0 | 0 | On | On |
| 1 | 0 | Off | On |
| 0 | 1 | On | Off |
| 1 | 1 | Off | Off |

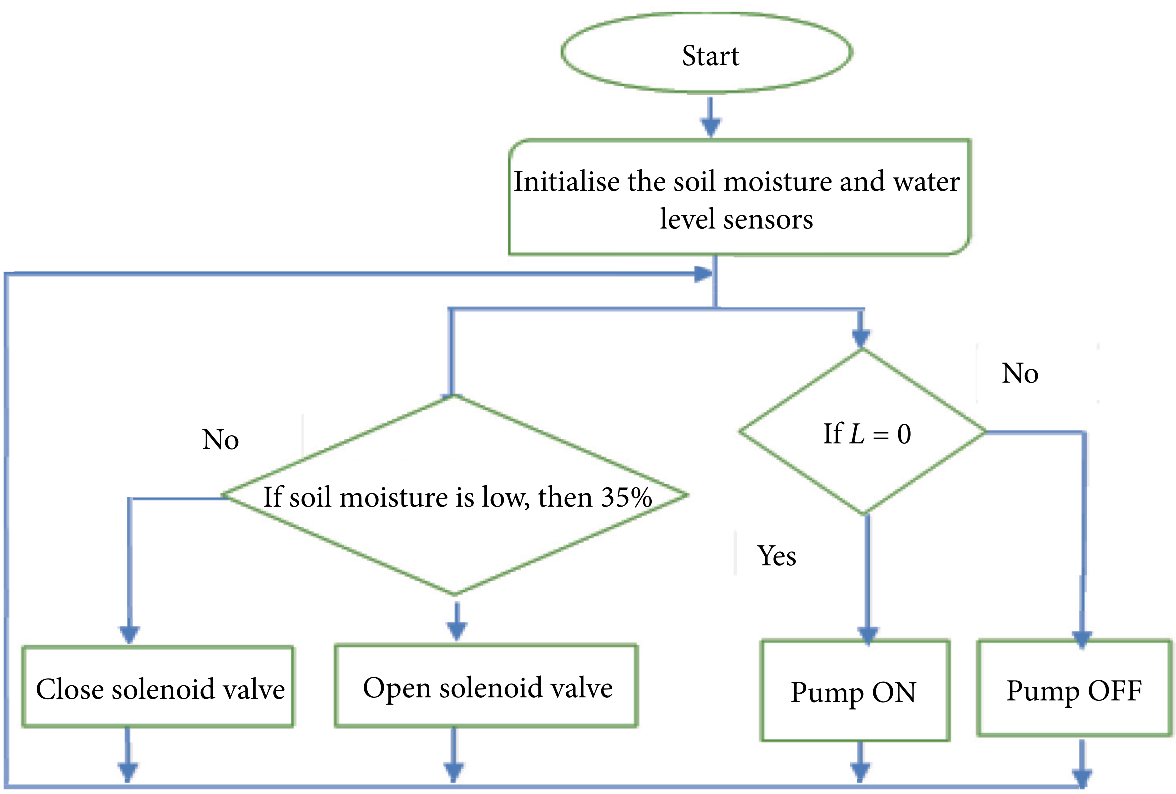


**Fig. 2.** The flowchart of the irrigation system

## MATERIALS AND SOFTWARE

**1. Moisture sensors.** Two sensors were used in this study:

### (a) Soil moisture sensor

A soil moisture sensor is an electronic device employed to determine soil moisture content. It is formed of two metal electrodes utilised for measuring the electric resistance between them. Soil moisture sensor MAS-1 with working current of 4–20 mA was used for this project. Its parameters are given in Table 2.

Table 2. **Parameters of the soil moisture sensor**

| | |
|---|---|
| Type | Volumetric water content (VWC) |
| Type of Equipment | Data Collection System |
| Model Number | MAS-1 |
| Power supply voltage | 12 to 32 VDC continuos |
| Current output | 4–20 mA |
| setting time | 4 second |
| Temperature | –40 to 60C° |
| Range | 0 to 100% VWC typical |
| Dimensions | 8.9 cm × 1.8 cm × 0.7 cm |
| Year of First Manufacture | 2008 |
| Manufacturer's Name | Decagon Devices, Inc. 2365 NE Hopkins Court Pullman, WA 99163 USA |

### (b) Water level sensor

The tank contained two digital water level sensors, high and low. It is a device used to measure and monitor the water level in a reservoir. The level sensor used in this project is the type AF001. Its parameters are given in Table 3.

Table 3. **Parameters of the water level sensor**

| | |
|---|---|
| Type | Digital level sensor |
| Name | AF001 |
| Operating voltage | 10 ... 36 V DC |
| Maximum intensity | max. 200 mA |
| Electrical form | PNP |
| Voltage drop | max. 2.5 V |
| Current absorbed | max. 22 Ma |
| Switching output | Programmable NO/NC contact |
| Protection class | III |
| Min ambient temperature | –25°C |
| Min ambient temperature | 80°C |
| Maximum tank pressure | ±0.5 bar |
| Degree of protection | IP65 |
| Manufacturer's Name | autosen gmbh • Annastraße 41 • 45130 Essen |

**2. DC/DC converter**

The PV generator and the motor pump are connected through a chopper. The boost converter functions by controlling the flow of current via an inductor with a switch, which is frequently a transistor as shown in Fig. 3. Once the switch is closed, the current passes through the inductor and stores energy. The energy is released and transferred to the output when the switch is opened. The main objective of this type is to obtain a higher voltage than the input voltage. The adaptation between the source and the load was achieved by the variation of the ratio cyclic and expressed in equation (1).

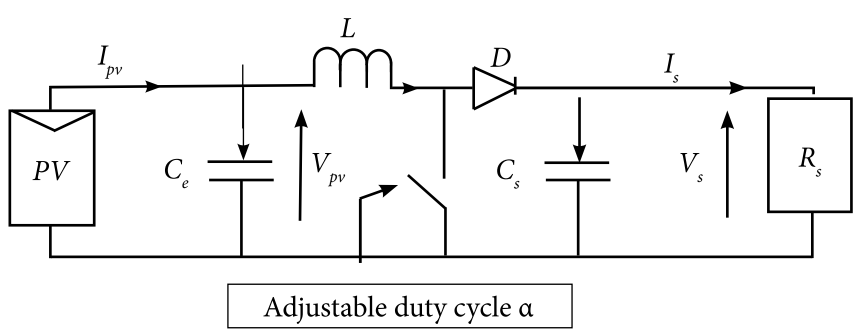


**Fig. 3.** DC/DC boost converter

$$V_o = \frac{v_{pv}}{1-\alpha}, \quad (1)$$

where $V_o$ and $V_{pv}$ are, respectively, the output and the input voltage of the DC/DC boost converter, **α** is the duty cycle, its value is between 0 and 1.

**3. Solenoid valve**

The solenoid valve is an electricity-operated valve, which has a moving magnetic core (piston) at the centre of an electric coil. The basic principle of opening and closing solenoid valves depends on the following: in the resting position, a little aperture is closed by the piston. Magnetic fields are produced by electric currents via the coil. The piston is then pushed upward by the magnetic field, opening the nozzle. The table 4 below show the characteristic of the solenoid valve used in this project.

Table 4. **Parameters of the solenoid valve**

| | |
|---|---|
| Connection size | 3/4 inch |
| Series direct | Flow (DF) |
| Operation | Semi-direct (S) |
| Function | 2/2 way |
| Position | Normally closed |
| Ambient temperature | Max 50°C |
| Min temperature | –30°C |
| Max temperature | 120°C |
| Min. pres. difference | 0 (bar) |
| Max pressure | 6(bar) |
| Voltage | 12V DC |
| Insulation class | Class F |
| Duty cycle | 100% ED |
| Connector | EN 175301-803 (formerly DIN 43650A) |
| Protection class | IP 65 (with cable plug) |
| Material | Brass |
| Reference | DF-SA034B200E-012DC |
| Manufacturer's name | JP Fluid Control |

**4. Centrifugal pump**

In our study, the choice of the pump used was focused on a range of pumps offered by Lorentz (Germany), see Table 5. According to our needs, an hourly flow rate of 6.73 $m^3$/h and a total manometer head of 14 m, the suitable pump would be the PS2-600 C-SJ8-5.

Table 5. **Pump parameters**

| Type | PS2-600 C-SJ8-5 |
|---|---|
| Max power | 0.70 kW |
| Max input voltage | 150 V |
| Optimal Vmp** | >68 V |
| Max. motor current | 13A |
| Temp. ambient | –40...50°C |
| Max efficiency | 98% |
| Protection class | IP68 |
| Rated power | 0.7 kW |
| Max drop | 15 m |
| Max flow | 12 $m^3$/h |
| Manufacturer's name | LORENTZ |

**5. PV generator**

In this study, the panel Kyocera KD135GX-LP was used as simulation under MATLAB R2020a. The module generated 135 W of the maximum rated power using 72 series-connected multi-crystalline silicon solar cells. Its characteristics are given in Table 6.

Table 6. **Photovoltaic panel parameters**

| | |
|---|---|
| Maximal power | 135 W |
| Voltage for maximal power | 17.7 V |
| Current for maximal power | 7.6296 A |
| Current of short circuit | 8.3696 A |
| Voltage of open circuit | 22.1 V |
| Temperature coefficient | 0.005022%/°C |
| Temperature coefficient | –0.8 v/°C |

**6. Programmable Logic Controller (PLC)**

A programmable logic controller, or PLC, is digital electronic device designed for process control. It sends commands to an output interface that includes pre-actuators or actuators such as motors, solenoid valves through- the data recorded by the input interface that contains sensors, push buttons, etc. There are several brands, the most used are Omron, Schneider, Siemens. The choice of a programmable logic controller depends on the complexity of the process, the number of inputs and outputs (E/S), the cost, etc. We used Siemens LOGO12/24RC PLC as the main controller of our system. It has eight digital inputs, two of which are analogue and 4 relays of 10A for each; which represent the outputs. Its parameters are given in Table 7.

Table 7. **Parameters of Siemens LOG012/24RC PLC**

| Type | PLC controller |
|---|---|
| Supply voltage | Rated value (DC): 12/24V |
| Permitted minimum and maximum voltages | 10.8–28.8 V |
| Current consumption 12 V CC 24 V CC | 30 ... 140 mA 20 ... 75 mA |
| Digital input | 8 |
| Analog input (0 to 10 V) | 2 (I7, I8) |
| Digital output | 4 relays of 10A each |
| Temperature | –200–550C |
| Manufacturer's name | Siemens |
| Reference | 6ED1052-1MD00-0BA4 |
| Software | Logo comfort v.8.0 |

The control program is made in the form of a function diagram (function block diagram, LOG), its task is described in Fig. 4:

I1 and I2 are digital inputs (TOR) indicating the minimum and maximum value of the water in the reservoir; the two inputs are connected to an RS flip-flop which is used for storage; the output of the latter is linked to another digital input I3 in order to self-maintain; the output (Q1) presenting the pump will be activated only when I1 and I3 have a value of 1; on the other hand, if input I2 is activated, output Q1 will be deactivated. A1 represents an analogue input, which indicates the value of the moisture in the ground, this input is connected to a threshold detector (0–20 mA), which will compare it with a threshold that varies between 200 and 600 and according to the value of comparison. Output Q2, which represents the solenoid valve, will be opened or closed.

**Software**

This research made use of three pieces of software: LOGO Comfort v.8.0 for irrigation control, MATLAB 2020a for the modelling of the solar pumping system, and HOMER for sizing.

## SOLAR PV SYSTEM MODELING

A PV cell model can be represented by an equivalent circuit as shown in Fig. 5 [14].

The output current-voltage (I–V) characteristic of a solar PV cell is given in equation 2 [15]:

$$I_d = N_p I_{ph} - N_p I_0 \left( e^{\frac{1}{k.T.A}\left(\frac{V_d}{N_s}+\frac{R_s I_d}{R_p}\right)} - 1 \right) - \frac{N_p}{R_s}\left(\frac{V_d}{N_s}+\frac{R_s I_d}{R_p}\right), \qquad (2)$$

where $N_p$ and $N_s$ are, respectively, the number of the cells connected in parallel and in series, $I_{ph}$ – the photocurrent, $I_o$ – the diode saturation current, $V_d$ and $I_d$ are, respectively, the voltage and the current

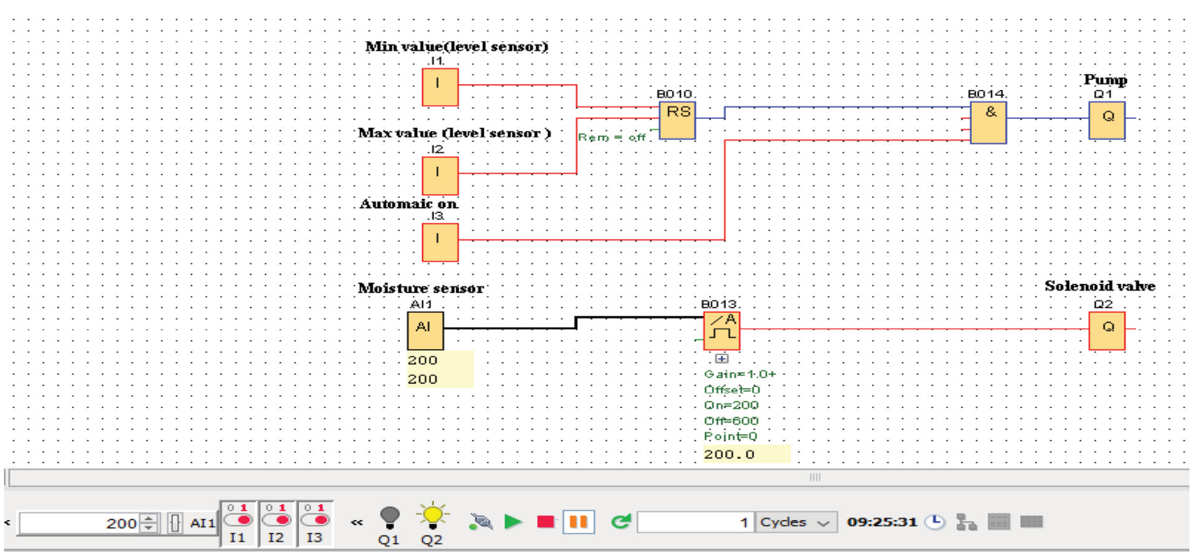


**Fig. 4.** Program with LOGO comfort v.8.0

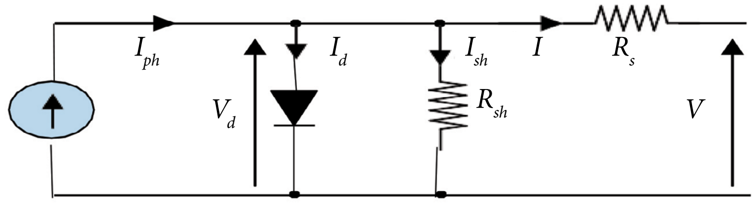


**Fig. 5.** Equivalent circuit of a PV solar cell

of the cell, $R_s$ and $R_p$ are, respectively, the series and parallel resistance of the cell, A is the ideality factor of the diode, $k = 1, 3805.10–38$ J/K is the Boltzmann constant, and T is the ambient temperature in °C.

**Influence of temperature**

As shown in Fig. 7, at constant irradiance (1000 W/m$^2$), temperature variation has a considerable impact on the characteristics of the solar panel. It

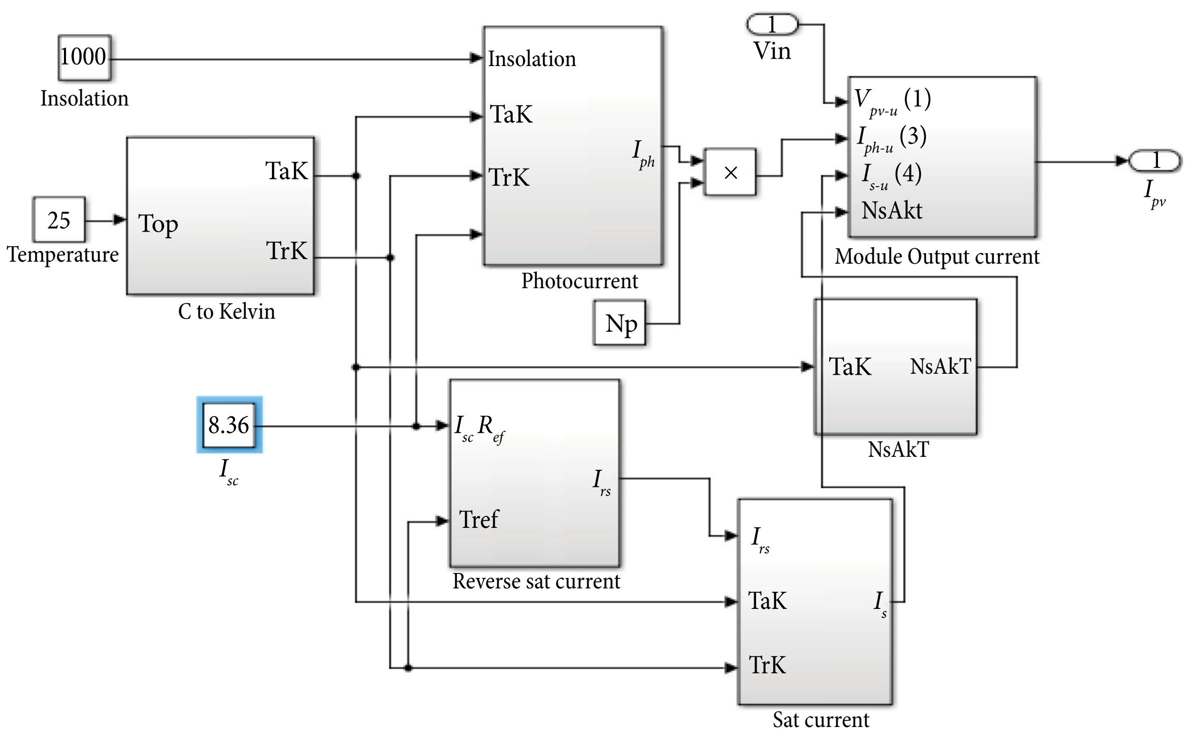


**Fig. 6.** Simulink model of the solar panel

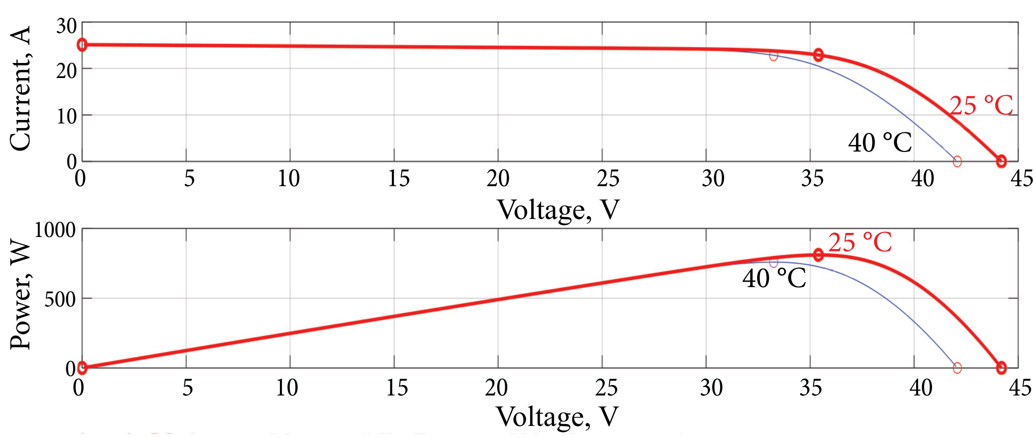


**Fig. 7.** I(V) and P(V) characteristics for a variable temperature and an illumination of 1 kW/m$^2$

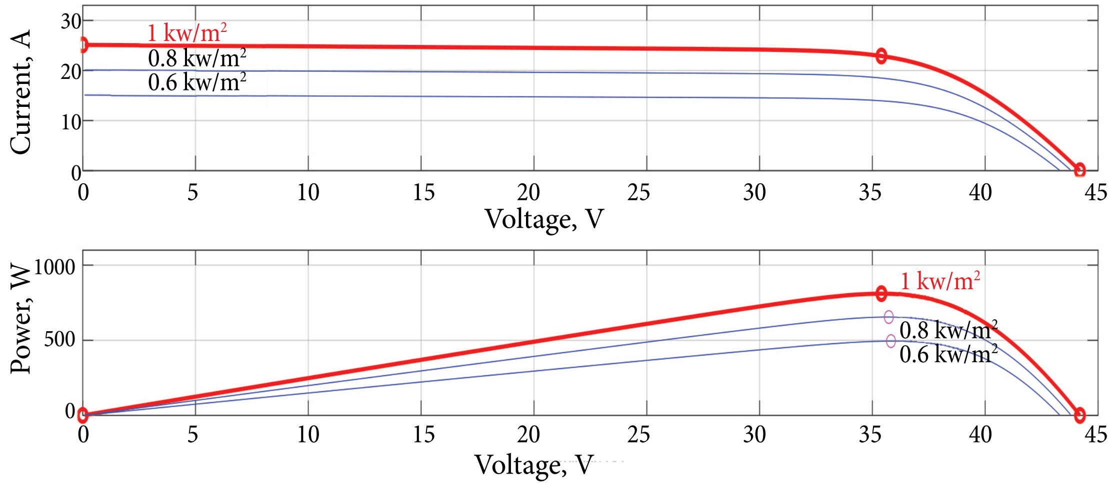


**Fig. 8.** I(V) and P(V) characteristics of a variable illumination and temperature of 25°C

is clear that an increase in temperature leads to the decrease in the voltage of the open circuit. The power output of *a* solar panel is also influenced by temperature. As the temperature rises, the power output decreases.

### Influence of irradiation

In the previous case, we maintained a constant temperature (25°C) at three different illuminations given in Fig. 8. We can clearly notice that the increase in the short-circuit current is more important than the increase in open circuit voltage and it can be observed that there is a proportional relation between the irradiation and the power output of a solar.

## CONTROL OF THE PROPOSED SYSTEM

In this research we used the P&O (perturb and observe) algorithm for power point tracking. Due to its simple structure on one hand, and the lack of parameters required for the algorithm, on the other hand, the method of perturbation and control is one of the most popular algorithms for tracking the maximum power point. This method finds the maximum capacity of the photovoltaic module through the average frequencies of the disturbances, monitoring, and comparing the generated power with the module's capacity. The chart of the P&O algorithm is shown in Fig. 9.

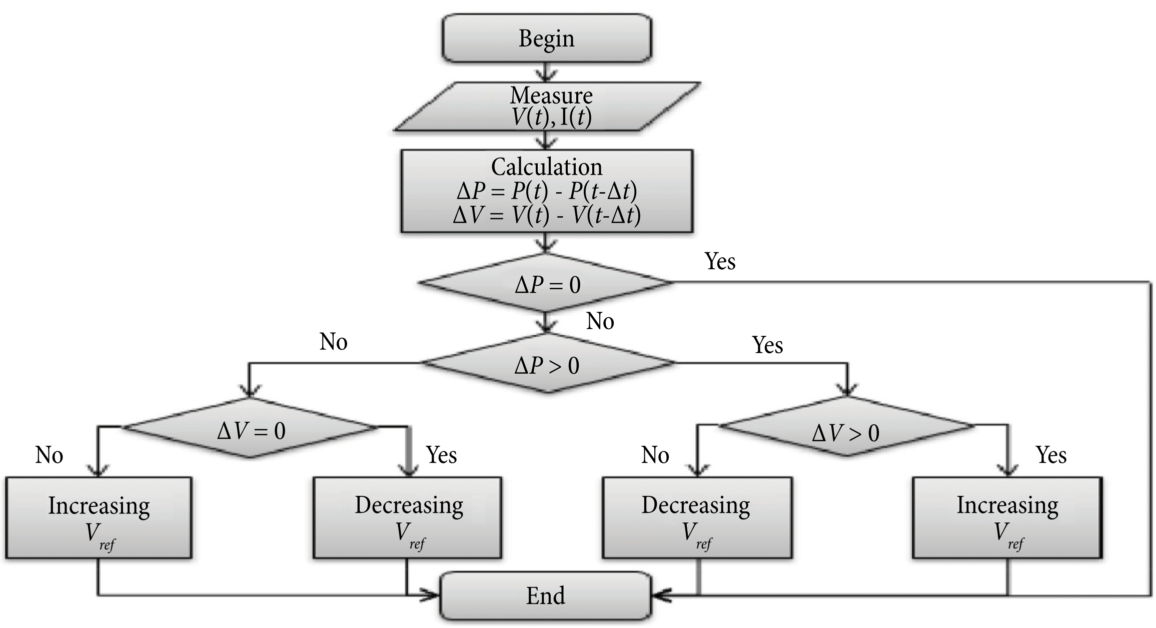


**Fig. 9.** The P&O algorithm

## DESIGN OF THE SOLAR PUMPING SYSTEM

To size a photovoltaic pumping system, we first need to choose an adequate pump that could reach the depth of our well and supply the required amount of water, Next, we need to calculate the peak power of the solar array, which depends on several factors, such as the volumetric flow rate of water, the total manometer head, and the average daily global irradiation.

The sizing of this system was performed by HOMER software (hybrid optimization and multiple energy resources) and manual calculation. Fig. 10 and the Table 8 show the global daily solar irradiance data for the selected site.

## CALCULATION OF THE PEAK PHOTOVOLTAIC POWER (PC)

The peak power ($P_c$) of the PV array can be expressed as follows:

$$P_c = \frac{2.725 \cdot Q \cdot h}{Ei \cdot n_{mp}}, \quad (3)$$

where $Q$ is the volumetric flow of water through the pump (33 $m^3$/day), $h$ is the total dynamic head (14 m), $Ei$ is the daily average global irradiation for each month (4.9 Wh/$m^2$/day).

Replacing all the parameters, we obtain the following result:

$$P_c = 546.65 \text{ watts} \quad (4)$$

In order to account for any potential power drop caused by hot temperatures, dirt, aging, cloud cover, or decreased insolation, several PV panel manufacturers advise increasing the minimum peak power value by 30%:

$$P_c = 546.65 \cdot 1.30 = 710.65 \text{ watts} \quad (5)$$

## CALCULATION OF THE TOTAL NUMBER OF MODULES

Equation 6 was used to determine the number of modules that constitute our solar generator:

$$N_m = \frac{P_c}{P_{pv}}, \quad (6)$$

where $P_{pv}$ is the nominal power of PV at standard test condition (STC) in (kW)

$$N_{pv} = \frac{710.65}{135} \simeq 6. \quad (7)$$

The number of solar panels required =135 W panel each ×6 panels =810 W, the number of

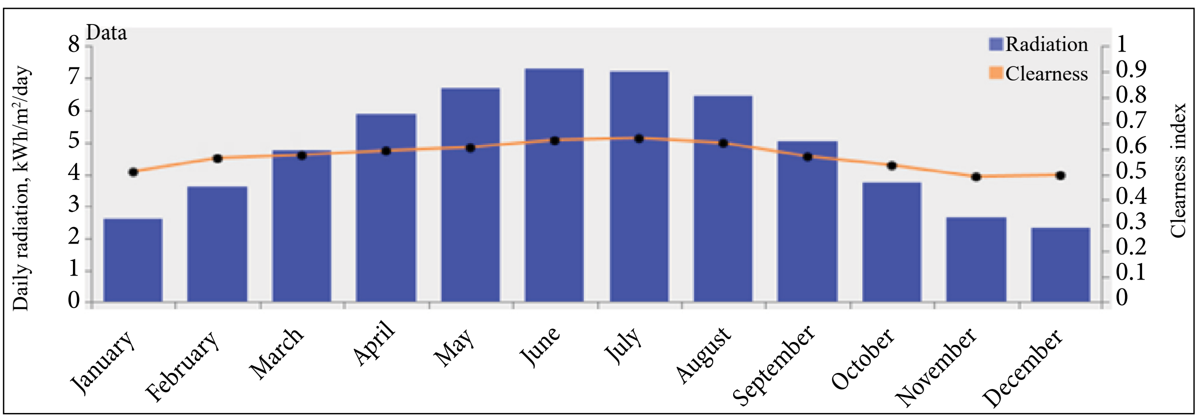


**Fig. 10.** Monthly solar energy

Table 8. **Monthly average global**

| Month | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Annual average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Daily radiation (kWh/$m^2$/day) | 2.610 | 3.620 | 4.730 | 5.88 | 6.690 | 7.270 | 7.210 | 6.420 | 5.010 | 3.720 | 2.650 | 2.340 | 4.85 |

series connected modules per strings is $N_s = 2$, and the number of parallels strings is $N_p = 3$.

## SIMULATION RESULTS

The program is simulated under MATLAB Simulink 2020a. The simulation results are given in order to check the PV system performances (Fig. 11):

The difference between the voltage and the output power of a boost chopper and those of the photovoltaic generator is showed in Figs 12 and 13. We suppose that we cannot reach the operating voltage 48 V of the pump until after

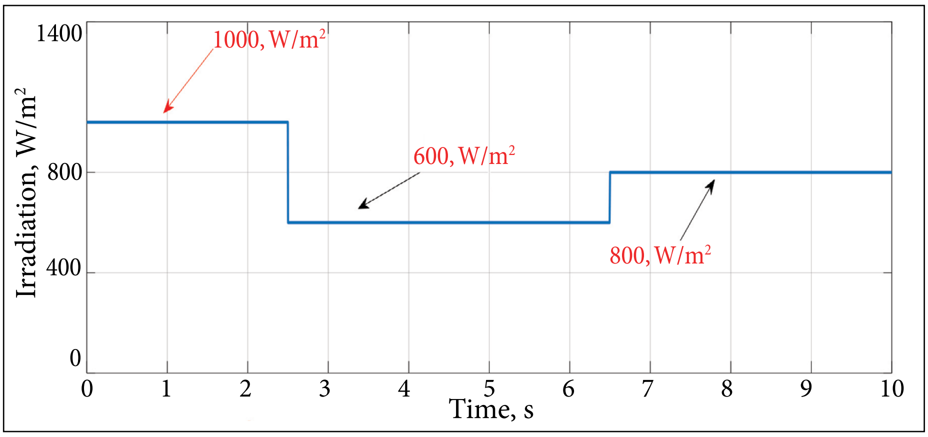


**Fig. 11.** Irradiation variations

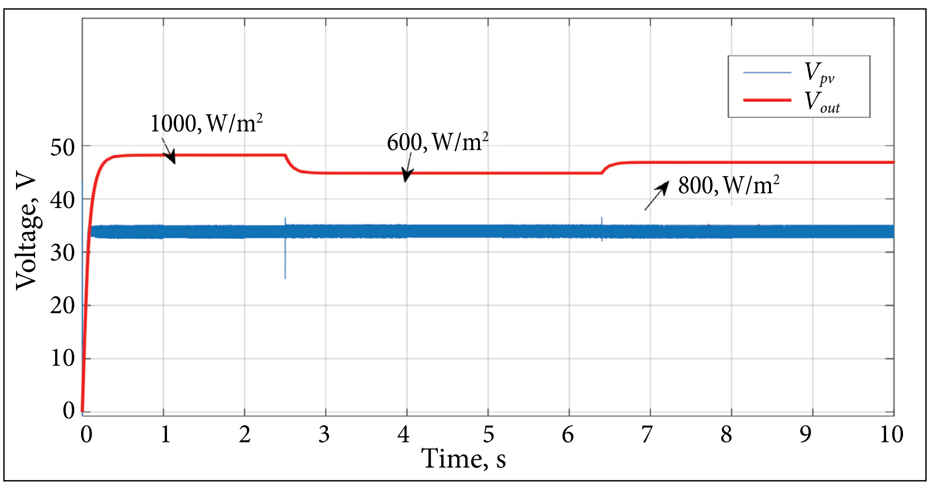


**Fig. 12.** Voltage variations

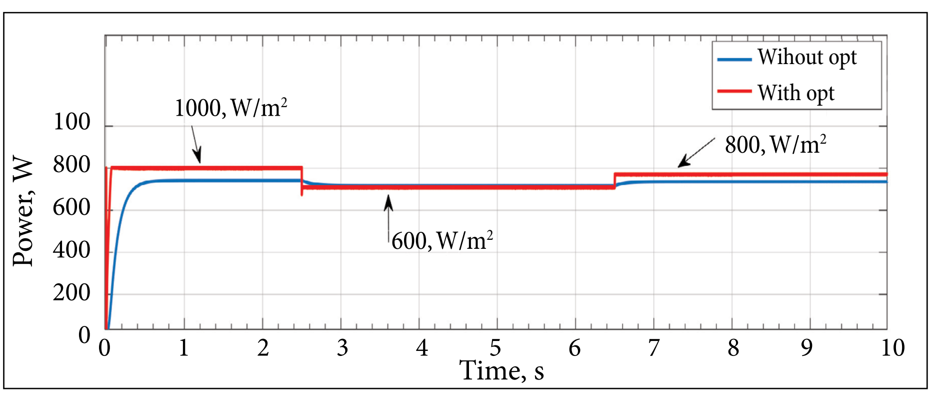


**Fig. 13.** Power variations

the use of the converter, which reflects the interest mainly served by the implementation of indirect coupling through a DC/DC converter (increased flexibility, improved efficiency, and enhanced solar pumping performance), which offers better adaptation to changes in irradiation and can provide **a** more stable power supply to the pump compared to a direct coupling, which is incapable of satisfying the voltage and power requirements of operation. Additionally, Fig. 14 shows

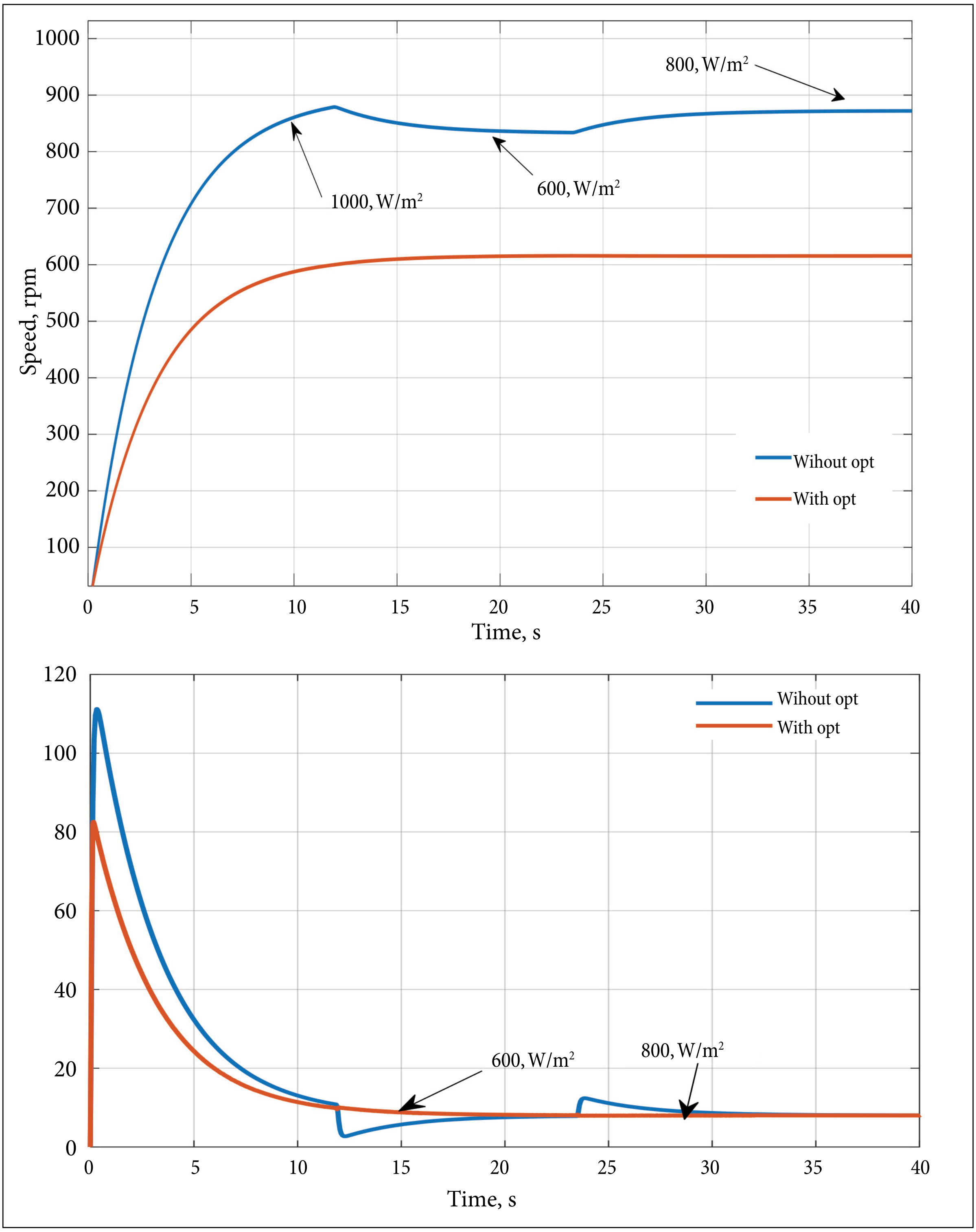


**Fig. 14.** Motor performances under variables illuminations with and without optimisation

the motor-pump speed and the motor-pump current, we can observe how the MPPT-controlled boost converters improve the performances of the motor.

## CONCLUSIONS

In order to obtain a good agricultural crop, this study discusses the design and optimization of an automatic solar irrigation system for one hectare of crops. Theoretical calculations and HOMER software were used to determine that a 710 W photovoltaic system with 6 × 135 W solar panels (3 parallel, 2 series) was needed to meet the water requirements of 33 m3/day. To optimize the power output of the panels, a boost converter controlled by a maximum power point tracker (MPPT) using the P&O algorithm was incorporated. Figures 13 and 14 demonstrate how this optimization improved the solar irrigation system's performance. Simulation results also showed that the optimal operating point responds to changing weather conditions like irradiation and temperature. Overall, careful sizing and integration of MPPT optimization enables the solar irrigation system to reliably meet water needs despite variable solar resources. Another goal of this study was to reduce water usage and prevent overwatering of plants while also minimizing human intervention. This was accomplished by implementing a PLC (programmable logic controller) system that collects sensor data to determine irrigation needs. A soil moisture sensor defines the water requirements of the plants. Based on this information, the PLC opens or closes a solenoid valve and activates or stops the water pump depending on the state of the water level sensor in the tank. The control program was simulated in Siemens LOGO comfort software and designed as a functional block diagram. By automating watering based on sensor feedback, the system can irrigate plants precisely as needed without human oversight or excess water use. The PLC-based control scheme allows responsive, optimized irrigation to be maintained.

Received 22 April 2023
Accepted 15 August 2023

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## AUTOMATIZUOTOS SAULĖS ENERGIJA GRINDŽIAMOS LAISTYMO SISTEMOS SU PROGRAMUOJAMU LOGINIU VALDIKLIU PROJEKTAVIMAS IR OPTIMIZAVIMAS

*Santrauka*

Drėkinimas yra svarbi žemės ūkio veikla. Norint gauti gerą žemės ūkio derlių, vanduo turi būti naudojamas protingai ir tinkamai. Šiame straipsnyje pristatyta autorių sukurta automatizuota saulės energija grindžiama laistymo sistema, susidedanti iš dviejų komponentų: fotovoltinio vandens siurbimo įrenginio ir valdymo bloko su programuojamu loginiu valdikliu. Programuojamame loginiame valdiklyje (PLC) naudojami du jutikliai: vienas įrengiamas lauke dirvožemio drėgmei matuoti, antrasis – vandens kiekiui saugykloje valdyti. Fotovoltinė siurbimo sistema sukurta taip, kad būtų galima drėkinti heninės lavsonijos (*Lawsonia inermis* L.) 1 ha plotą, kurio vandens poreikis yra 33 $m^3$/para, bendras dinaminis aukštis – 14 m. Šiam tyrimui ir analizei pasirinktas regionas yra Zeribet al Vedo mieste Biskros provincijoje, Alžyre (koordinatės – 34°41,1' šiaurės platumos ir 6°29,6' ilgumos).

**Raktažodžiai:** saulės siurbimo sistema, automatinis laistymas, programuojamas loginis valdiklis