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SOFTWARE DESIGN FOR SIMULATION AND MANAGEMENT OF SOLAR-POWERED IRRIGATION PUMPING SYSTEMS

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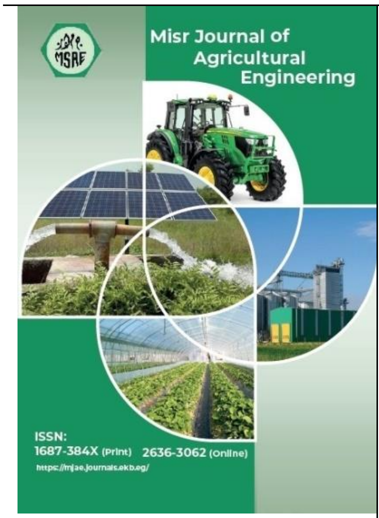


Keywords:
Solar-powered pumping;
Irrigation management;
Simulation software;
Water demand.

ABSTRACT

Despite the increasing use of solar-powered pumping systems in agriculture, particularly in dry areas where effective irrigation water management is crucial, such as Egypt, remains a lack of user-friendly software tools tailored to local conditions to aid in simulation, planning, and management. To address this issue, this research develops a simulation-based software tool called Solar-Powered Pumping System Software (SPPS) for solar-powered pumping systems utilized in farming. This tool efficiently meets agricultural energy demands, while minimizing greenhouse gas emissions and promoting sustainable farming practices. It offers a simple interface where users can enter system details, design it, and simulate how it will work under different weather and usage situations. The software combines technical, environmental, and management aspects to support decision-makers in planning and managing water efficiently. It uses a model of solar energy, irrigation demand, and pump performance to simulate real conditions and find the best system setups and operation plans. The simulation results of the SPPS were validated against experimental data collected from a tomato crop cultivated inside the greenhouse under a drip irrigation system at the Nuclear Research Center's Experimental Farm in Inshas city, Atomic Energy Authority, Sharkia Governorate, Egypt. The results showed a strong correlation of approximately 90% between the simulated and actual system performance. This research highlights the potential of integrating renewable energy into irrigation systems to enhance sustainability, especially in regions facing water scarcity or unreliable electricity. Efficient system design, correct PV panel alignment, and real-time monitoring are crucial to maximizing energy use and irrigation performance.

INTRODUCTION

In regions facing prolonged drought and unstable electricity supplies, solar-powered pumping systems (SPS) have emerged as a promising solution for securing sustainable agricultural production. These systems leverage renewable solar energy to power water pumps, offering an environmentally friendly alternative to fossil fuel-based irrigation methods.

However, the global adoption of SPIS has been limited by insufficient knowledge regarding their physical behavior, management, and performance optimization. Advanced modeling techniques, such as neutron scattering, provide valuable insights into the hydraulic dynamics of these systems. As noted by **Fragueyro (2024).**

Conventional irrigation methods often result in significant water loss and are heavily dependent on non-renewable energy, particularly in remote rural areas **(Quimbeta et al., 2022).** Amid growing concerns over global water scarcity and its impact on food security, automated smart irrigation technologies have been developed to optimize water use. These systems utilize meteorological data, such as evapotranspiration rates, rainfall, and temperature to inform control strategies and enhance irrigation efficiency. The architecture and performance of solar PV systems are crucial to SPIS effectiveness. PV arrays were formed by connecting modules in series and parallel to achieve the desired power output **(Yağan, 2018).** Key components of an SPIS include photovoltaic panels, inverters, and variable-speed pumps, all of which must be carefully selected and sized based on local solar radiation and system demands **(Ibrahim et al., 2018).** The efficiency of such systems depends not only on solar cell characteristics and environmental conditions but also on proper system design and energy storage **(Al-Shawabkeh et al., 2017).** The focus is on creating solar-powered water pumps that are particularly effective in desert or rural areas where conventional electricity is often unavailable. Solar energy is a clean, non-polluting, and inexhaustible source of power, making it ideal for remote locations **(Kumar et al., 2023)**. Photovoltaic (PV) pumping systems can significantly reduce operational costs over time compared to traditional diesel generators, which are initially cheaper but become more expensive due to fuel and maintenance costs **(Zegait et al., 2022).** Additionally, solar pumps can enhance water accessibility for domestic use, irrigation, and livestock management, thereby improving living conditions in arid and semi-arid regions **(Ksentini, et al., 2019).**

Several studies highlight the growing relevance of SPIS in addressing the global energy crisis, environmental degradation, and rural development challenges. In off-grid areas, particularly, PV-powered water pumps offer a cost-effective and sustainable irrigation option **(Chikaire et al., 2010)**. As countries expand their renewable energy strategies **(Owusu and Asumadu-Sarkodie, 2016; Gielen, 2019)**, solar-powered irrigation stands out as a critical tool for achieving agricultural resilience and energy sustainability. Therefore, this research aimed to (1) Design efficient and sustainable solar-powered water pumps, especially in desert or rural areas, (2) Model and optimize the solar pumping systems.

MATERIAL AND METHODS

2.1 Study Location:

The experimental study was conducted at the Experimental Farm of the Soil and Water Research Department, Nuclear Research Center, located at Inshas city of Atomic Energy Authority, Sharkia Governorate, Egypt as shown in Figure (1), during the period from October 2022 to June 2023. The Latitude and Longitude of the experiment site (30 º 24 N, and 31 º 35 E), respectively and the altitude is 20 m. The site is located in a semi-arid region and was selected due to its typical climatic and agricultural conditions, representing the challenges of solar-powered irrigation in arid zones. It did not present trees or structures that could shade the photovoltaic cells, damaging the performance. There was a greater concern about the positioning of the panels and their alignment with the geographical north because their incorrect positioning can lead to a decrease in the efficiency of the photovoltaic system.

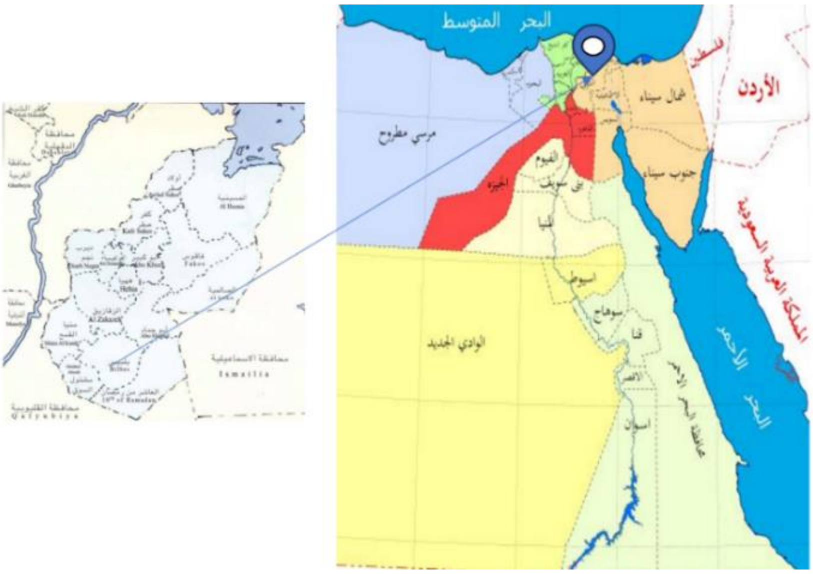


Fig. 1: Location of the Experimental Farm at Inshas, Sharkia Governorate, Egypt.

2.2 System Component:

The solar-powered pumping system (SPPS) consisted of the following main components:

2.2.1. Photovoltaic System Description:

A photovoltaic (PV) system was implemented, consisting of one module consisting of 18 panels with a tilt angle of 30º from the horizontal as shown in Figure (2a). The system passed through four stages: the first stage: generate “DC” power from PV cells, the second stage: convert “DC” power to the “AC” power using inverter, the third stage: convert “AC” power to mechanical power using the “AC" motor and the fourth stage: convert mechanical power to hydraulic power using submersible pump. Panels were connected in series to generate power for running the “AC” motor pump as shown in Figure (2b) and all the solar panels are of the same type and power rating.

Fig. 2: (a) Panel’s module with tilt angle, (b) Panel’s module connection.

The single PV produces a 38.5-V and 9.35 A as presented in Table (1); therefore, the array will produce an output voltage of 693 V (38.5+38.5+……+38.5) at 9.35 A, giving 6,479.55 W (volts x amps) at full sun.

Table 1: Specifications of the PV module.

Standard Test Condition (STC)	Irradiance 1000W/m², Air Mass 1.5gram, 25°C
Maximum power	280W
Maximum power current	8.95 A
Maximum power voltage	31.3V
Short circuit current	9.35A
Open circuit voltage	38.5V
Maximum System voltage	DC 1000V
Nominal operating cell temperature	45±2°C
Frame dimensions	1650x992x35mm
NET weight	18Kg

2.2.2. Drip Irrigation System:

A drip irrigation system was installed to irrigate 5 greenhouses; the area of each one was (40*9 m^2). Irrigation net consists of the following components:

- Main line is a UPVC pipe of (90 mm) outer diameter, 76.5m length for delivering water from the submersible pump to the later line.

- Sub-main line is an HDPE pipe (50 mm) in outer diameter.

- Laterals are PE tube (16 mm) diameter, the spacing between lines is 50 cm (two drip lines for each row of plants), and the spacing between each row is 100 cm.

- Drippers are built-in drippers (4 l/h discharge at 1.0 bar operating pressure with a spacing between drippers of 50 cm). The layout of the drip irrigation system is shown in Figure (3).

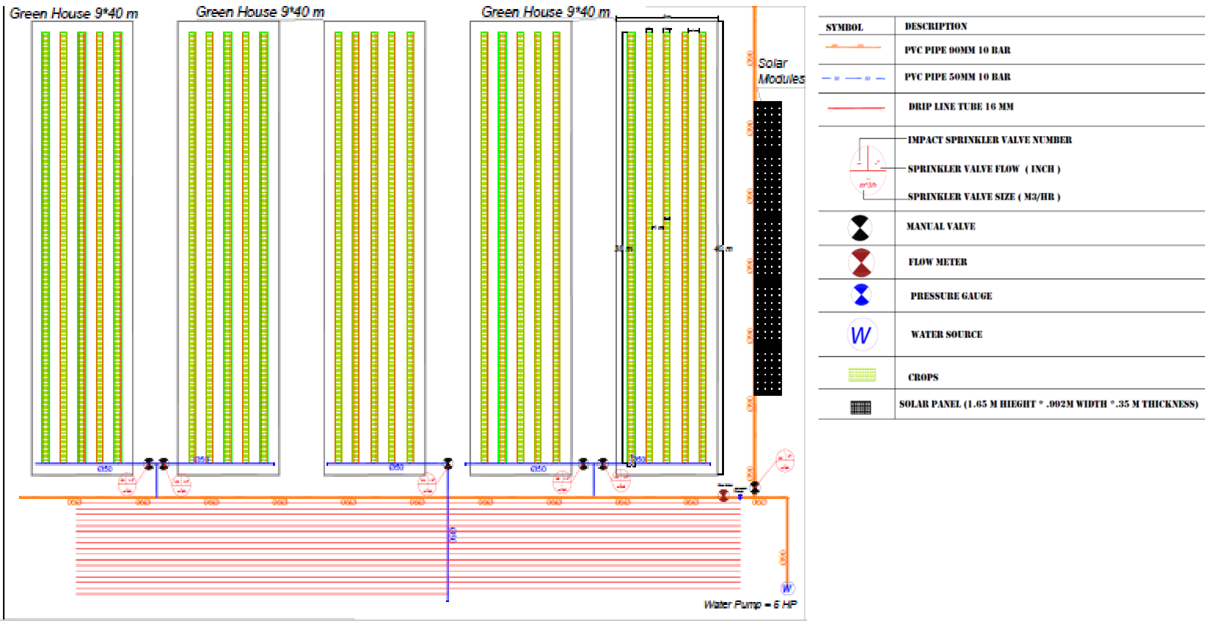


Fig. 3: Layout of drip irrigation system.

2.2.3. Submersible Pump Unit:

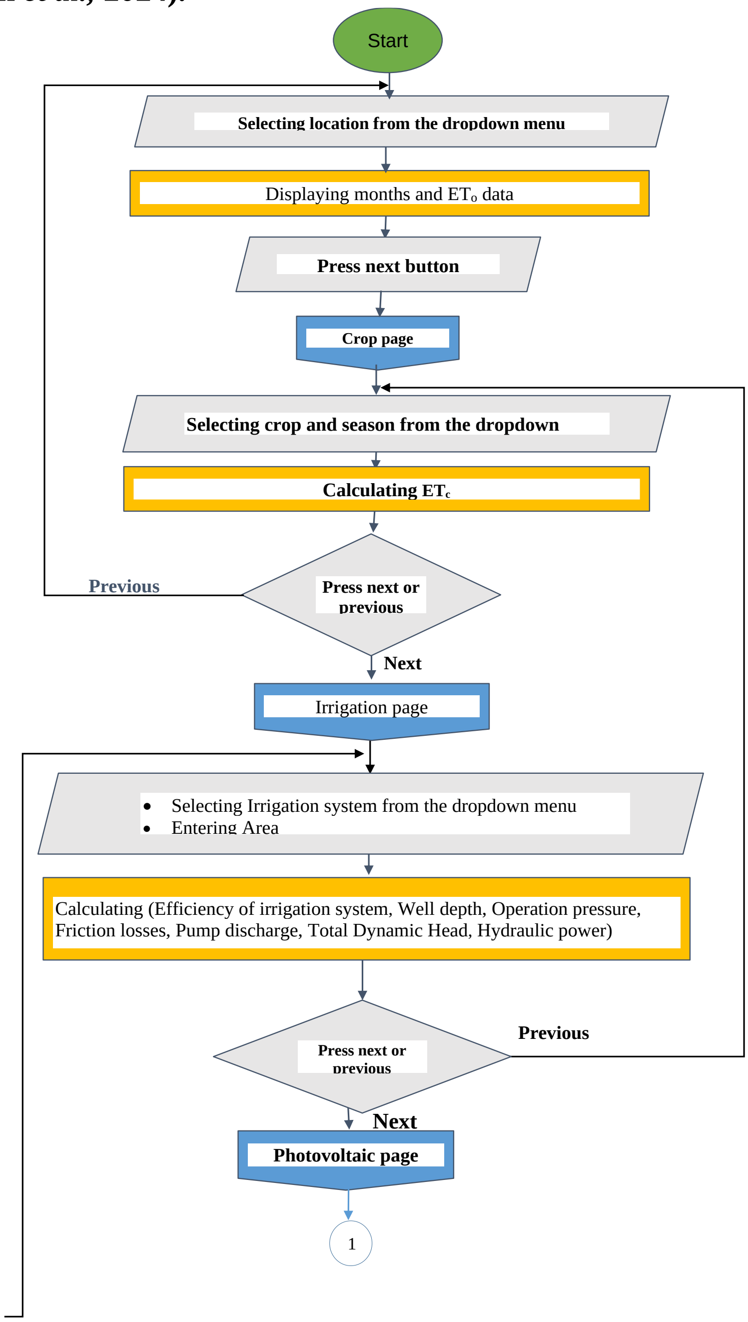
The pump was installed to lift the water from a well and deliver it to a drip irrigation system with specifications as shown in Table (2). Pump selection and pump size can be calculated based on these factors: pump flow rate (m^3/day), pumping head (m), water source (surface or submersible) and different manufacturers' available manuals (**Ibrahim *et al*., 2018).**

Table 2: Specifications of the submersible pump

Pump type	Stages	Motor		Current	Discharge	Head
		kW	HP	(A)	(m^3/h)	(m)
VPP 0604/05	5	4	5.5	10.2	5	69

2.3. Software Flow-Chart of SPPS:

Flowcharts offer a visual representation of information that acts as cues for recalling knowledge, thereby enhancing academic performance, as shown in Figure (4). As an instructional tool, flowcharts facilitate content integration by clearly connecting prior knowledge with new information, making learning more coherent and accessible. (**Zimmermann *et al*., 2024).**



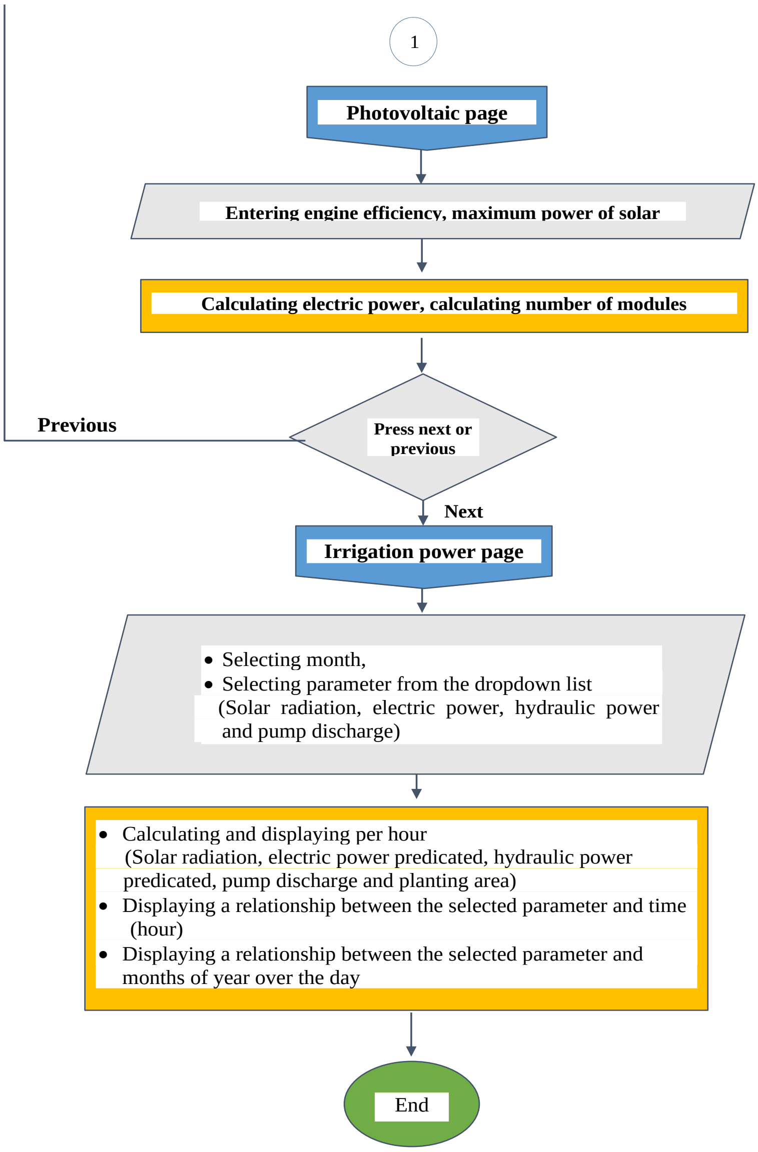


Fig. 4: Flow-chart of solar-powered pumping system software (SPPS).

A simulation-based software tool, named the Solar-Powered Pumping System Software (SPPS) was developed to model system behavior under various environmental and operational conditions. The software allows users to input local solar data, location, reference evaporation data, crop data, and irrigation requirements to simulate:

- Solar energy generation
- Water demand and irrigation scheduling
- Pump performance and power consumption

The main program interface of the climate and crop data (SPPS) model are shown in Figures (5 and 6). Simulation models were based on standard PV performance equations, crop water demand estimations using local evapotranspiration data, and empirical pump performance curves.

The Penman-Monteith model was used to assess water needs during different tomato growth stages (initial, development, middle, and late**)** according to **(Kaunkid *et al*., 2023).**

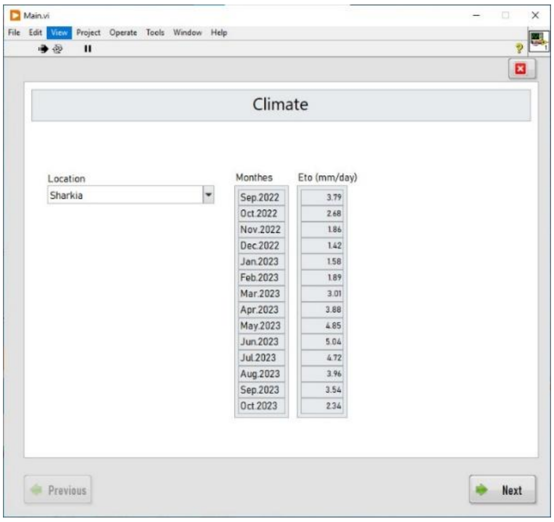


Fig. 5: The main program interface of the climate data (SPPS) model; source: own elaboration

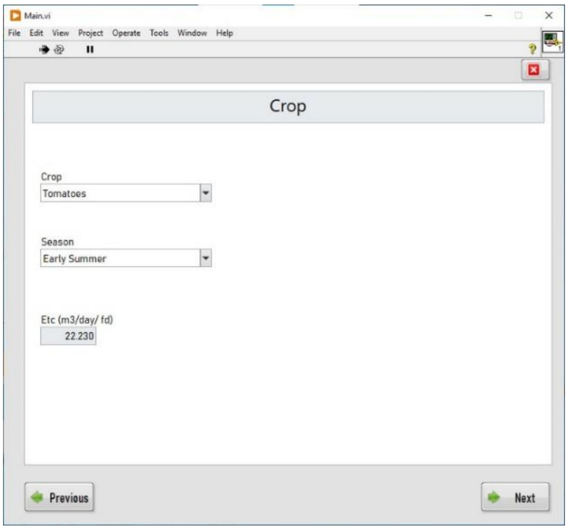


Fig. 6: The main program interface of crop data (SPPS) model; source: own elaboration

2.4. Data Collection and Validation:

Real-time monitoring was conducted throughout the growing season. Data collected included:

Solar radiation intensity (W/m²), DC voltage (V) and current (A), AC power output (W), Water flow rate (l/h), and System pressure (bar).

These data were compared to the simulation outputs from SPPS. A statistical analysis was conducted to evaluate the correlation between real-world data and simulation results. The SPPS data were applied to a greenhouse drip irrigation system for tomato cultivation at the Experimental farm of the Soil and Water Research Department, Nuclear Research Center, located at Inshas city Atomic Energy Authority, Sharkia Governorate, Egypt. Through field testing and simulations, the system proved to be reliable and efficient in meeting the water needs of the crop. The software was also tested and confirmed using real field data collected during different seasons.

2.5. System Design Equations:

2.5.1. Pumping Energy Requirements:

The energy requirements of a pump (P) are the energy needed to lift water to a certain height with system efficiency. This is determined from (**White, 2011).**

$$P = (\rho * g * Q * H) / 1000, \eta \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}.$$

where: (P) is pump power in kW, (ρ) is density of the fluid (kg/m³), (g) is acceleration due to gravity (9.81 m/s²), (Q) is volumetric flow rate (m³/s), (H) is total head or differential head (m), and (η)is efficiency of the system (%).

Total head (Ht) consists of four main components according to (**Chikuni ,2012)**:

- A dynamic head (Hd), it is known that when pumping action occurs, the water level drops and after several hours stabilizes. The level in these stabilized circumstances is called the dynamic head.
- A head due to the elevation of the delivery pipes from the ground (He)

- A head due to friction losses (Hf)
- A velocity head (Hv)

The sum of the above is the total head **(Chikuni, 2012).**

$$Ht = Hd + He + Hf + Hv \quad \text{.................................(2).}$$

where:

(Ht) is total dynamic head (m), (Hd) is dynamic head (m), (He) is elevation head (m), (Hf) is friction losses (m), and (Hv) is velocity head (m).

The Darcy's Equation is a fluid dynamics equation that attempts to predict energy loss during fluid flows in pipes, considering the velocity of flow and frictional resistance. For turbulent flow through a circular pipe, the following flow is used **(Chikuni, 2012).**

$$Hf = f\,\frac{v2}{2g} * \frac{l}{d} \quad \text{.................................... (3)}$$

where:
(Hf) is friction losses, (m), (v) means velocity of fluid (m/s), (f) is friction factor, (l) is length of pipe (m), and (d) is pipe diameter (m).

2.5.2. Sizing of PV array:
The PV array size must be related to the pump requirements. However, we need to acknowledge the depreciation of the panel due to ageing and environmental factors (dust, etc.). If a depreciation of 30 percent is allowed for **(Chikuni, 2012).**

$$P\,(Array) = P\,(kW)\,(1.2) \quad \text{............................ (4)}$$

The required photovoltaic module power (W), to meet the electric load demand, can be estimated as follows (**Ibrahim *et al.*., 2018).**

$$P_{pv} = A_{pv} \times Hsc \times \eta_{pv} \quad \text{..................(5)}$$

where:
(P_{pv}) is the photovoltaic module's power (W), (H_{sc}) is the standard solar irradiation (1,000 W/m^2), (A_{pv}) is the total area of PV panels (m^2), and (η_{pv}) is the photovoltaic efficiency (%).

The number of total modules (Nm) can be determined based on the commercially available area of a single PV panel. The number of modules can be defined as follows **(Ibrahim et al.., 2018)**.

$$N_m = \frac{P_{PV}}{P_m} \quad \text{..........................(6).}$$

where: (N_m) is the number of total modules (No.), (P_{pv}) is the Photovoltaic modules power (W), and (P_m) is the power of the single module (W).
To calculate the actual area of all modules and the exact peak power for the total modules, use the following equation **(Ibrahim et al.., 2018):**

$$A_t = N_m \times A_m \quad \text{....................................(7).}$$

where: (A_m) is area of the single module (m^2), and (N'_m) is the corrected number of modules is to the nearest integer.

2.5.3. Hydraulic Power:

Another calculator that several variables were measured when the system was operating for collecting these data: water flow rate and pressure at the pump output, instantaneous irradiation level, and panel output. **Eqs. (8 and 9)** used to determine the solar panel power rating and hydraulic power **(Farag et al., 2008).**

$$P_{output} = Voc \text{ x } I\ sc \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (8).$$

$$\eta_s = P_{hyd} * P_{output} \ *100 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (9).$$

where:

(P_{output}) is PV panel output power (kW), (Isc) is panel output current (short circuit) at (A), (V) is panel output voltage (open circuit) at (V), and (η_s) is efficiency of the pumping system (%), P_{hyd} is hydraulic power (kW).

RESULTS AND DISCUSSION

3.1. Performance of solar pumps:

Variations in discharge and pressure of solar pump with solar radiation at different times of the day was tested in the Experimental Farm at Inshas, and presented in Figures (7a, b, c and d).

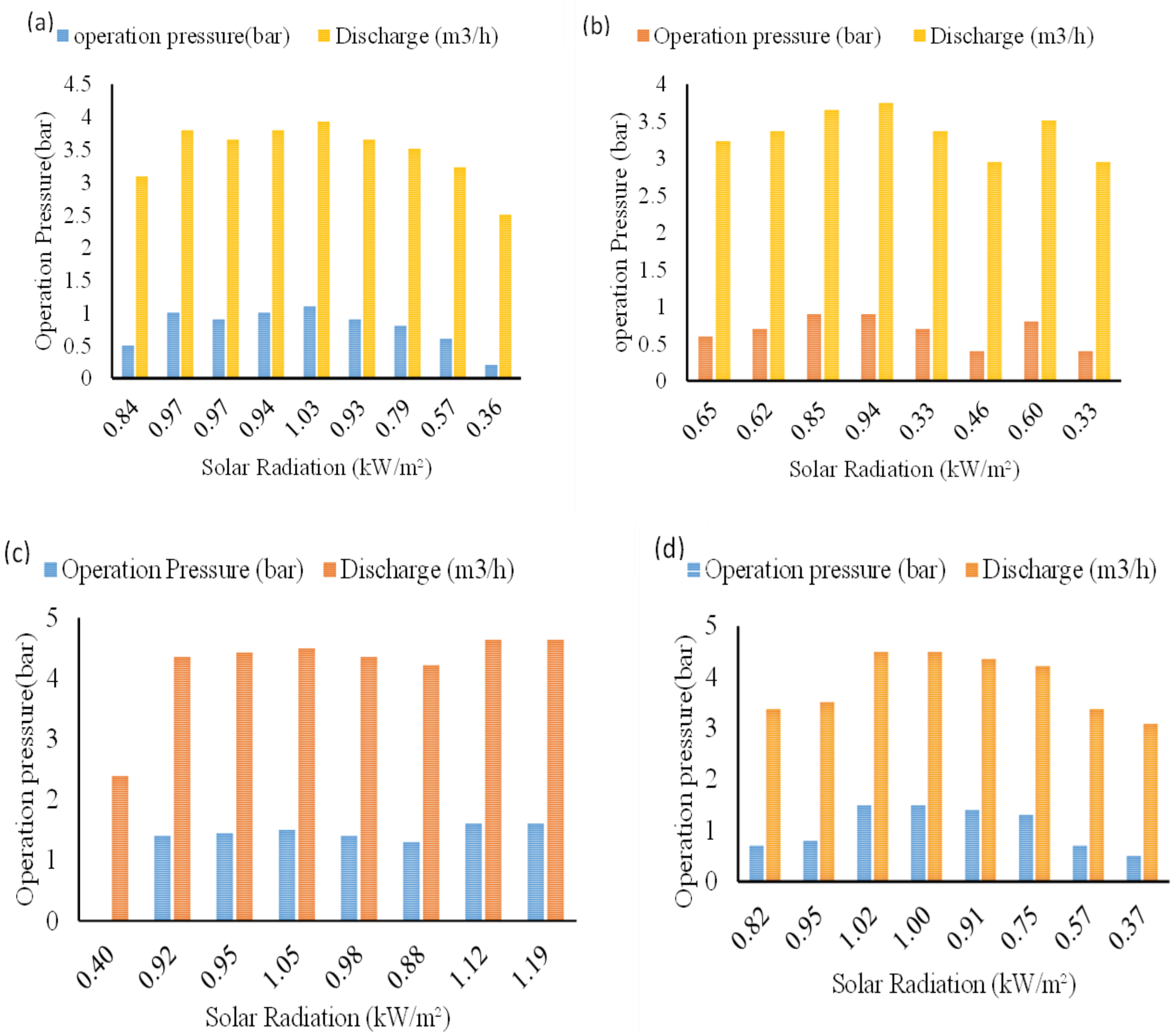


Fig.7c: The variation of discharge and operation pressure with solar radiation in (a) Autumn season, (b) winter season, (c) Spring season and (d) Summer season

The test was conducted from January 2022 to January 2023 from dawn to dusk. It is observed from the figure that solar pumps cannot lift any water at low solar radiation levels (<200 W/m²). Discharge increased with the increase in solar radiation, reaching a peak at noon and then decreasing gradually as solar radiation decreased during the testing period. Solar pumps require a minimum level of solar radiation to operate effectively. For instance, a PV-powered water pumping unit started flow at a solar radiation intensity of 100 W/m² and became smooth at 650 W/m² (**Munir et. al. 2012)**. This aligns with the observation that the pumps could not lift water below 200 W/m².

3.2. Emitter Flow Rate:

The pump was tested during the period from 9:00 am to 5:00 pm. Figure (8) shows that the highest emitters flow rate was 2.76 l/h for each emitter at 1:00 pm when the maximum AC was recorded as 8.1 A. indicates optimal performance during this period. The design flow rate can be estimated by dividing the total crop water requirement by the average number of effective sunshine hours (Abd Allah et al., 2019) It is worth noting that the maximum daily water requirement for tomatoes was 22.23 m³ per day per feddan, with an average peak hourly requirement of 3.7 m³/h**.** Based on the site-specific climatic conditions, the peak solar energy availability was estimated at approximately 6 hours per day.

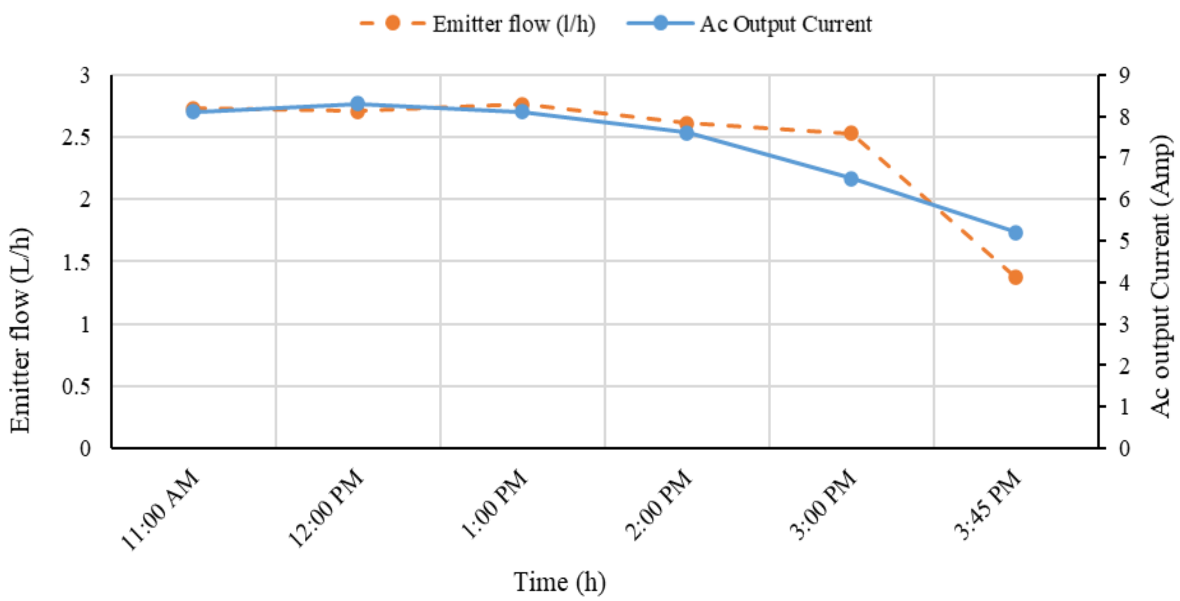


Fig. 8: Variation of emitter flow rate with AC at different times of day in October (average)

3.3. Operating Pressure:

The pump was tested during the period from 9:00 am to 5:00 pm. Figure (9) shows that the highest pressure of the pump was 1.1 bar at noon when the maximum solar radiation was recorded as 1.026 kW/m^2**.** The peak performance at noon aligns with the maximum solar radiation, which is typically around midday. This pattern is supported by studies showing that solar irradiance peaks around noon, significantly impacting the efficiency and output of solar-powered systems **(Yong, et. al.2022) (Ahmed, et al.2023).**

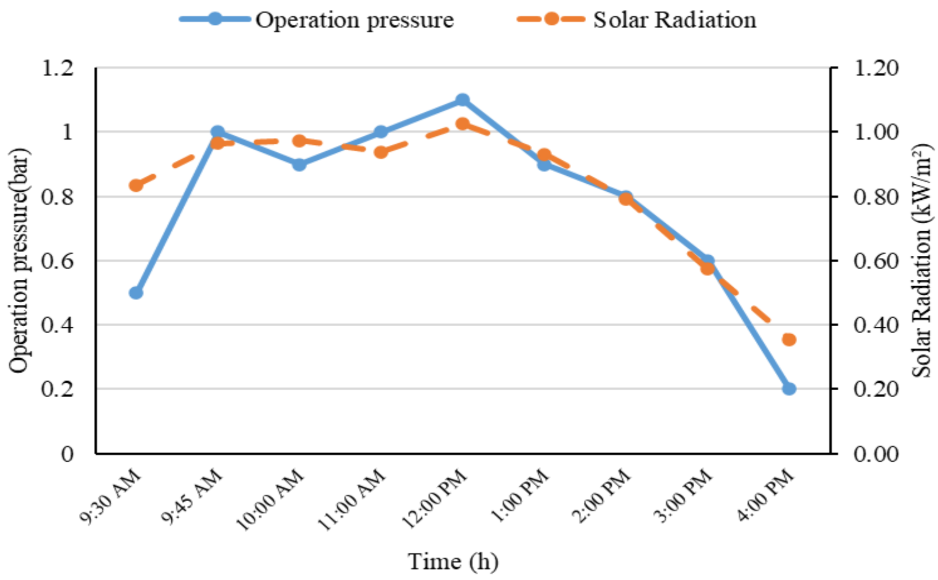


Fig. 9: Variation of pressure with solar radiation at different times of day in October (average).

3.4. Solar Radiation:

The results presented indicate a clear relationship between solar radiation and the performance of the solar energy system, as shown in Figure (10). The peak solar radiation value recorded was 1.026 kW/m² at noon, coinciding with the maximum alternating current (AC) of 8.3 A. This observation aligns with the expected behavior of solar panels, where solar radiation is typically high during midday, leading to increased energy generation.

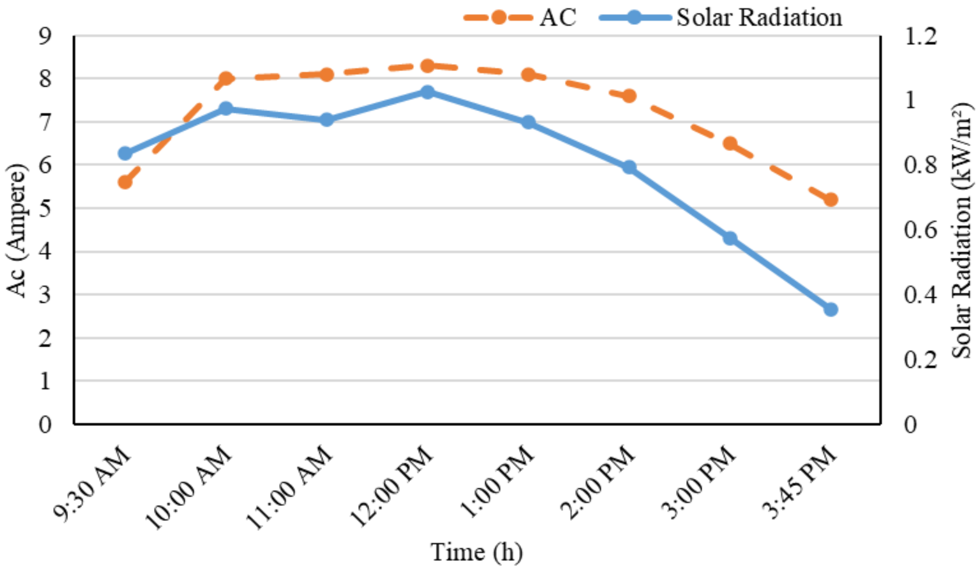


Fig.10: Variation of solar radiation with (AC) Current at different times of the day in October (average).

3.5. Electric Power:

Figures (11 and 12) show that **t**he highest value of electrical power and discharge was 5.13 kW and 7 m^3/h, respectively at 11:00 am in Autumn. The peak values observed at 11:00 am suggest a strong correlation with solar energy availability, as this time typically coincides with high solar irradiance, especially in Autumn when the sun is lower in the sky but still provides substantial energy.

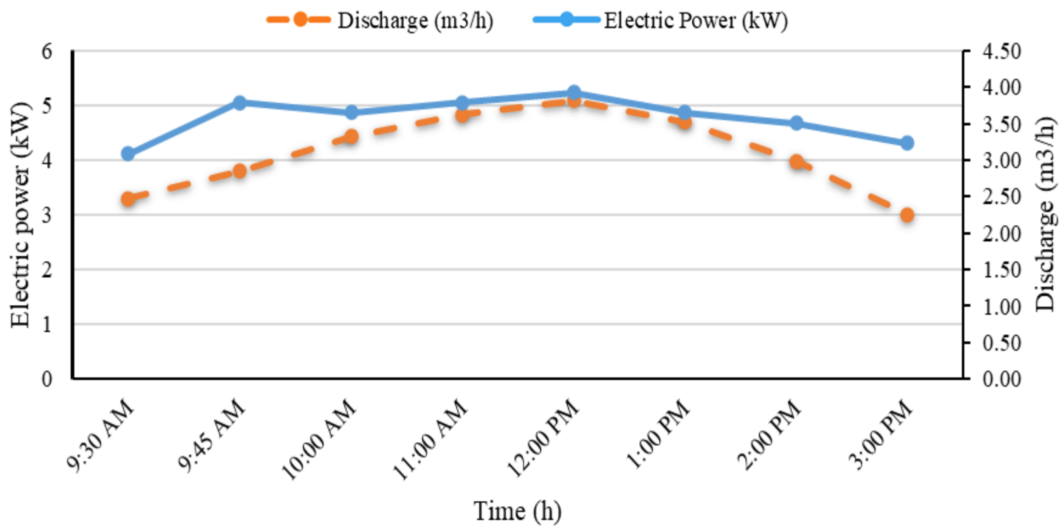


Fig.11: The average Electric power and discharge during the day.

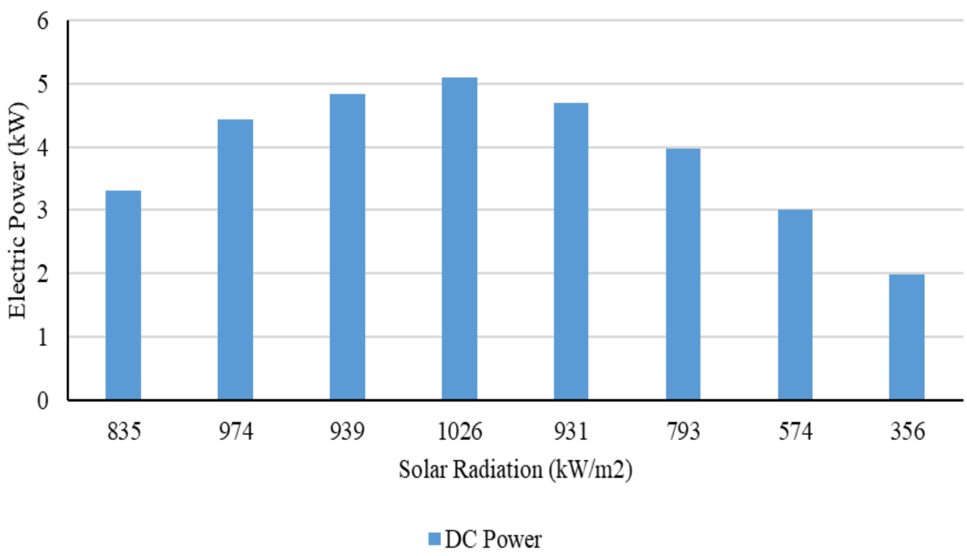


Fig.12: The variation of Electric power with solar radiation.

3.6. Data of SPPS Model Simulation:

The software model of solar energy generation, water demand, and pump performance across varying climatic and operational conditions. Data are illustrated in Figures (13a, b, c, and d) show that the SPPS software interface for variation of hydraulic power over time during the day in January, March, June and October months, 2023. Meanwhile, the SPPS software interface for variation of pump discharge over time during the day at the same month of the year is shown in Figures (14a, b, c, and d).

Data presented in Figure (15) shows that the model successfully predicted:

- Peak water discharge was (0.782 m^3/h) at noon, aligning with observed field data. This suggests that the model accurately captures the diurnal variation in solar irradiance and its impact on water discharge rates. The alignment with field data enhances the credibility of the model's predictions **(Gutierrez, et al., 2021).**

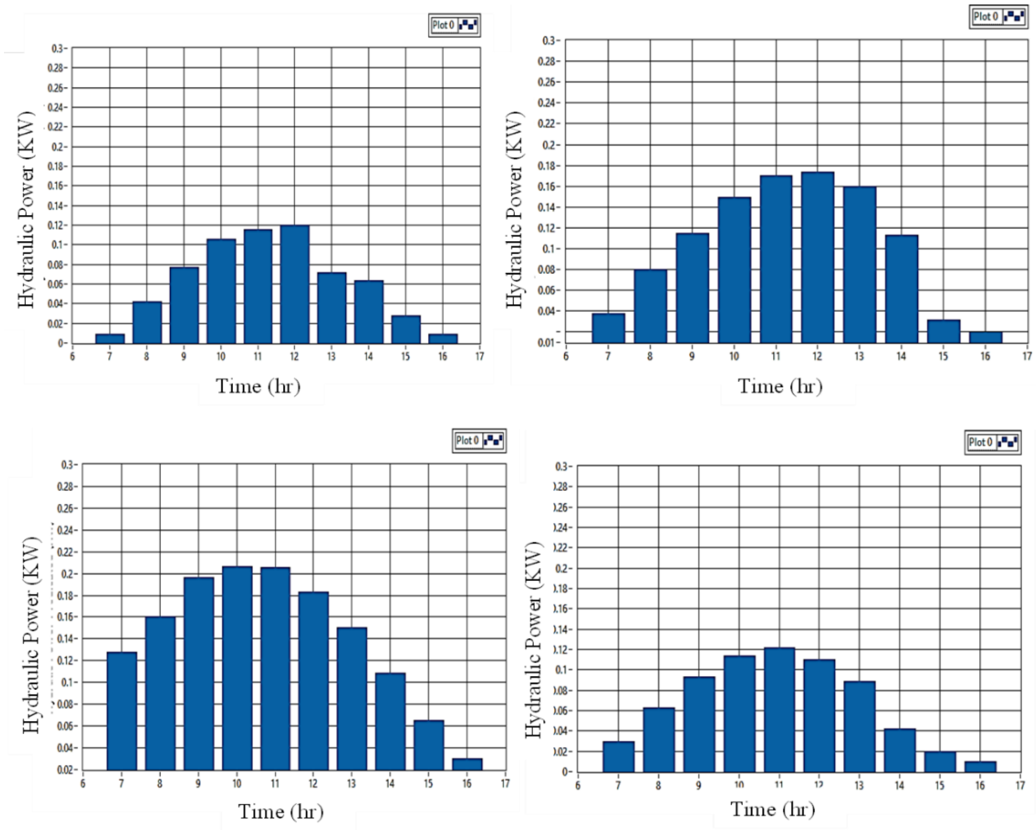


Fig.13 Hydraulic power variation throughout the day during different months using SPSS software interface for (a) January 2023, (b) March 2023, (c) May 2023, and (d) October 2023. Source: Author's own elaboration

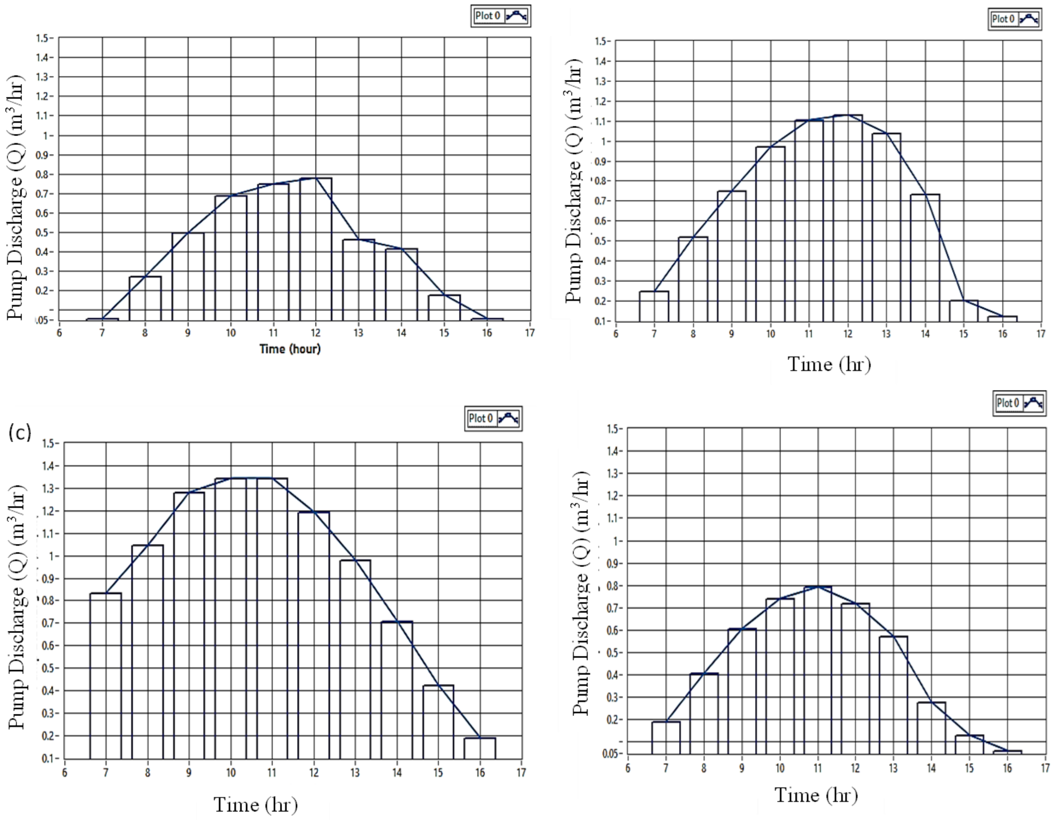


Fig.14: Daily variation of pump discharge across different months using SPSS: (a) Jan 2023, (b) Mar 2023, (c) May 2023, (d) Oct 2023. Source: Author's own elaboration

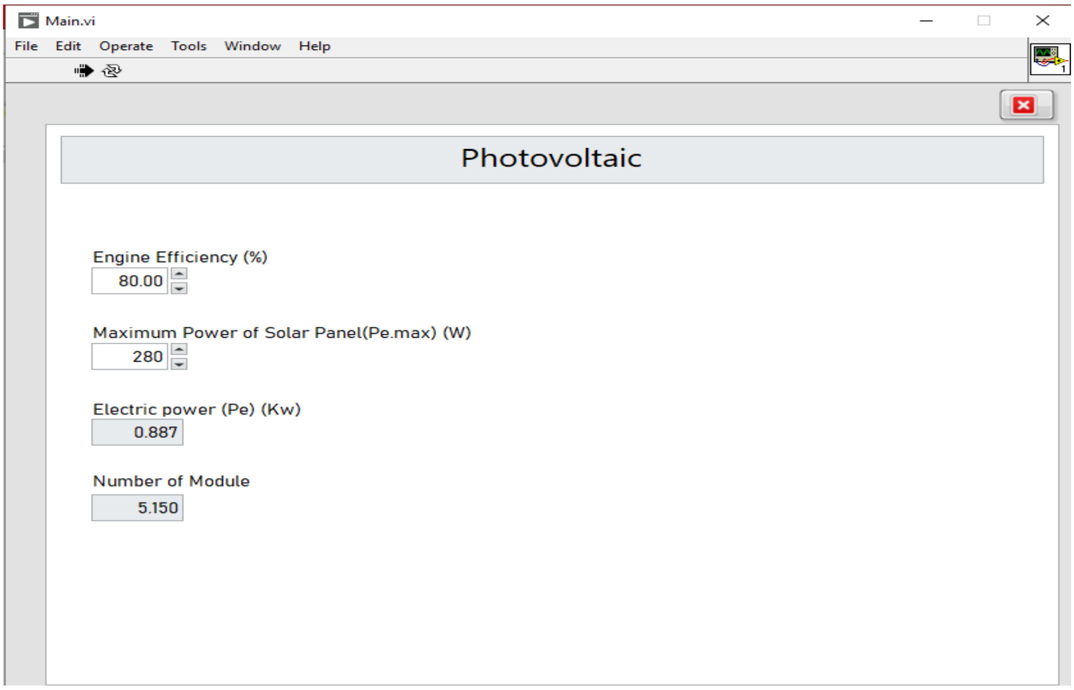


Fig. 15: SPPS simulation results of discharge, hydraulic power, planting area and power output across different hours of the day (October 2023).; Source: own elaboration.

- Maximum system hydraulic power was (0.12 kW) under peak solar radiation of 535 W/m². This indicates that the system is capable of efficiently converting solar energy into hydraulic power, which is crucial for effective irrigation. The efficiency of solar energy conversion is a critical factor in the performance of photovoltaic systems **(Cristaldi, et al., 2012).**
- DC power output reaching 149.82 W to irrigate 0.174 feddan. This demonstrates the system's capability to support small-scale irrigation needs, making it suitable for smallholder farmers. The efficiency of the photovoltaic system in converting solar energy to electrical power is essential for its practical application in irrigation **(Louazene, et al., 2017).**

The SPPS model facilitated the estimation of the optimal size of the photovoltaic array required, incorporating a 30% panel degradation factor for long-term performance planning. This allowed for the identification of the most energy-efficient and cost-effective configuration for sustainable irrigation operations as shown in Figure (16)**.** This consideration of degradation is crucial as photovoltaic panels typically degrade over time due to factors such as UV exposure and thermal cycling. The degradation rates for PV systems are generally around 0.5% to 1% per year, and accounting for this ensures the system remains effective over its lifespan **(Marion, 2021).**

The SPPS software interface provides a reliable simulation of the system's performance under varying climatic conditions. It helps in predicting the hydraulic power and pump discharge rates accurately, aiding in the optimization of the system **(Serbouh, et al., 2022) (Bora, et al., 2017).** By analyzing the data from different months, the software can suggest optimal configurations for the solar panels and pumps to maximize efficiency and water output throughout the year **(Salilih, et al., 2020).**

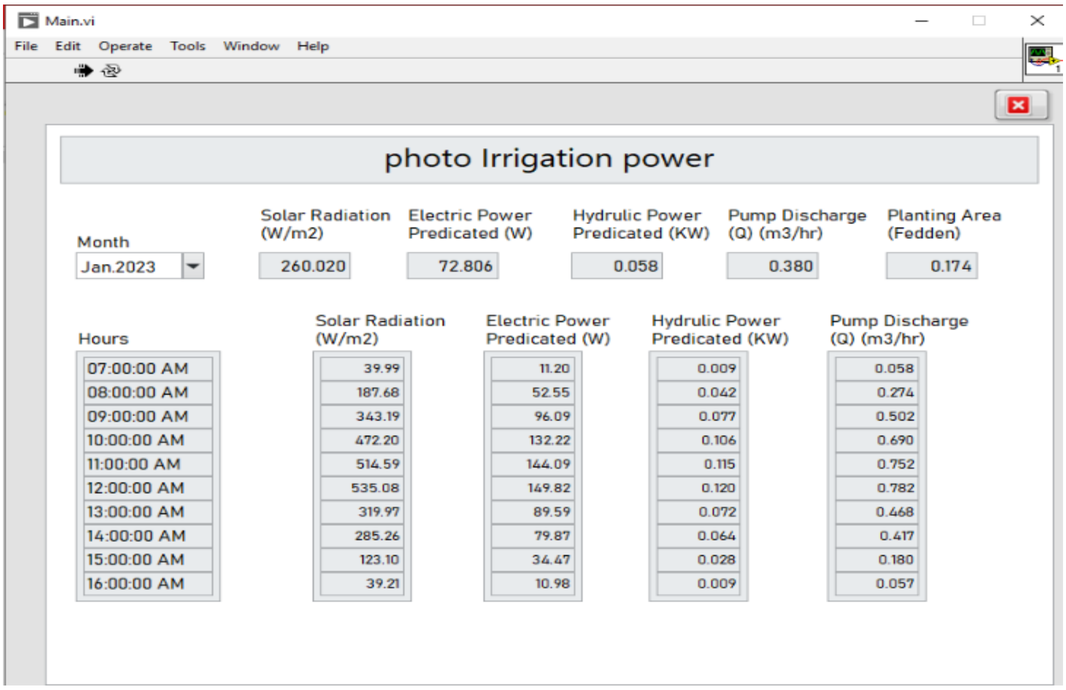


Fig. 16: **SPPS software interface for estimating the optimal size of the Photovoltaic array based on system requirements, solar radiation data, and efficiency factors.*; Source: own elaboration.***

3.7. SPPS Model Simulation Validation:

The SPPS simulation results are presented in Figures (17, 18 and 19), showed a high degree of accuracy when compared to field measurements. The correlation between simulated and observed data was approximately 76%, confirming the model's reliability. Key system parameters such as electrical consumption, power output, water discharge, and operating pressure of the irrigation system were monitored and matched closely with the SPPS outputs.

The simulation results underscore the software's applicability as a decision-support tool for the design, operation, and management of solar-powered irrigation systems. Its integration of environmental, hydraulic, and photovoltaic parameters ensures precise system sizing, efficient resource use, and improved agricultural productivity

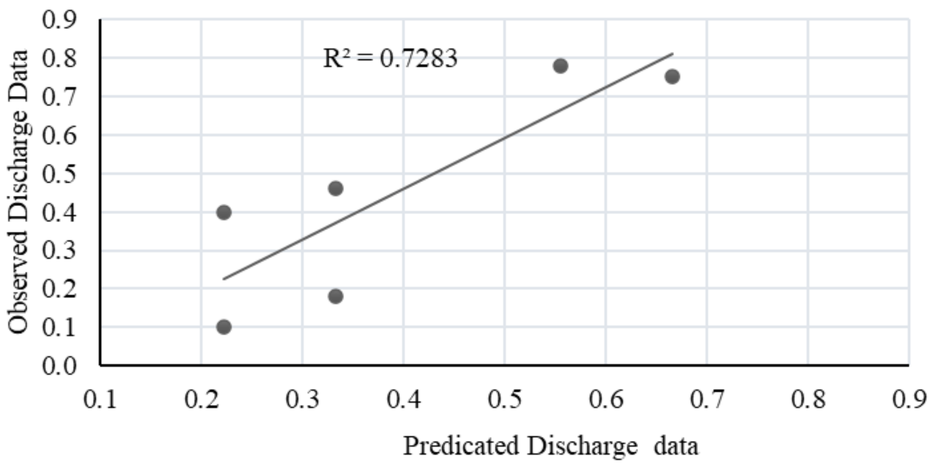


Fig. 17: Predicted and observed data of discharge (m^3/h).

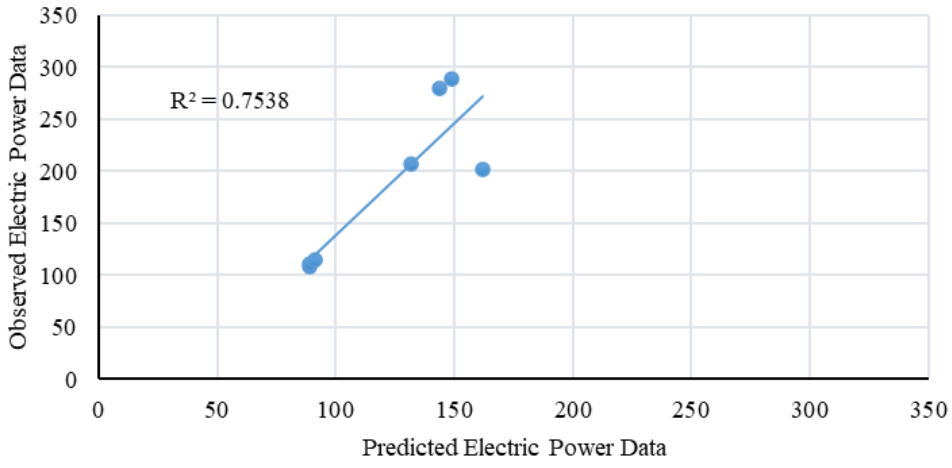


Fig. 18: Predicted and observed data of Electric power (W).

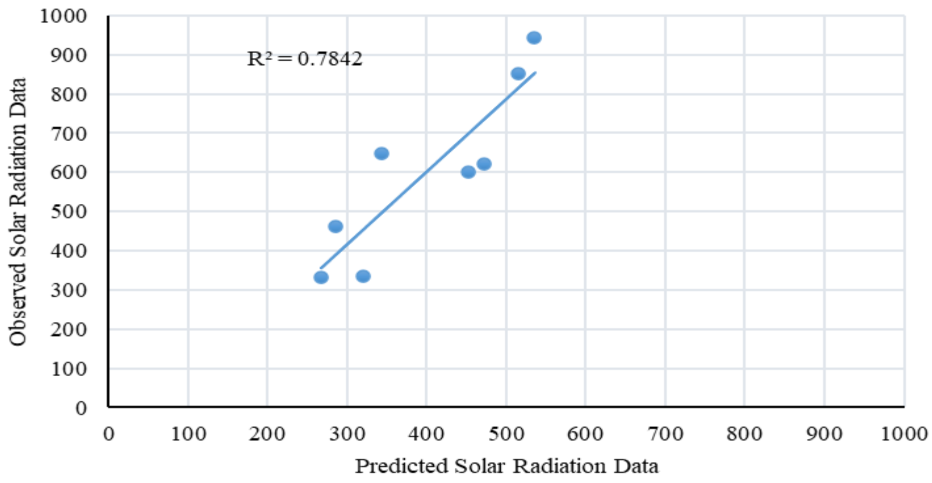


Fig. 19: Predicted and observed data of solar radiation (W).

CONCLUSION

This study presents the successful design and application of a solar-powered pumping system (SPPS) developed to support irrigation in dry regions, with a particular focus on conditions in Egypt. The system was modeled using the SPPS software created as part of this research, which takes into account important factors such as weather conditions, water requirements, and solar energy availability.

The SPPS data were applied to a greenhouse drip irrigation system for tomato cultivation at the Experimental Farm of the Soil and Water Research Department, Nuclear Research Center, located at Inshas city Atomic Energy Authority, Sharkia Governorate, Egypt. Through field testing and simulations, the system proved to be reliable and efficient in meeting the water needs of the crop. The software was also tested and confirmed using real field data collected during different seasons.

The results of this study can be summarized in the following points:

- The SPPS was an effective tool for planning and managing solar-powered irrigation systems.
- It helps improve the use of renewable energy in agriculture, especially in areas with strong sunlight and limited access to electricity.

- The correlation between simulated and observed data was approximately 76%, confirming the model's reliability, so the SPPS can support engineers, researchers, and decision-makers in developing sustainable farming solutions that save both water and energy.

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تصميم برمجيات لمحاكاة وادارة انظمة ضخ مياه الرى تدار بالطاقة الشمسية

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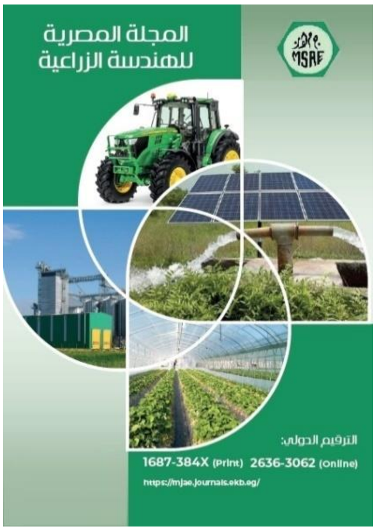

الكلمات المفتاحية:
نظام الضخ بالطاقة الشمسية، إدارة الري، برمجيات المحاكاة، الاحتياجات المائية.

الملخص العربي

على الرغم من الاستخدام المتزايد لأنظمة الضخ بالطاقة الشمسية في الزراعة، وخاصة في المناطق الجافة ذات الإدارة المائية الحرجة مثل مصر، ولا يزال هناك نقص في أدوات برمجية سهلة الاستخدام مصممة للظروف المحلية للمساعدة في المحاكاة والتخطيط والإدارة. ولحل هذه المشكلة، تم تطوير أداة برمجية قائمة على المحاكاة هو نظام الضخ بالطاقة الشمسية (SPPS) لأنظمة الري المعتمدة على الطاقة الشمسية في الزراعة. وتساهم هذه الأداة في تلبية احتياجات الطاقة اللازمة للزراعة بكفاءة عالية مع تقليل انبعاثات الغازات الدفيئة، وتعزيز الممارسات الزراعية المستدامة. وتوفر واجهة بسيطة يقوم المستخدمون بإدخال تفاصيل النظام فيها، ويصممونه، ويحاكون أداءه تحت ظروف مناخية واستخدامية متنوعة. ويجمع البرنامج بين الجوانب الفنية والبيئية والإدارية لدعم صانعي القرار في تخطيط وإدارة المياه بكفاءة. ويعتمد على نماذج محاكاة للطاقة الشمسية، والاحتياجات المائية، وأداء المضخات لمحاكاة الظروف الواقعية وتحديد التصميمات المثلى للنظام وخطة التشغيل والادارة.

وتم التحقق من نتائج محاكاة نظام (SPPS) بمقارنتها ببيانات تجريبية مُجمعة من مزرعة مركز البحوث النووية التجريبية في إنشاص، مصر، بناءً على دراسة حالة لمحصول الطماطم المنزرع داخل الصوب الزراعية تحت نظام الري بالتنقيط. وأظهرت النتائج تطابقًا قويًا بنسبة ٧٦٪ بين أداء النظام المحاكي والنظام الفعلي.

ويُبرز هذا البحث إمكانية دمج الطاقة المتجددة في أنظمة الري لتعزيز الاستدامة، وخاصة في المناطق التي تعاني من ندرة المياه أو عدم استقرار الكهرباء. ويؤكد أن التصميم الفعال للنظام، ومحاذاة الألواح الشمسية بدقة، والمراقبة في الوقت الفعلي عوامل حاسمة لتعظيم استخدام الطاقة وأداء نظام الري. بشكل عام، وتؤكد الدراسة أن الري باستخدام الطاقة الشمسية يمكن أن يساهم بشكل كبير في الإدارة المستدامة للمياه والطاقة في المجال الزراعي.