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Irrigation Technique Based on Photovoltaic with Pumped Storage System

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ABSTRACT

This study proposes an irrigation system for a 100-hectare olive farm situated near Mosul dam, housing a total of 28,500 olive trees. The determined water requirement for the farm is 390 m^3/day. Initial calculations were conducted to ascertain the appropriate sizing of the irrigation system components. Subsequently, the PVsyst program was employed for both system design and validation of the theoretical calculations. The irrigation system is comprised of a photovoltaic (PV) power station, pump, and tank. Based on water demand considerations and the average head between the farm and Tigris River, a configuration was selected, featuring a PV system with a size of 42 kW, a pump with a capacity of 40 kW, and a tank with a capability of 400 m^3. PVsyst simulation results indicate that the system is capable of provide 98.9% of the water demand, with 91.1% of the produced energy effectively utilized, resulting in an overall system efficiency of 80%.

1. INTRODUCTION

With the growing global demand for sustainable and environmentally friendly agricultural practices, the combination of renewable energy sources into irrigation schemes has become imperative [1]. To achieve the best possible yield and quality, olive farms need a steady and dependable water supply. Conventional energy sources are frequently used in traditional irrigation techniques, which increases carbon emissions and degrades the environment [2-4]. So that, improve the sustainability of agricultural operations, engineers and scientists have been looking into creative solutions in response to this challenge. One promising approach to addressing the energy-water nexus in olive farming is the synergistic integration of photovoltaic (PV) technology and pumped storage systems. The main goal of this paper is to offer a sustainable water supply for agricultural practices while keeping down environmental effects and maximizing energy efficiency through the introduction and analysis of a hybrid photovoltaic-pumped storage system specifically designed for olive farm irrigation [5, 6]. Using PV panels to harness solar energy offers a financially and environmentally responsible way to produce electricity. This system not only lessens reliance on traditional energy sources but also helps to reduce greenhouse gas emissions overall by utilizing the abundant sunlight in olive farming regions. Nevertheless, the sporadic character of solar energy generation presents difficulties in satisfying the constant energy requirements of irrigation systems, particularly in times of low solar irradiance [7, 8].

This paper explores the technical design and performance evaluation, considering the specific requirements of olive farm irrigation. Through a comprehensive analysis, we aim to demonstrate the potential of this integrated approach to enhance energy sustainability, optimize water resource management, and promote the adoption of environmentally conscious practices in agriculture. As the global community seeks innovative solutions to moderate the effect of climate change and ensure food security, the proposed hybrid system represents an important step toward a more workable future for olive farming and, by extension, for agriculture as a whole [9, 10]. To address the energy requirements of modern farming, PV systems utilize solar panels to generate electricity specifically for irrigation machinery. This conversion of solar energy into power for water pumps represents a significant advancement in agricultural engineering [11]. As an off-grid power source, PV systems eliminate the need for grid connectivity and boast minimal long-term maintenance costs. However, the initial expenditure for PV water pump storage infrastructure remains significant. The design process integrates CROPWAT 8.0 software to ensure the system is scaled accurately to meet specific crop water demand [12].

2. SYSTEM CHARACTERIZATION

The irrigation system contains of PV array, inverter, pump and storage. The system is designed for olive farm irrigation which is located in Mosul dam, the farm area is 100 hectares containing 28500 trees, the average demand of water for each tree is equal 5000 L/year and the whole need of the farm is 150,000 m^3/year, so the daily need of water is 390 m^3, so a storage of 400 m^3 has been selected. The mean head between Tigris and the farm is 112 m, and the distance between them is 100 m [13-15].

3. THEORETICAL CALCULATIONS

Theoretical analysis of the water pumping system comprises the following calculations for hydraulic power, PV system sizing, motor sizing, and efficiency:

3.1 Hydraulic power requirements

The required hydraulic power system is calculated using Eq. (1) [16].

$$P_H(kW) = \frac{\rho.g.Q.H}{3.6 * 10^6} \tag{1}$$

where,

ρ: Density of Water (1000 kg/m^3)
g: The gravity (9.81 m/s^2)
Q: Discharge of Water (80 m^3/h)
H: Head (112 m)

$$P_H(kW) == \frac{1000*9.8*80*112}{3.6*10^6} = 24.39kW$$

The pump operating hours can be calculated as:

$$Time(hours) = \frac{Total\ Volume(V)}{Discharge\ rate(Q)}$$

$$Time(hours) = \frac{390}{80} = 4.87\ hours \cong 5\ hours$$

3.2 Sizing of motor

An AC motor powers the pump, and the motor's power consumption is based on the pump's efficiency [16, 17].

$$\text{Requirement Power by motor} = \frac{\text{Hydraulic power required by pump}}{\text{Efficiency of pump}} \tag{2}$$

The motor must provide more power than the required hydraulic power to cover both the power needed for the water and the power lost (loss inside the pump). Because the pump operates qt 75% efficiency, it means if only uses 75% of the power provided by the motor to convert it into hydraulic power. Therefore, to obtain 24.39 kW (hydraulic power), the motor must provide a large amount of power; this is calculated mathematically by dividing the hydraulic power by the efficiency.

$$Requirment\ Power\ by\ Motor = \frac{24.39\ kW}{0.75} = 32.52\ kW$$

3.3 Sizing of photovoltaic array

The PV array's size determines the PV's overall size. The efficiency of the system affects how much power is needed as well.

$$Requirement\ Power\ from\ PV\ array = \frac{Power\ required\ by\ motor}{Efficiency\ of\ the\ system}$$

$$P = \frac{P\ motor}{\eta_{\boldsymbol{motor}}.\ \eta_{\boldsymbol{inverter}}.\ \eta_{\boldsymbol{MPPT}}.\ PR} \tag{3}$$

where, PR is the performance ratio.

$$P_{max} = P_{STC}.[1 + \gamma(T_{cell} - 25)]$$

where,

STC is the Standard test condition, γ is temperature coefficient power, and T_{cell} is cell temperature.

$$Power\ required\ from\ PV\ array = \frac{32.52\ kW}{80\%} = 40.65\ kW$$

3.4 System sizing calculation

The number of PV array modules required

$$\text{Total no.} = \frac{\text{Power output required from PV array}}{\text{Power rating of the unit module}} \tag{4}$$

$$Total\ no. = \frac{40.6\ 5kW}{500\ W} = 81\ Modules$$

$$E_{day} = \int_{sunrise}^{sunset} P_{hydrolic(t)dt} \tag{5}$$

$$E_{PV} = \sum I_{solar}\ .Area\ .\ \eta_{PV} \tag{6}$$

The motor-pump efficiency is given as [9]

$$\eta_{M-P} = \frac{P_H}{\text{Power required by motor}} \tag{7}$$

$$\eta_{M-P} = \frac{24.39\ kW}{32.52\ kW} = 75\%$$

PV system efficiency (η_P) is given by

$$\eta_P = \frac{Total\ power\ used\ from\ PV\ array}{PV\ array\ capacity} \times 100 \tag{8}$$

$$\eta_P = \frac{40.65\ kW}{42\ kW} \times 100 = 96.78\%$$

4. METROLOGICAL DATA

Physical parameters that are measured directly by instrumentation, like radiation and temperature, are included in the PVsyst.

4.1 The location and water resource

Table 1 provides data about the system installation location which is lactated at Mosul dam and the water resource is Tigris River.

Table 1. The location and water resource data

Location	Mosul Dam
Latitude	36.6375
Longitude	42.8152
Altitude	316
Water resource system	lake or river to storage
Application	irrigation

4.2 Monthly climate data of the location

Details about radiation are included in the climate data (Table 2).

Table 2. Climatic data

Month	Global Horizontal (kWh/m^2)	Beam Radiation (kWh/m^2)	Diffuse Radiation (kWh/m^2)
January	78.8	42.1	36.72
February	91.2	50.5	40.68
March	138.3	76.6	61.63
April	170.5	93.4	77.1
May	196.2	104.1	89.11
June	226.6	146.7	79.87
Julay	232	154.9	77.05
August	217.1	155.2	61.89
September	177.1	131.7	45.32
October	128.5	79.5	49.03
November	90.7	57.4	33.24
December	75	46.1	28.89
Year	1821.9	1141.4	680.54

5. MATERIALS AND METHOD

The materials which are used in this paper are PV modules, a built-in MPPT inverter, pump and storage tank.

5.1 Details of photovoltaic array

The specific details of the PV cell and PV array are given in Table 3.

Table 3. Photovoltaic (PV) array data

Manufacturer	Futurasun
Model	FU500M Silk Premium
Type	Si-mono
No. of PV panels	84
No. of panels in series	14
No. of panels in parallel	6
Power rating panel	500 W
Current ratings (Impp)	11.69 A
Voltage ratings (Vmpp)	42.8 V
Area	168 m^2
Power capacity	42 kW

5.2 Inverter details

Details regarding the inverter are shown in Table 4 [16-18].

5.3 Pump water storage tank

Details regarding the pumping system, pump and water storage tank are shown in Table 5 [18-20].

Table 4. Inverter details

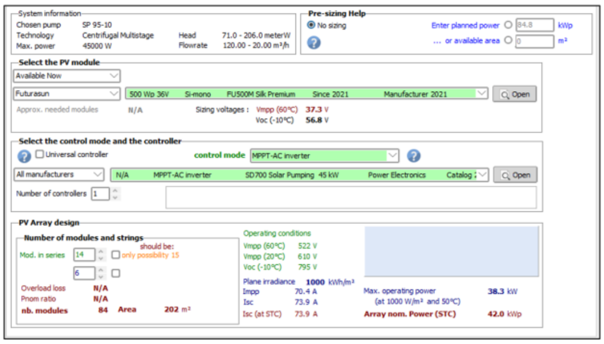
Inverter	SD700 Solar Pumping
DC voltage (Max.)	800 V
DC voltage (Min.)	540 V
Nominal otput voltage	400 V
Nominal output current	138 A
Nominal output power	55 kW
Max. Efficincy	98%

Table 5. Pumping system data

Type	Centrifugal Multistage
Motor	AC motor, three-phase
Power	45 kW
Manufacturer	Grundfos
Storage tank volume	400 m^3
Water requirement	390 m^3/day
Autonomy	4 days
Head Min/Nom/Max	71/143/206 m
Efficiency	78%
Length of pipe	122 m
Pipe size	5 Inch

6. PVSYST SIMULATION

The PVsyst simulation has been done according to the system parameters as shown in Figure 1.



System information
Chosen pump SP 95-10
Technology Centrifugal Multistage
Max. power 45000 W
Head 71.0 - 206.0 meterW
Flowrate 120.00 - 20.00 m³/h

Pre-sizing Help
● No sizing
Enter planned power ○ 84.8 kWp
... or available area ○ 0 m²

Select the PV module
Available Now
Futurasun
500 Wp 36V Si-mono FU500M Silk Premium Since 2021 Manufacturer 2021
Approx. needed modules N/A
Sizing voltages : Vmpp (60°C) 37.3 V
Voc (-10°C) 56.8 V

Select the control mode and the controller
☐ Universal controller
control mode MPPT-AC inverter
All manufacturers
N/A MPPT-AC inverter SD700 Solar Pumping 45 kW Power Electronics Catalog
Number of controllers 1

PV Array design
Number of modules and strings
Mod. in series 14 should be: ☐ only possibility 15
6 ☐
Overload loss N/A
Pnom ratio N/A
nb. modules 84 Area 202 m²
Operating conditions
Vmpp (60°C) 522 V
Vmpp (20°C) 610 V
Voc (-10°C) 795 V
Plane irradiance 1000 kWh/m²
Impp 70.4 A
Isc 73.9 A
Isc (at STC) 73.9 A
Max. operating power 38.3 kW
(at 1000 W/m² and 50°C)
Array nom. Power (STC) 42.0 kWp

Figure 1. PVsyst system parameters

7. PVSYST RESULTS

PVsyst's system efficiency of 79% demonstrates the useful performance of the designed system when various parameters are selected. The findings indicate that the pumping system uses the majority of the energy produced by the PV array, with only 12.6% of the total energy made was unused (Table 6).

Table 6 illustrates the main simulation results of the PV powered irrigation system. The data reveals a clear seasonal variation in system performance. The PV array energy production peaked in August at 7.586 kW, directly correlating with higher solar irradiance levels during summer months, while the minimum production occurred in February at 5.130 kWh.

Regarding the irrigation requirements, the system demonstrated high reliability during the growing season (from April to December), where the amount of water pumped consistently met the required water demand. This indicates an optimal design, a match between the PV array capacity and the irrigation load during these months.

However, a critical performance gap was identified during the winter season, specifically in January, February, and March, where a total water deficit of 824.4 m^2 was recorded.

Table 6. Main simulation results

Month	Array Energy kWh	Water Pumped m^3	Water Used m^3	Missing Water m^3
January	5321	11042	11792	297.6
February	5130	10801	10695	225
March	6251	12193	11788	301.8
April	6701	12575	11700	0
May	6756	12072	12090	0
June	7135	11718	11700	0
Julay	7340	12090	12090	0
August	7586	12088	12090	0
September	7287	11689	11700	0
October	6521	12087	12090	0
November	5991	11700	11700	0
December	5552	12076	12090	0
Year	**77561**	**142132**	**141526**	**824.4**

7.1 System schematic

The PVsyst software created this schematic design, which includes information on how to connect each component required for a solar water pump with a capacity of 400 m^3. The power curve and V-I characteristic are also used to explain the system's performance (Figure 2).

7.2 Reference incident energy

The reference incident energy graph (Figure 3) displays the average monthly solar irradiance at standard test conditions, excluding losses.

7.3 Performance ratio

The PV system's actual yield divided by its reference yield. The design performance ratio (PR) for this one is 0.681. The system losses, the optical losses, and the array losses are all included in the performance ratio, Figure 4.

The total system efficiency (η_{sys}) can be expressed as a product of the ideal efficiency of solar panels (η_{PV}) and the PR. The relationship is generally expressed as:

$$\eta_{sys} = \eta_{PV}.PR$$

7.4 Normalized production

This outcome displays a cumulative analysis of the PV array's overall production as well as the various power generation loss factors. To better understand the system, a bar chart with varying colors represents the power generation and losses (Figure 5).

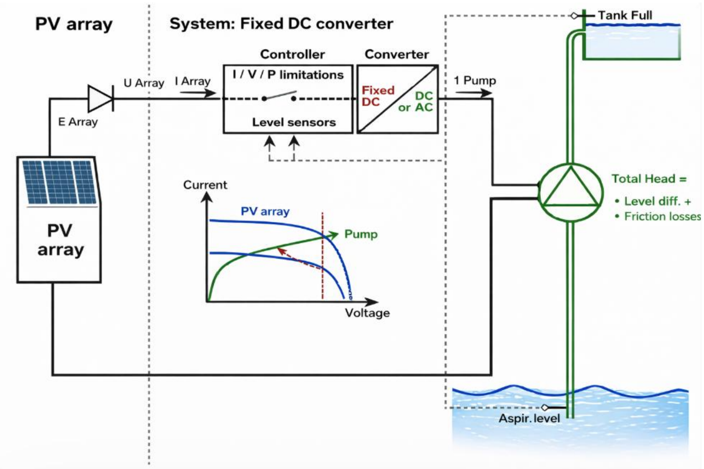


Figure 2. Schematic diagram of the system

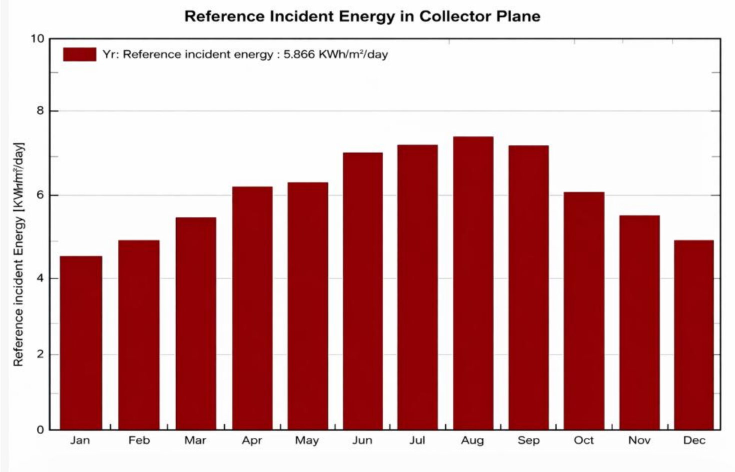


Figure 3. Reference incident energy

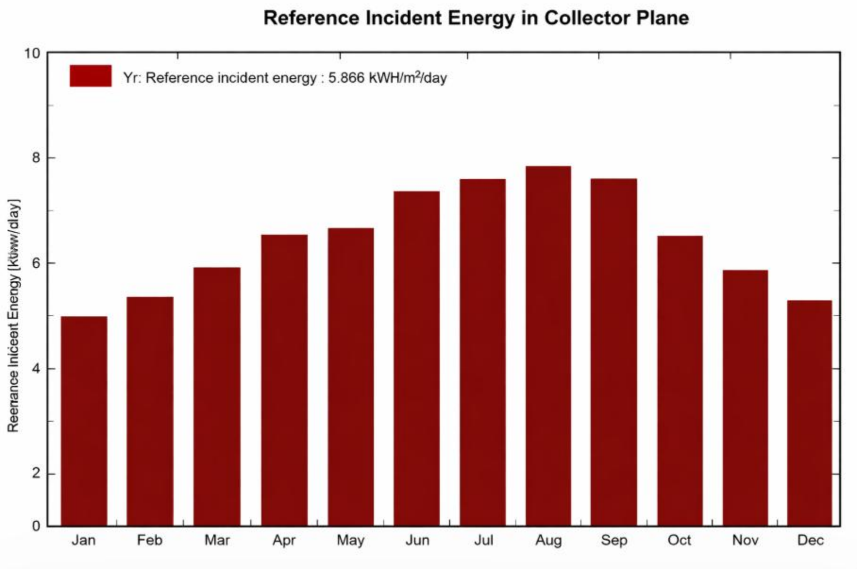


Figure 4. Performance ratio (PR)

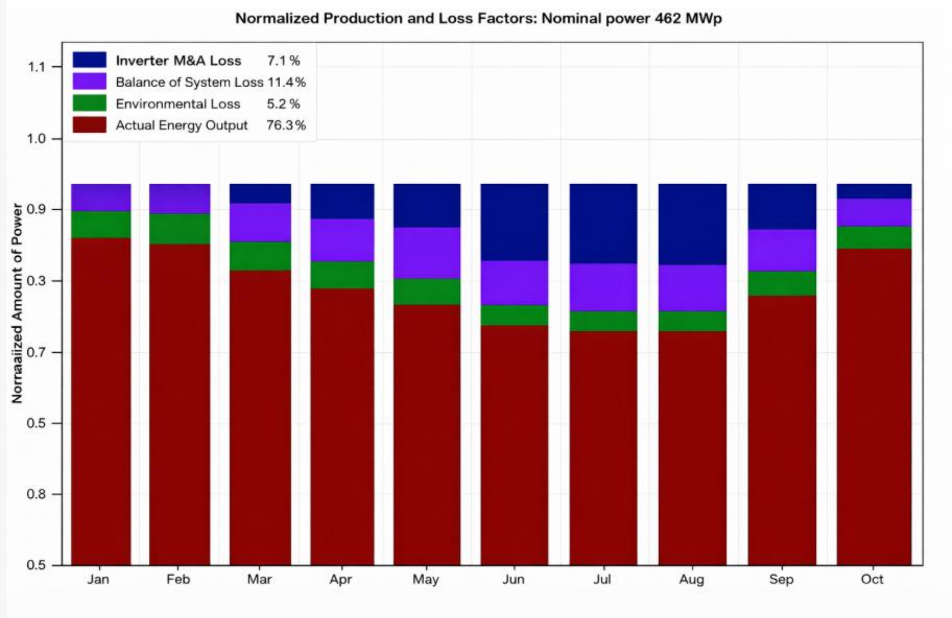


Figure 5. Normalized production

7.5 The pump power function

The relative between the pump's flow rate and the available energy is depicted in this diagram. Water flow of the pump is increasing along with the available energy at the pump (Figure 6).

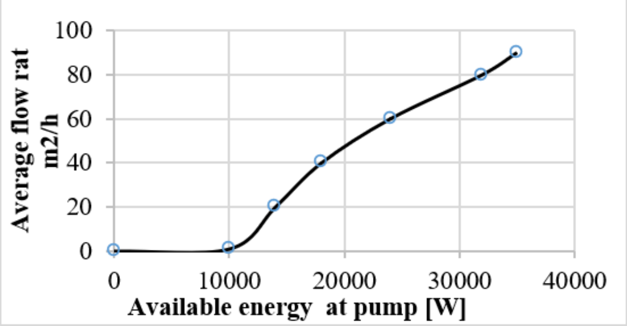


Figure 6. Flow rate function

The pump does not produce significant flowrate until a specific threshold of available energy is reached approximately (10000 w). Before this point, the energy is likely insufficient to overcome the internal friction or mechanical resistance. Proportional increase, ones the threshold is surpassed, then is a clear positive correlation between the energy input and flow rate. As more energy supplied to the pump, the volume of water it can displace increase accordingly, but for operating trend point of view, the curve shows that the flow rate rises steadily as the available energy increases, demonstrating the pump’s efficiency in converting electrical or mechanical power into hydraulic work.

7.6 Loss diagram

With a brief and insightful glance, the loss diagram aids in determining the quality of the design of solar water pumping systems. Converter loss, wiring loss, module loss, soiling loss, mismatch loss, temperature loss conversion loss, and other losses are among those shown in the loss diagram. Additional analysis of this loss result can be done to increase system efficiency (Figure 7).

The relationship between energy losses and cost, every percentage point lost in the diagram represent a leaked investment.

Capital expenditure (OpEx) impact, when the losses are high it is necessary to over-size the system (solar panel, converter, and pump) just to meet the required water demand, this increases the initial purchase price.

Operational expenditure (OpEx) impact, while solar has low ongoing costs, insufficient components may require more frequent maintenance, cleaning to avoid soiling losses or premature replacement which may be add to lifetime costs.

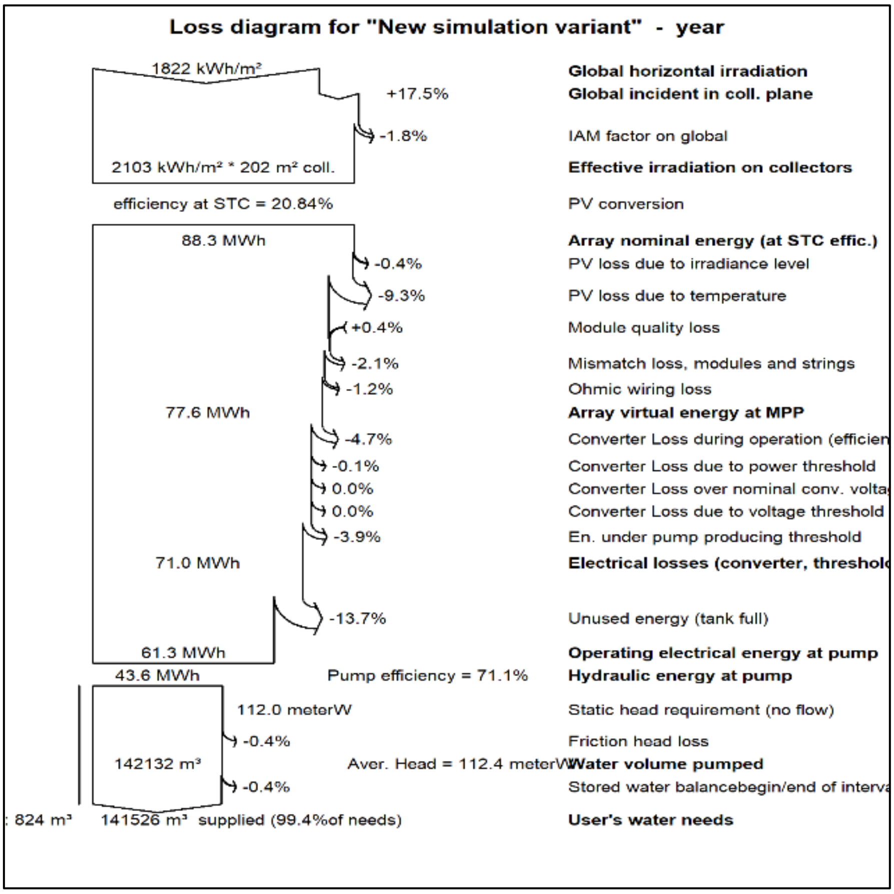


Figure 7. System loss distribution

8. CONCLUSIONS

This study demonstrates a robust methodology for the design and optimization of PV water pumping system by integrating theoretical numerical modeling with PVsyst. Software simulation. The dual approach framework serves as a validation mechanism, bridging the gap between high level design parameters and real-world operational performance.

The utilization of PVsyst software facilities a more granular sensitivity analysis, allowing for the observation of how variable environmental conditions like, solar irradiance, fluctuations and ambient temperature impact the system's instantaneous and long-term performance.

The simulation results offer a comprehensive, step by step roadmap for system architecture significantly reducing the margin of erroring component selection and performance evaluation this project achieves a suitable balance between operational performance and fiscal restraint. This lean approach not only mitigates immediate overhead but also ensure a scalable, high-yield return on investment without requiring additional capital.

In the meantime, generally traditional irrigation-like surface or flood irrigation is often characterized lower upfront costs but lower water efficiency higher labor requirements as compared with the work in this paper.

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