# DESIGN AND ANALYSIS OF SOLAR AGRICULTURAL WATER PUMPING SYSTEM FOR IRRIGATION PURPOSE

**Debashree Debadatta Behera[1], Shiv Sankar Das[2], R.C. Mohanty[3], A.M. Mohanty[4], Pradyumna Kumar Das[5]**

[1,3,4,5] Department of Mechanical Engineering, Centurion University of Technology and Management, Odisha, India
[2] Independent Researcher in Clean Energy, Management

Corresponding Author

**Debashree Debadatta Behera**
Department of Mechanical Engineering, Centurion University of Technology and Management, Odisha, India
*Email: debashree.behera@cutm.ac.in*

**Abstract**

Sustainable agriculture is the central to achieve sustainable development goals from poverty alleviation to food security to livelihood security. Solar photovoltaic water pumping system is one of the most potential and economic viable as compared diesel operated or grid operated solar pump. The main objective of this paper is to help the farmer to irrigate their field through drip irrigation by using of a DC solar pump. In this paper Simulation of solar water pumping system was carried out by considering various parameters such as geographical site, pumping system parameters, collector plane orientation, the efficiency of pump (39.5%), amount of water pumped as 5486 $m^3$ were calculated by using PV Syst software. In this paper a MPPT DC-converter, solar PV panel 250 WP was used.

**Key words:** Agricultural, Irrigation, PV Syst software, MPPT DC-converter.

## Introduction

Most of the future growth in agriculture is likely to come from intensification, in which irrigation plays an important role. For irrigation, we require energy which is fulfilled using a pump set run by diesel. Though government heavily subsidises agricultural grid connections but in rural areas there is 54 intermittent, fraught with voltage fluctuations, with waiting time for an initial connection being too long. To meet these challenges, solar based irrigation systems like solar operated pumps is an attractive option and is an alternative solution to those powered by grid electricity and diesel. Solar based irrigation system converts solar energy to produce electricity. This electricity is used to pump water. Solar based irrigation system is commercially viable irrigation technology, which has low operational and maintenance cost. So far, 0.14 million solar pumps have been installed including 0.31 million during 2016-17, 2017-18 and 2018-19.

Arrouf et al. [1] had done simulation of photovoltaic pumping system by using MATLAB simulation and got result regarding photovoltaic generator. Ghoneim [2] had done simulation work on solar water pumping system which consists of PV array, DC motor, centrifugal pump and integrated multi point power tracking system to improve the efficiency. Benghanem et al. [3] had estimated the pumping head of photovoltaic water pumping system under four numbers of head and found that it depended on pumping head and global solar radiation. Yadav et al. [4] presented a paper on solar operated water Pumping system and calculated efficiency on basis of variation of solar intensity, ambient temperature and water head. Korpale et al. [5] had done performance test on Solar agricultural water pumping system in which Cd-Te solar panel taken to power the 2HP water pump and maximum flow rate obtained as compared to conventional method. Zahab et al. [6] had simulation standalone solar water pumping system by using MAT lab simulink. The MPPT technique was used to control DC –DC boost converter and to drive BLDC motor. Kumar et al. [7] had done simulation on PV powered water pumping system by using two MPPT algorithms and got significant increase in efficiency as compared without using MPPT. Kolhe et al. [8] had done performance testing of PV powered water pumping system integrated with DC motor and run by manual tracking system.

**Design and Calculation**

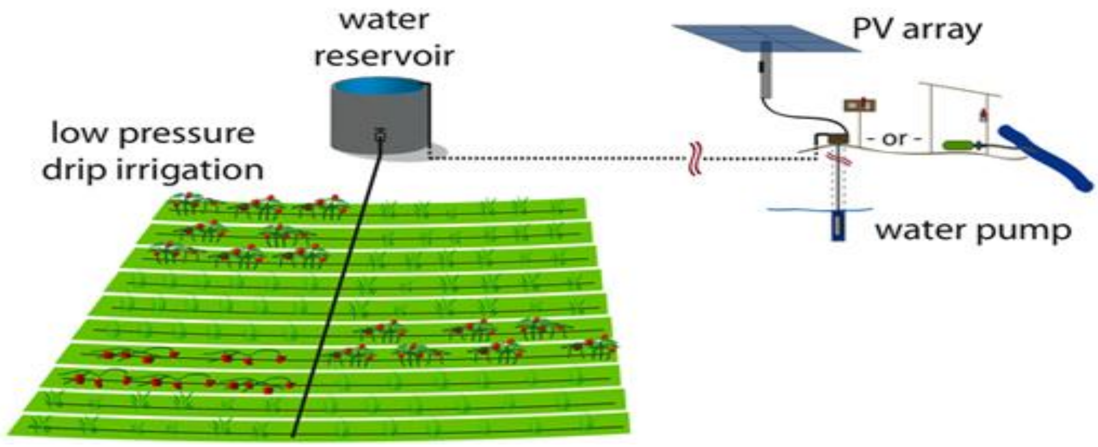



Figure-1. Schematic diagram of solar water pumping system

The main components are Solar Panel (150W solar polycrystalline panel), MCB combo box (6 Amp maximum), DC solar pump (DC pump -96w, 4.1 Amp (max), 310 Lph), Telescopic mounting structure. In this paper we have used a 24 VDC of 96W and a 0.025 HP pump. A solar tracker is a device that orients solar panels towards the sun. We have a manually tracking system used and the tilt angle depends upon the latitude of the place. There we have given the tilt angle as 22 degree. A telescope for mounting the solar panel which was standstill. Which height around (13ft) it can be adjustable. A PENTAIR submersible pump (maximum voltge-12/24v, maximum current-3.9/4.1A, Lph-138/310, pressure-6bar).

| 24 Volt DC Flow Table | | | | | |
|---|---|---|---|---|---|
| Total Vertical Lift | | Flow Rate Per Hour | | Solar Array Size Minimum Total Power Rating | Current |
| Feet | Meters | Gal | Litre | Watts | Amps |
| 20 | | 117 | 443 | 58 | 1.5 |
| 40 | 12.2 | 114 | 432 | 65 | 1.7 |
| 60 | 18.3 | 109 | 413 | 78 | 2.1 |
| 80 | 24.4 | 106 | 401 | 89 | 2.4 |
| 100 | 30.5 | 103 | 390 | 99 | 2.6 |
| 120 | 36.6 | 101 | 382 | 104 | 2.8 |
| 140 | 42.7 | 99 | 375 | 115 | 3.1 |
| 160 | 48.8 | 98 | 371 | 123 | 3.3 |
| 180 | 54.9 | 93 | 352 | 135 | 3.6 |
| 200 | 61.0 | 91 | 345 | 141 | 3.8 |
| 230 | 70.1 | 82 | 310 | 155 | 4.1 |

Table 1- 24 Volt DC Flow Table

### 2.1 Bill of Quantity

| BOQ for Solar Drip Irrigation System | | | | | |
|---|---|---|---|---|---|
| Item No | Description of Item | Unit | Quantity | Rate @Kg | Total price |
| 1. | GI pipe | 2'' dia 6 ft | 15kg | 50 /- | 750 /- |
| 2 | GI pipe | 1½ '' dia 6ft | 11 kg | 50/- | 550 /- |
| 3 | Angle | 35 x35x 5 | 2 piece18 kg | 35/- | 630 /- |
| 4 | Bolt | 8 mmX254 mm | 4 Nos ,0.50 kg | 85 /- | 42.50 /- |
| | | 8 mmX88.9 mm | 4 Nos ,0.35 kg | 85 /- | 30/- |
| | | 0.5 mmX38.1 mm | 6 Nos ,0.20 kg | 85 /- | 17/- |
| 5 | Washer | 8 mm | 10 | 85 /- | 10/- |
| 6 | PVC water pipe | 16 mm | 15 m | 20@/m /- | 300 /- |
| 7 | Wire red(+) & black(-) | 1.5 mm | 10 m | 240/- | 240 /- |
| 8 | MCB Combo | 6 A | 1 no | 400/- | 400/- |
| 9 | Rope (Plastic) | | 10 m | 100/- | 100 /- |
| 10 | Gum (Silicon gel) | | As per required | 50 /- | 50 /- |
| 11 | Insulation Tape | | 2 nos | 5 /- | 10 /- |
| 12 | Dripper | | 100 nos | 3 /- | 300 /- |
| 13 | Connector | 16 mm | 10 nos | 3/- | 30/- |
| 14 | End Cap | 18 mm | 10 nos | 3/- | 30/- |
| 15 | Tee | 16 mm | 10 nos | 10/- | 100/- |
| 16 | Fabrication charge | | | | 990/- |
| 17 | Mounting charge | | | | 1500/- |
| Total | | | | | 6229.50/- |

Table 2. BOQ for Solar Drip Irrigation System

### Installation and Fabrication Process

After the preparation of BOQ we procured the materials. It means how we installed the entire panel, motor & the equipment. At first we did site survey and choose a better placed place where the telescope is being installed & the sunlight can come to the solar panel without any obstacle without shadow effect. And with in this unit fabrication of a desired telescope by fabricating the GI pipe, angles & bolts. We used a polycrystalline solar panel due to cost effectiveness and reliability factor. The solar panel consists at two terminal which is determined before the procure of the panel. The solar gives power 150W maximum volte 18.5V and maximum current 8.85A.To join the solar panel to the pump 6A (Max) a MCB combo is used through a 1.5mm wire is used. The MCB combo whose rating is 6A was chosen to consideration because the pump can run up to current 4.1A and it can sustain.

**Observation and Calculation**

| S.N | Time | Litre | Current | Voltage |
|---|---|---|---|---|
| 1 | 10:30 AM | 4.6 lit | -- | -- |
| 2 | 11:00 AM | 5 lit | -- | -- |
| 3 | 11:15 AM | 5 lit | -- | -- |
| 4 | 11:30 AM | 5 lit | -- | -- |
| 5 | 11:45 AM | 5 lit | -- | -- |
| 6 | 12:00 PM | 5 lit | 6.1 A | 18.8 V |
| 7 | 12:15 PM | 5 lit | 7.0 A | 18.68 V |
| 8 | 12:30 PM | 5 lit | 6.25 A | 18.63 V |
| 9 | 12:45 PM | 4.4 lit | 6.08 A | 18.62 V |
| 10 | 1:00 PM | 4.6 lit | 6.14A | 18.67V |
| 11 | 1:15 PM | 5 lit | 5.86A | 18.69V |
| 12 | 1:20 PM | 5.8 lit | 5.63A | 18.75V |
| 13 | 2:00 PM | 6.00 lit | 5.65A | 18.08V |

Table 3. Discharge rate verses Time

***4.1 Calculation***

$Q = 8.33\times 10^{-3} m^3/sec$

Area of pipe = $\pi/4\times d^2 = 1.5386\times 10^{-4} m^2$

$Q = A\times V$ (Rate flow of water)

$V = 0.54$ m/sec

Reynolds Number (Re) $= \frac{v\times d}{d} = 7560$

$f = \frac{0.079}{Re^{1/4}} = 8.4722\times 10^{-3}$

Head lost $(h_f) = \frac{4fLV^2}{2gd} = 0.658$ m

$(H+h_f) = = 2.108$ m

$H+h_f+\frac{v_1{}^2}{2g}+\frac{p}{fg}$

=12.12

Water Head ($h_f$ = Loss of Head)

$$H = \frac{\rho g Q(H + h_f + \frac{v_1^2}{2g} + \frac{p}{\rho g})}{VI}$$

$\eta$ =8.63%

The efficiency from the calculation we have found to be 9 % approximately, whereas the normal efficiency of any DC pump varies from 10% to 25%.

**Result and Discussion**

| PVSYST V6.81 | | 22/11/20 | Page 1/5 |
|---|---|---|---|

## Pumping PV System: Basic simulation parameters

**Project :** **Solar water pumping system**

| | | | | |
|---|---|---|---|---|
| **Geographical Site** | **Jatani** | | Country | **India** |
| **Situation** | Latitude | 20.16° N | Longitude | 85.71° E |
| Time defined as | Legal Time | Time zone UT+5.5 | Altitude | 33 m |
| | Albedo | 0.20 | | |
| **Meteo data:** | **Jatani** | Meteonorm 7.2 (1981-2010), Sat=100% - Synthetic | | |

**Simulation variant :** **New simulation variant**

Simulation date 22/11/20 11h45

**Simulation parameters**

| | | | | |
|---|---|---|---|---|
| **Pumping System parameter** | System type | **Deep Well to Storage** | | |
| Well characteristics | Static level depth | 40 m | Specific drawdown | 0.00 m / m³/h |
| (Diameter 40 cm) | Pump depth | 44 m | Max. pumping depth | 43 m |
| Storage tank | Volume | 30.0 m³ | Diameter | 2.8 m |
| Feeding by top | Feeding altitude | 5.0 m | Height (full level) | 5.0 m |
| Hydraulic circuit | Piping length | 70 m | Pipes PE32 | Dint = 35 mm |
| **Water needs** | Yearly constant: | 15.00 m³/day | | |
| **Pump** | Model | **SQF 3A-10 30-300V** | | |
| | Manufacturer | Grundfos SQFlex | | |
| Pump Technology | Centrifugal Multistage | Deep well pump | Motor | DC motor, permanent magnet |
| Associated or Integrated converter | Type | MPPT | Voltage range | 30 - 300 V |

| Operating conditions | head Min | head Nom | head Max | |
|---|---|---|---|---|
| | 30.0 | 50.0 | 70.0 | mWater |
| Corresponding maximum Flow Rate | 4.90 | 4.00 | 3.00 | m³/h |
| Required power | 1400 | 1400 | 1400 | W |

| | | | | |
|---|---|---|---|---|
| **Collector Plane Orientation** | Tilt | 20° | Azimuth | 0° |
| **PV Array Characteristics** | | | | |
| **PV module** Si-mono | Model | **Mono 250 Wp 60 cells** | | |
| Original PVsyst database | Manufacturer | Generic | | |
| Number of PV modules | In series | 8 modules | In parallel | 2 strings |
| Total number of PV modules | Nb. modules | 16 | Unit Nom. Power | 250 Wp |
| Array global power | Nominal (STC) | **4000 Wp** | At operating cond. | 3547 Wp (50°C) |
| Array operating characteristics (50°C) | U mpp | 217 V | I mpp | 16 A |
| Total area | Module area | **26.0 m²** | Cell area | 22.8 m² |
| **Control device** | Model | Generic device (optimised for the system) | | |
| | System Configuration | **MPPT-DC converter** | | |

Figure 2. The details about Pumping System Parameters

1. In Figure 2, Taking geographical Site and considering various Pumping system parameters such as diameter of well, static level depth, volume of storage tank, yearly water needs, PV array characteristics, and MPPT-DC converter details were mentioned

| PVSYST V6.81 | | 22/11/20 | Page 2/5 |
|---|---|---|---|

## Pumping PV System: Detailed Simulation parameters

**Project :** **Solar water pumping system**

**Simulation variant :** **New simulation variant**

| | | | | |
|---|---|---|---|---|
| **Main system parameters** | System type | **Deep Well to Storage** | | |
| System Requirements | basic Head | 45.0 meterW | Water needs | 15.0 m³/day |
| Pump | Model / Manufacturer | SQF 3A-10 30-300V / Grundfos SQFlex | | |
| PV Array | Model / Manufacturer | Mono 250 Wp 60 cells / Generic | | |
| | Nb. of modules | 8 S x 2 P | Array Power | 4000 Wp |
| System Configuration | Control Strategy | **MPPT-DC converter** | | |

**System Operating Control** (Generic device, params adjusted acc. to the system)

**Power conditioning unit** MPPT - DC converter

| | | | | |
|---|---|---|---|---|
| Operating conditions | Minimum MPP Voltage | 30 V | nominal power | 1400 W |
| | Maximum MPP Voltage | 300 V | Power Threshold | 14 W |
| | Maximum Array Voltage | 300 V | Max. efficiency | 96.5 % |
| | Maximum Input Current | 13.0 A | EURO efficiency | 94.5 % |

**Remarks and Technical features**

Generic regulator for pumping systems.
for systems with MPPT converters
The parameters are pre-setted according to the system (pumps and Array),
at the beginning of the simulation.
Unlike exceptions, they are not modifiable by the user.

**PV Array loss factors**

| | | | | |
|---|---|---|---|---|
| Thermal Loss factor | Uc (const) | 20.0 W/m²K | Uv (wind) | 0.0 W/m²K / m/s |
| Wiring Ohmic Loss | Global array res. | 226 mOhm | Loss Fraction | 1.5 % at STC |
| Module Quality Loss | | | Loss Fraction | -0.8 % |
| Module Mismatch Losses | | | Loss Fraction | 1.0 % at MPP |
| Strings Mismatch loss | | | Loss Fraction | 0.10 % |

Incidence effect (IAM): Fresnel smooth glass, n = 1.526

| 0° | 30° | 50° | 60° | 70° | 75° | 80° | 85° | 90° |
|---|---|---|---|---|---|---|---|---|
| 1.000 | 0.998 | 0.981 | 0.948 | 0.862 | 0.776 | 0.636 | 0.403 | 0.000 |

Figure 3. Main system parameters and PV array loss factors

In figure 3, different parameters such as PV array loss factors; basic head of solar water pumping system was mentioned.

| PVSYST V6.81 | | 22/11/20 | Page 3/5 |
|---|---|---|---|

## Pumping PV System: Main results

**Project :** **Solar water pumping system**

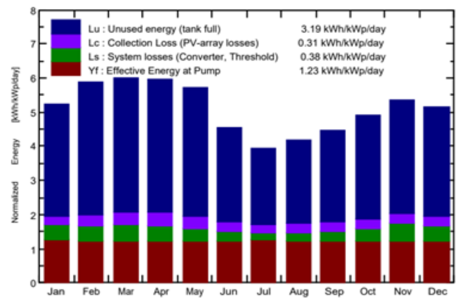
**Simulation variant :** **New simulation variant**

| | | | | | |
|---|---|---|---|---|---|
| **Main system parameters** | System type | **Deep Well to Storage** | | | |
| System Requirements | basic Head | 45.0 meterW | Water needs | 15.0 m³/day | |
| Pump | Model / Manufacturer | SQF 3A-10 30-300V / Grundfos SQFlex | | | |
| PV Array | Model / Manufacturer | Mono 250 Wp 60 cells / Generic | | | |
| | Nb. of modules | 8 S x 2 P | Array Power | 4000 Wp | |
| System Configuration | Control Strategy | **MPPT-DC converter** | | | |

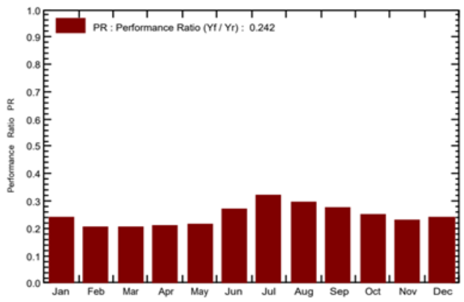
**Main simulation results**

| | | | | |
|---|---|---|---|---|
| System Production | **Water Pumped** | **5486 m³** | Specific | 297 m³/kWp/bar |
| | Water needs | 5475 m³ | Missing Water | -0.2% |
| | Energy At Pump | 1801 kWh | Specific | 0.33 kWh/m³ |
| | Unused PV energy (Tank full) | 2464 kWh | Unused Fraction | 40.2 % |
| | System efficiency | 29.4 % | Pump efficiency | 39.5 % |

**Normalized productions (per installed kWp): Nominal power 4000 Wp**




**Performance Ratio PR**




**New simulation variant**

**Balances and main results**

| | GlobEff kWh/m² | EArrMPP kWh | E_PmpOp kWh | ETkFull kWh | H_Pump meterW | WPumped m³ | W_Used m³ | W_Miss m³ |
|---|---|---|---|---|---|---|---|---|
| **January** | 157.9 | 547.9 | 155.4 | 210.9 | 47.41 | 475.6 | 465.0 | 0.000 |
| **February** | 159.9 | 540.3 | 136.0 | 210.5 | 47.54 | 420.0 | 420.0 | 0.000 |
| **March** | 180.9 | 598.0 | 152.1 | 231.3 | 47.39 | 465.0 | 465.0 | 0.000 |
| **April** | 173.1 | 570.3 | 148.5 | 229.1 | 47.17 | 450.0 | 450.0 | 0.000 |
| **May** | 170.6 | 565.6 | 151.4 | 244.5 | 47.13 | 465.0 | 465.0 | 0.000 |
| **June** | 130.8 | 447.6 | 148.0 | 196.9 | 46.70 | 450.1 | 450.0 | 0.000 |
| **July** | 116.7 | 406.9 | 155.3 | 171.8 | 46.49 | 464.5 | 465.0 | 0.000 |
| **August** | 124.9 | 434.8 | 152.4 | 187.7 | 46.74 | 465.5 | 465.0 | 0.000 |
| **September** | 129.1 | 444.7 | 147.4 | 184.2 | 46.81 | 450.0 | 450.0 | 0.000 |
| **October** | 147.3 | 503.6 | 153.3 | 205.5 | 47.01 | 465.0 | 465.0 | 0.000 |
| **November** | 156.6 | 532.7 | 149.5 | 189.9 | 47.10 | 450.0 | 450.0 | 0.000 |
| **December** | 155.1 | 536.5 | 152.2 | 201.4 | 47.32 | 465.0 | 465.0 | 0.000 |
| Year | 1802.9 | 6128.8 | 1801.4 | 2463.7 | 47.03 | 5485.6 | 5475.0 | 0.000 |

| Legends: | | | | |
|---|---|---|---|---|
| | GlobEff | Effective Global, corr. for IAM and shadings | H_Pump | Average total Head at pump |
| | EArrMPP | Array virtual energy at MPP | WPumped | Water pumped |
| | E_PmpOp | Pump operating energy | W_Used | Water drawn by the user |
| | ETkFull | Unused energy (tank full) | W_Miss | Missing water |

Figure 4. Simulation result of Pumping PV system

In the figure 4 different simulation results such as amount of water pumped, energy available at pump, system efficiency, pump efficiency was obtained.

| PVSYST V6.81 | | 22/11/20 | Page 4/5 |
|---|---|---|---|

Pumping PV System: Special graphs

**Project :** **Solar water pumping system**

**Simulation variant :** **New simulation variant**

| | | | | |
|---|---|---|---|---|
| **Main system parameters** | System type | **Deep Well to Storage** | | |
| System Requirements | basic Head | 45.0 meterW | Water needs | 15.0 m³/day |
| Pump | Model / Manufacturer | SQF 3A-10 30-300V / Grundfos SQFlex | | |
| PV Array | Model / Manufacturer | Mono 250 Wp 60 cells / Generic | | |
| | Nb. of modules | 8 S x 2 P | Array Power | 4000 Wp |
| System Configuration | Control Strategy | **MPPT-DC converter** | | |

**Daily Input/Output diagram**

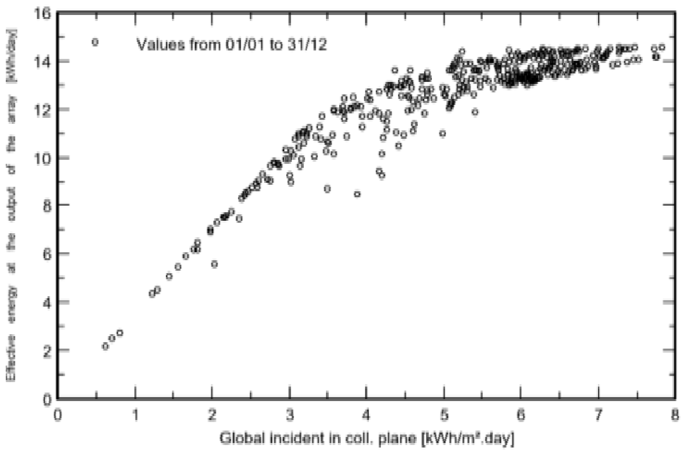
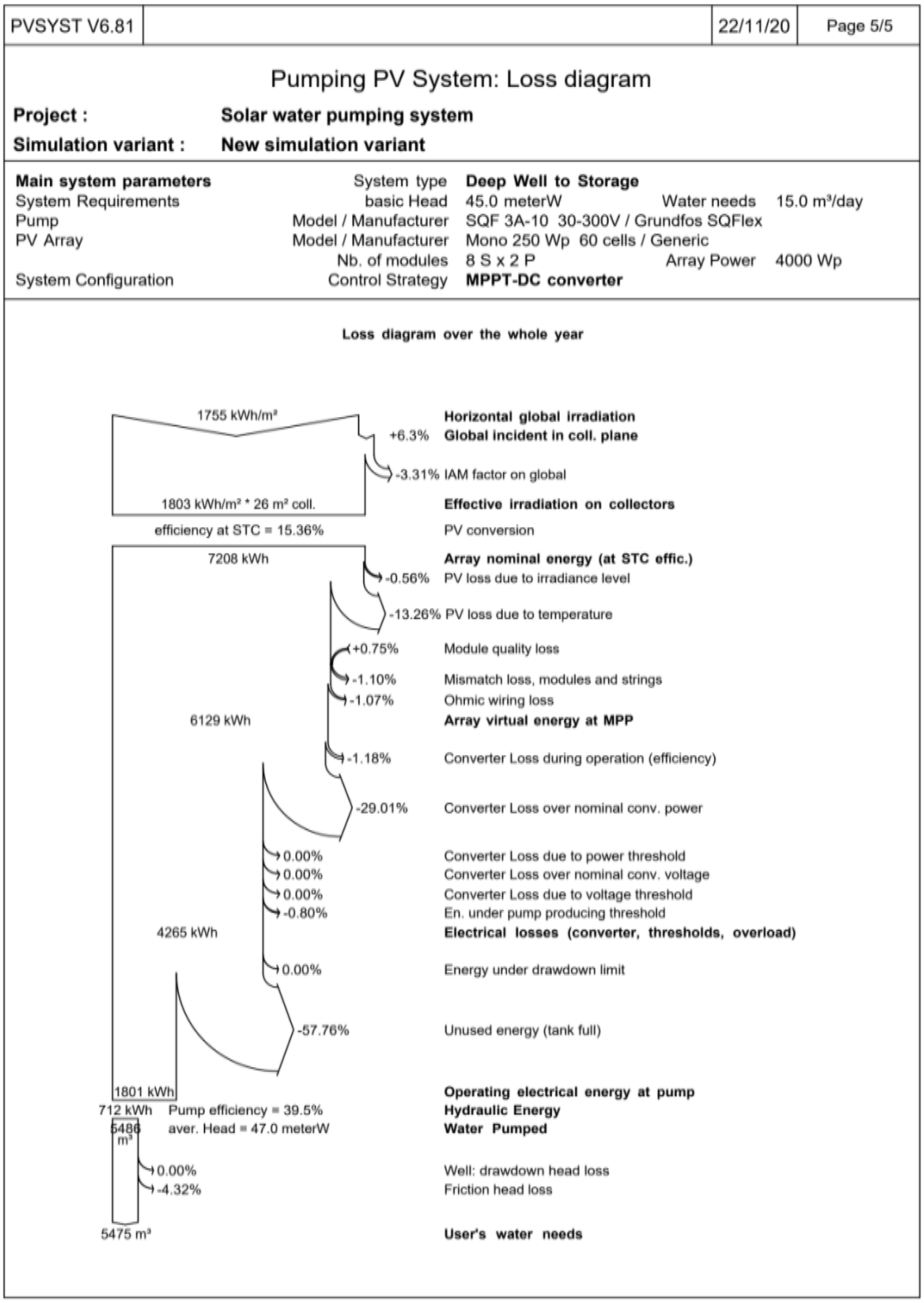



Figure 5. Global incident in collector plane Verses effective energy at the output of array



| PVSYST V6.81 | | 22/11/20 | Page 5/5 |
|---|---|---|---|

Pumping PV System: Loss diagram

**Project :** **Solar water pumping system**

**Simulation variant :** **New simulation variant**

| | | | | |
|---|---|---|---|---|
| **Main system parameters** | System type | **Deep Well to Storage** | | |
| System Requirements | basic Head | 45.0 meterW | Water needs | 15.0 m³/day |
| Pump | Model / Manufacturer | SQF 3A-10 30-300V / Grundfos SQFlex | | |
| PV Array | Model / Manufacturer | Mono 250 Wp 60 cells / Generic | | |
| | Nb. of modules | 8 S x 2 P | Array Power | 4000 Wp |
| System Configuration | Control Strategy | **MPPT-DC converter** | | |



Figure 6. Loss diagram over the whole year

In Figure 6. Overall losses such as horizontal global irradiation, effective irradiation on collectors, array nominal energy, hydraulic energy, and water pumped and amount water needed had been calculated.

**References**

1. Arrouf, Mohamed, and S. Ghabrour. "Modelling and simulation of a pumping system fed by photovoltaic generator within the Matlab/Simulink programming environment." *Desalination*, 209.1-3, 2007: 23-30.
2. Ghoneim, A. A. "Design optimization of photovoltaic powered water pumping systems." *Energy conversion and management* 47.11-12, 2006: 1449-1463.
3. Benghanem, Mohamed, “Effect of pumping head on solar water pumping system." *Energy Conversion and Management* 77, 2014: 334-339.
4. Yadav, Kamlesh, "Solar photovoltaic pumps operating head selection for the optimum efficiency." *Renewable Energy,* 134, 2019: 169-177.
5. Korpale, V. S., D. H. Kokate, and S. P. Deshmukh. "Performance assessment of solar agricultural water pumping system." *Energy Procedia* 90, 2016: 518-524.
6. Zahab, Essam E. Aboul, Aziza M. Zaki, and Mohamed M. El-sotouhy. "Design and control of a standalone PV water pumping system." *Journal of Electrical Systems and Information Technology* 4.2, 2017: 322-337.
7. Oi, Akihiro. "Design and simulation of photovoltaic water pumping system." *California Polytechnic State University*, 2005.
8. Benghanem, M., K. O. Daffallah, and A. Almohammedi. "Estimation of daily flow rate of photovoltaic water pumping systems using solar radiation data." *Results in Physics* 8, 2018: 949-954.