Assessment of Water Pumping System Powered By Solar Pump in Dry Areas

Amadou Yacouba Moussa, Patrick Kuloba, Robert Kiplimo

Abstract: ***The rapid increase of desertification's degradation is one of the worst environmental and economic threats for dry areas. Climate changes, very year impacts thousands of areas across the globe. The high cost of electricity and diesel-based fuel affects photovoltaic water pumping requirements for irrigation in many parts of the world. Solar irradiance in every dry place is extremely high due the drought increase. Thus, using solar energy for water pumping is a promising alternative sources of energy. Undertaking irrigation for a particular place and crop requires not only skills in the irrigation planning but also in the power requirement of the entire system. A reliable and accurate estimation of ET rate and irrigation water requirement (IWR) are soundly important in irrigation field. This sought to accurately estimate the irrigation power requirement by using PVsyst software on nine different pumps technologies combinations with different type of converters at 100m, 150m, 180m, and 200m of Total dynamic Head (TDH). The study has been conducted in four sections, the first section dealt with the assessment of the collected data, the second section with the simulations, the third one with the irrigation water requirement and finally irrigation water requirement. The results found in study show that IPR of a crop is majorly depend on the TDH. Among the nine combinations, results show that the Maximum Power Point Tracking (MPPT) technology is the best in terms of power requirement of selected the crop. Furthermore, the maximum and minimum values of the irrigation water requirement for millet crop was found to be 12.9 mm/day and 4.9mm/day respectively.***

Keywords: Photovoltaic water pumping system, dry areas, nine combinations, PVsyst software, Irrigation power requirement (IPR).

I. INTRODUCTION

Water pumping worldwide is generally dependent on conventional electricity or diesel generated electricity. Solar water pumping minimizes the dependence on diesel, gas or coal-based electricity [1]. The use of diesel or propane-based water pumping systems require not only expensive fuels, but also create noise and air pollution. Solar pumping systems are environment friendly and require low maintenance with no fuel cost. Keeping in view the shortage of grid electricity in rural and remote areas in most parts of world, P.V pumping is one of the most promising applications of solar energy. The technology is similar to any other conventional water pumping system except that the power source is solar energy. P.V water pumping is gaining importance in recent years due to non-availability of electricity and increase in diesel prices. The flow rate of pumped water is dependent on incident solar radiation and size of P.V array. A properly designed P.V system results in significant long-term cost savings as compared to conventional pumping systems.

In dry areas agricultural activities are largely dependent on rainy seasons and is adversely affected by the non-availability during the dry spell season [2]. However, maximum solar radiation is available in dry spell season as such more water can be pumped to meet increased water requirements. Urban water supply systems are also dependent on electricity to pump water in towns. There is a wide scope to utilize PV pumping systems for water supplies in remote rural areas as well as, urban, industry and educational institutions.

Fig.1. Desertification's threat in dry areas

II. LITERATURE REVIEW

A. Introduction

This section highlights the theories upon which the research is based on as well as the empirical review of existing related research. It is organized starting with theoretical literature and empirical literature review. In general, a brief literature review establishing the theoretical and modeling foundation of the research study is discussed.

B. Sizing and Modelling of Photovoltaic water pumping system

Hamidat and Benyoucef [3] proposed a mathematical model to find out the best choice of motor, and the inverter as the sizing of the PV pumping system is the most significant stage. The authors proposed mathematical models to calculate the water flow. The first model was able to estimate the total water flow for a fixed total head. Testing was done with two different pumping systems.

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The second models a more general scenario applicable for any total head of pumping. First one consists of three-phase DC/AC inverter, submersible AC motor and multistage centrifugal pump. The second option includes DC/DC controller, submersible DC Brushless motor, and a positive displacement pump. The authors applied the proposed mathematical models to observe the PV pumping system efficiency and found that DC engine with a positive displacement pump is more efficient and discharge more water than AC engine with a centrifugal pump for a wide range of total dynamic head.

Mokaddem [4] carried out an experimental study to investigate the performance of a low-cost direct-current PV system. The system comprised of PV array, permanent magnet (PM) DC. Motor coupled with a single impeller centrifugal pump and identical water storage tank. The authors tested the system for two different static heads and recorded all relevant operational parameters for four months. Fixed operating point for steady state operation was decided from the I-V characteristics of motor-pump set and PV array I-V characteristics. The conditions were: motor and pump torque remain equal, the voltage across motor armatures is equal to the voltage supplied by the PV array, and motor armature current is same as the current delivered by the PV array. The authors observed that the motor has a greater impact on motor-pump overall efficiency than the pump. From the observations, the authors found that the system is suitable for low delivery flow rate application. Meah [5] examined the feasibility of PV water pumping system and found that it is a cost-effective application in developed countries whereas in developing countries, it is facing some challenges, especially in operation and maintenance. They noticed that the capital cost is not only the constraint for solar PV application; some other technical and socio-environmental challenges are associated with it. Cell efficiency, availability of spare parts, skilled technicians, operation costs and maintenance costs are technical challenges. The authors gave some suggestion to overcome problems such as: health, ownership, theft/vandalism, community, and educational problem.

C. Modeling and simulation of Photovoltaic water pumping system

Jafar [6] examined simple method for modeling the output of a solar Photovoltaic water pumping system, which relies on easily measurable data. The procedure is applied to a Solar Star 1000 pumping system to develop a model that predicts the volume flow rate for a given head and irradiance. The model predicts the flow rate within 8 percent of the measured values. The small deviation is attributed to fluctuation in the solar irradiance and unsteady module temperatures during the measurements. Gad [7] developed a MATLAB simulation program to predict the performance of a direct coupled solar Photovoltaic water pumping system in Egypt. Solar irradiance data, Photovoltaic array with intermittent tracking and the pump models was used in the program. The system they proposed consists, Photovoltaic array, submersible pump, and pump controller. The program simulates the hourly performance of the system at any day of the year, under different PV array orientations. The south-facing PV array with different tilt angles yields the same result. The predicted values of PV array efficiency ranges from 13.86 % (winter) to 13.91 % (summer) which is larger than the specified efficiency (13) by tender.

D. Software tools for Photovoltaic system

A large simulation tools exist for analyzing and dimensioning a Photovoltaic system widely. These include HOMER, System Advisor Model (SAM), PVsyt, RESTScreen, Solarius PV, Solar pro, PVF-chart, SOLARGIS, and Helioscope.software.This computer software is used to calculate sometimes annually, monthly,weekly or daily solar energy output of a Photovoltaic system. In this study five (5) different softwares (HOMER, Photovoltaic System, Helioscope, RETScreen, and SOLARGIS pvPlanner) developed for Photovoltaic system simulation have been studied in order to find the best among them befitting for our study case discussed along with a comparative analysis. The study was carried based on the performance analysis, PV sizing, data analysis, economic analysis, advantages and limitations of the software.

E. PVsyst (Photovoltaic System*)*

PVsyst is Photovoltaic system software developed by Swiss physicist Andre Mermoud and Electrical engineer Michel Villoz [8]. To start a simulation, PVsyst has four features include Preliminary Design, Project Design, Databases, and Tools which gives the user the possibility to select the one corresponding to his project. It simulates grid-connected, standalone, pumping, DC-grid PV system, PV systems components databases, as well as general solar energy tools. PVsyst is a very helpful software for educational training in school, also can be geared by architects, engineers, and researchers. Worldwide, this software is considered a standard for PV system design and simulation tool which is the most convenient. The inputs data require are location (Altitude, longitude and Latitude), plane orientation, system components, PV array (number of PV modules in series and parallel), inverter model, battery pack etc. to perform the simulation. In PVsyst good results are generated in graphs in terms of yearly, monthly, daily or hourly. For each simulation run the results are printed one by one. An economic analysis is always performed giving the real prices of components, additional costs, investment conditions. PVsyst software has limitation like unfitness to handle detailed on shadow analysis, the screen of the computer is always the same, it cannot be maximized therefore using a small monitor is absolute.

Table- I: Advantages and disadvantages of PVsyst software

Advantages	Ability to identify the weaknesses of the system design through loss
	Good diagram; results include several dozens of simulation variable
	Extensive meteorological and PV systems components databases
	User-friendly
Limitations	Inability to handle shadow analysis,
	No single line diagram,
	Program screen cannot be maximized to enable user to see all parameters

III. METHODOLOGY

The approach used in this study is shown as indicated in the figure 2:

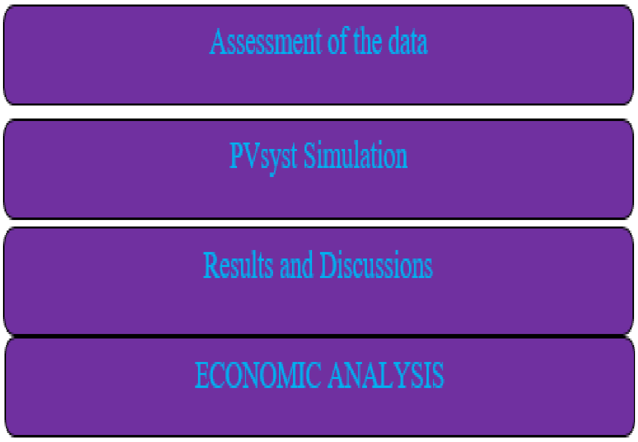

Fig.2. Summary of the research methodology

A. Assessment of the data

The assessment of the data collected in this work was carried out by assessing the weather parameters which were the Maximum and Minimum temperature, the average of solar radiation rate, the wind speed, and the Maximum and Minimum relative humidity of the particular area metrological.

A. Area of the data collect

The data used in this research was obtained from Lodwar town, Turkana Country, Kenya. Turkana County is a county in the former Rift Valley Province of Kenya. In term of land area, Turkana is the second largest after Marsabit County with an area of nearly 77,000 km^2. According to the Kenya 2009 National Population and Housing Census report, the county has a total population of 855,399[9] people. Lodwar is the capital of Turkana County with a population of 48,316. Figure 3 represents the area of study.

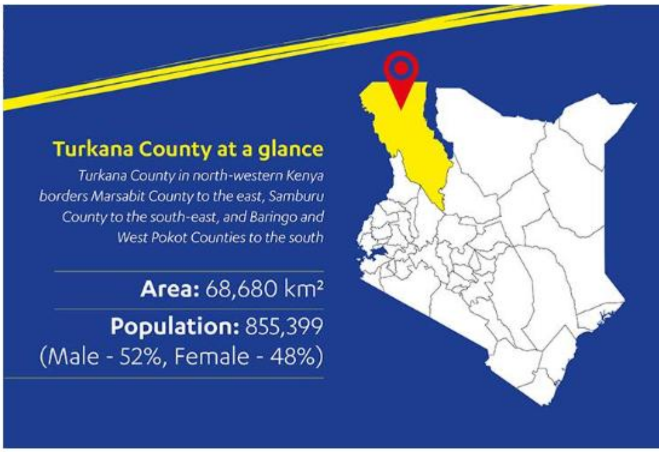

Fig.3. Map of Kenya showing the area where the data was collected

C. Type of data and the sources

The data used in this research study are of two types i.e. Experimental and Metrological data, collected from Turkana Metrological Station for the year 2018-2019.

a. Experimental Measurements data

In the literature, there exist several methods for modeling solar radiation components (global, beam, and diffuse) on the ground of parametric models and decomposition models. Solar irradiance, is measured in terms of power per unit at a particular time. The units can be W/m^2 or kW/m^2.This measurement is instantaneous and is only valid for a particular point in time. A more useful measurement is the amount of solar energy received per unit area over a given time frame. This is called irradiation

Fig.4. Solar Radiation experimentally using radiation pyranometer

Fig.5. Maximum and Minimum temperature experimentally

Fig.6. Maximum and Minimum Relative Humidity experimentally by using the Dry Bulb thermometer

b. Meteorology data

Meteorological data was obtained from Turkana Meteorological Station Department. This data was obtained for the Year 2017-2018.This is a polar orbiting satellite at an altitude of 1.5 km. It consists of three instruments- Atmospheric Infrared Sounder (AIRS), Advanced Microwave Sounding Unit (AMSU) and the Humidity Sounder (HS).The instrument of Air senses the earth's infrared using several detectors, each assessing a particular wavelength. It gives various measurements such as water vapor, clouds, precipitation among others.

Table .II. Meteorological data for the year 2018-2019

Months/ Temp	Min °C	Max°C	Mean°C	RsMJ/m^2	Net Rs MJ/m^2	HR %	U m/s
Jan	19	34	26.5	17.87	10.06	22	8.5
Feb	23	37	30.0	19.41	10.97	20	8.4
Mar	25	40	32.5	20.40	11.58	25	7.2
Apr	28	42	35.0	20.97	11.93	38	7.7
May	27	39	33.0	21.01	11.96	52	8.2
Jun	25	36	30.5	21.13	12.03	65	8.5
Jul	24	34	29.0	20.20	11.41	77	7.7
Aug	23	33	28.0	19.12	10.80	82	6.0
Sep	23	34	28.5	20.25	11.49	79	5.6
Oct	23	37	30.0	20.33	11.54	60	6.2
Nov	21	38	29.5	19.29	10.90	32	7.6
Dec	19	35	27.0	18.40	10.35	25	8.3

D. PVsyst software simulation

PVsyst software of Photovoltaic developed have been used in order to find the most befitting power requirement for the Dosso area PV array system. PVsyst is a comprehensive Photovoltaic system analysis and design program. Historically the software was developed in the year 1978 by the University of Geneva [8] It calculates the size of PV system considering the specific location, the specific loads, and the designer selects the different components afterwards the results are automatically given. This software allows the user to estimate energy production that accounts for losses due to weather and climate. PVsyst software simulation processes the data in four sections that include preliminary design, project design among others as shown in figure 7.

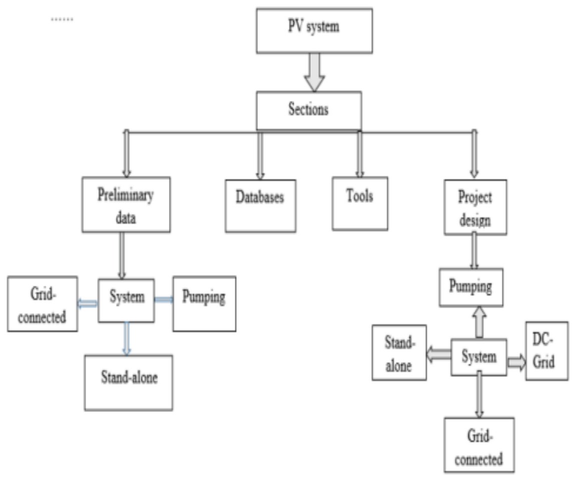

Fig 7: Flowchart of the PVsyst design process

E. PVsyst simulation input data

PVsyst requires some input data such as the area climatic data like the latitude, the longitude, the altitude, time zone, the geographical country location, the azimuth and the tilt angle orientation.

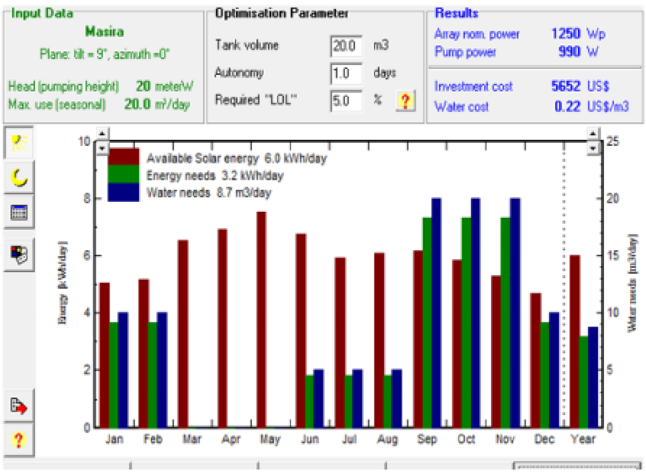

Fig 8: Energy generation and use graph

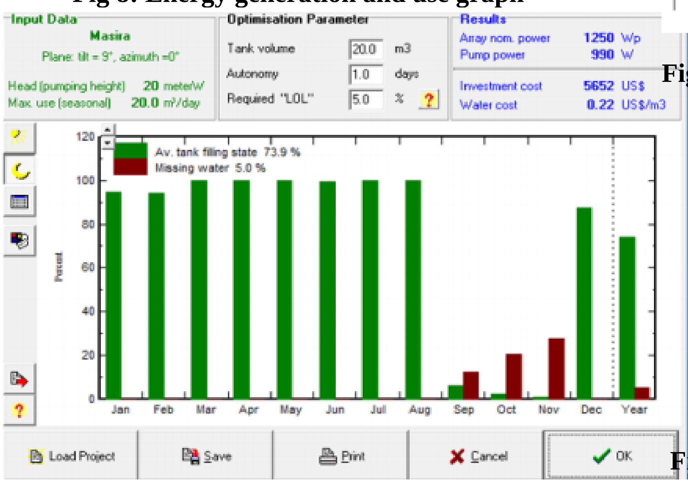

Fig 9: Loss of load and battery state of charge (SOC)

IV. Results and Discussion

A. PV array and Pump sizing

In order to find the estimated PV array power generation, PV system software was used to simulate the entire system. Under nine combinations of pump technology and converter type the best among them was found as illustrated in the following tables and figures:

Table 1: The 9 combinations

Technology of the pump type	Power converter
DC positive displacement	Direct coupling
	Direct with current booster
	MPPT(Maximum power point tracking)
AC positive displacement	Direct coupling
	Direct with current booster
	MPPT(Maximum power point tracking)
Centrifugal	Direct coupling
	Direct with current booster
	MPPT(Maximum power point tracking)

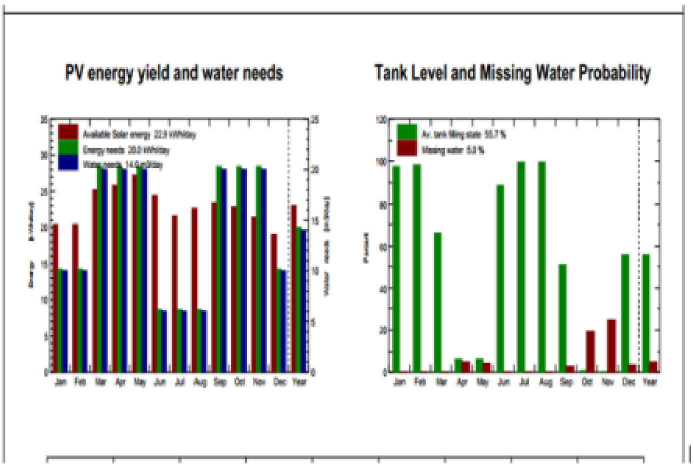

Fig 10: DC positive displacement pump & direct coupling pump converter combination

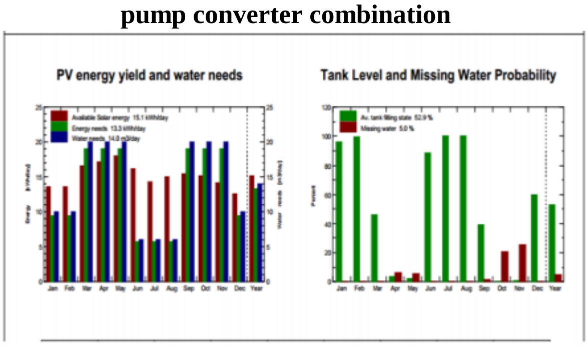

Fig11: DC positive displacement pump & direct booster current converter combination

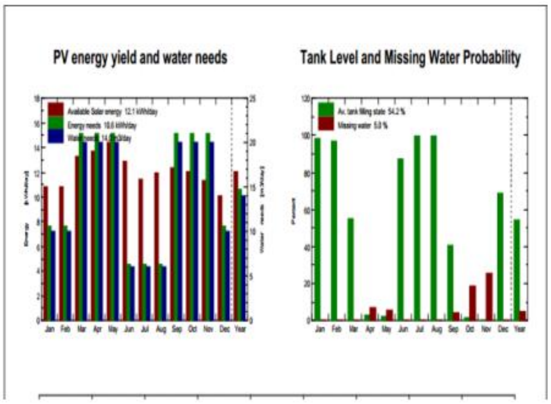

Fig.12: DC positive displacement pump & MPPT converter combination

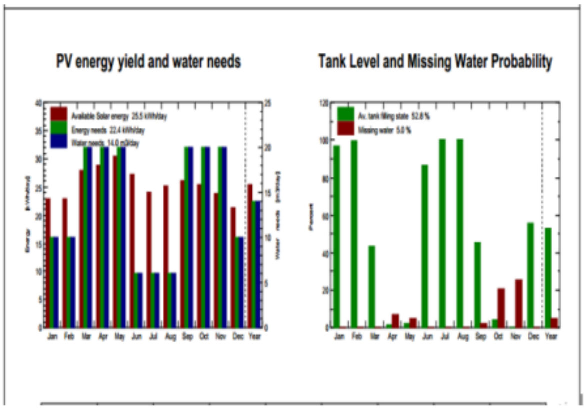

Fig.13: AC positive displacement pump & direct coupling pump converter combination

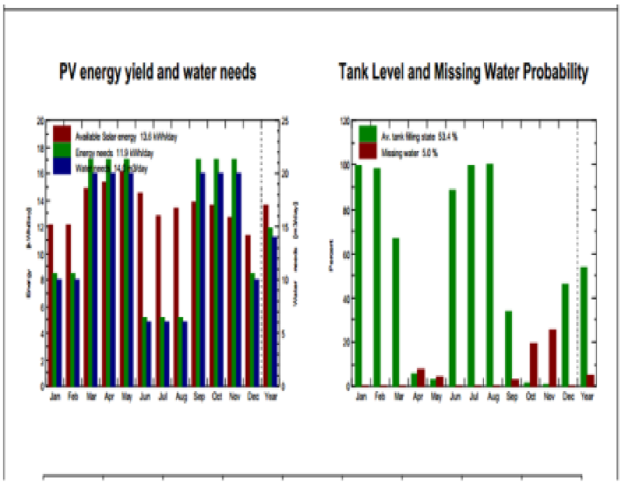

Fig 14: AC positive displacement pump & direct booster current converter combination

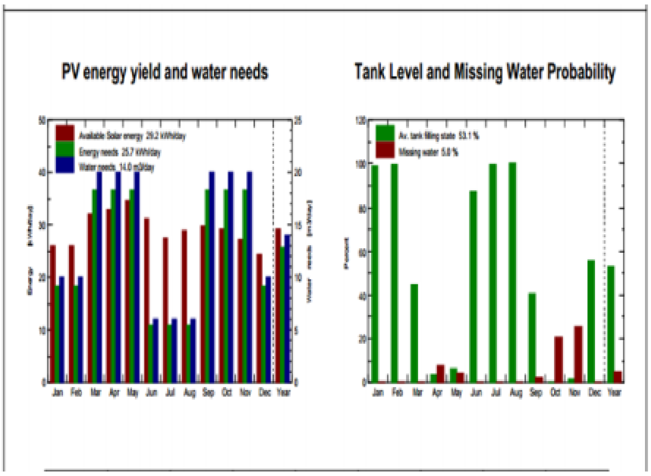

Fig.15: AC positive displacement pump & MPPT converter combination

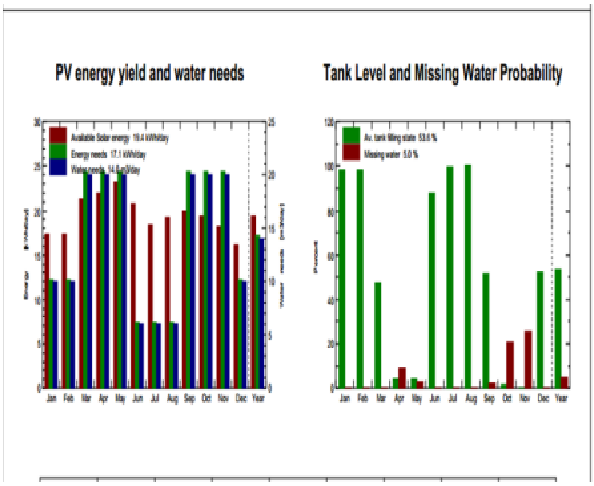

Fig.16: Centrifugal pump & direct coupling pump converter combination

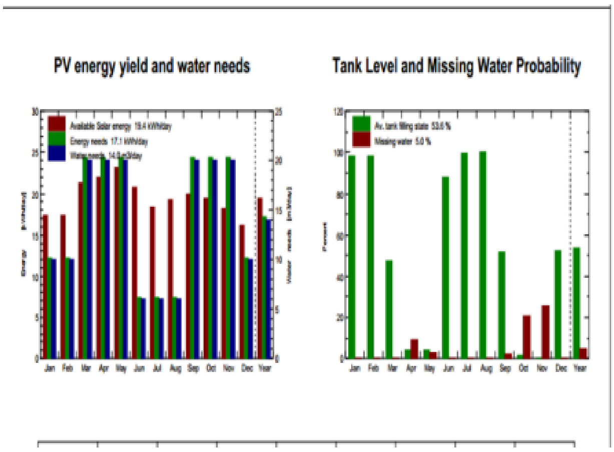

Fig .17: Centrifugal pump & direct booster current converter combination

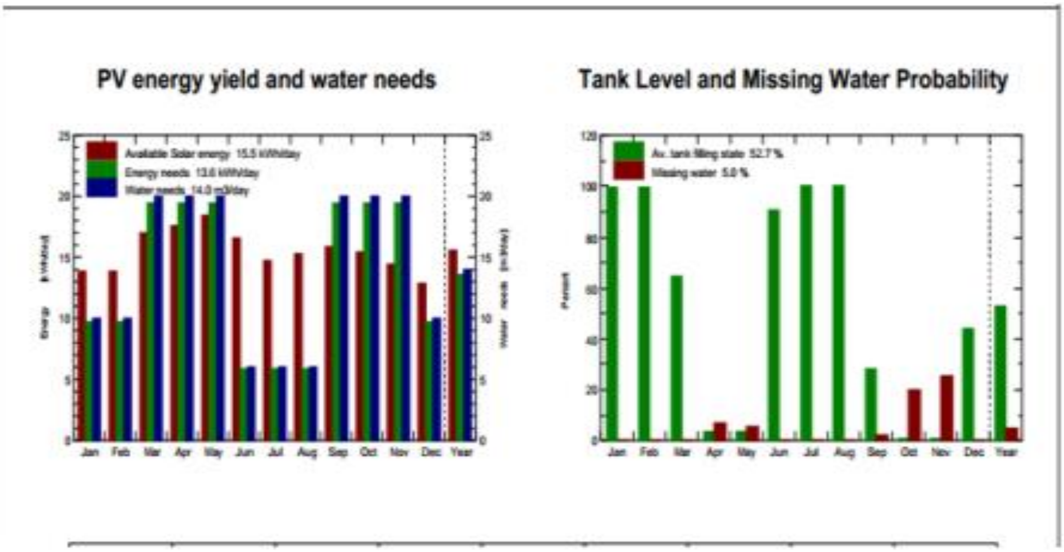

Fig.18: Centrifugal pump & MPPT converter combination

Table III: Simulation results are shown in the following table

Pump technology	Power converter	PV Nominal Power requirement in (Wp)	Pump power(Wp)
DC positive displacement pump	DC	5064	396
	DWB	3342	396
	MPPT	2671	396
AC positive displacement pump	DC	5633	396
	DWB	3733	396
	MPPT	2999	396
Centrifugal pump	DC	6437	396
	DWB	4293	396
	MPPT	3428	396

Based the simulation carried out to determine the PV irrigation power requirement which allows to design the PV array for the entire system the following array has been designed according to the best combination found. The array is composed with 12 panels (6 series x 2 parallel). This configuration was based on the normal configuration which gives the maximum solar energy in the particular area as stated by many researchers [10, 11].

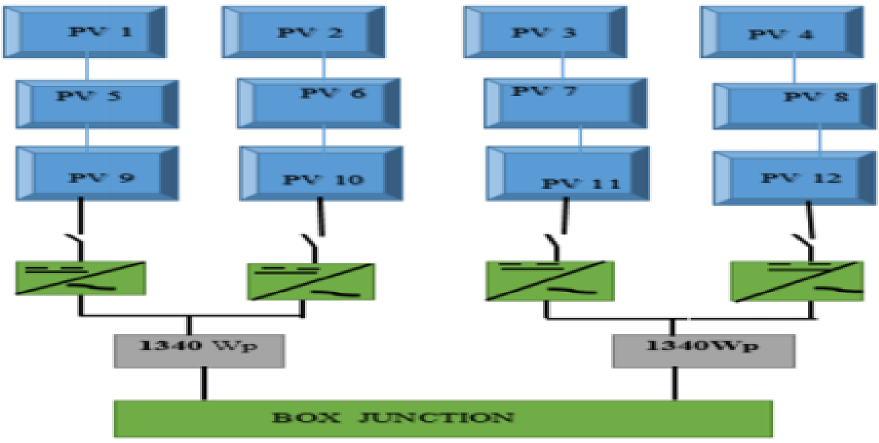

Figure 19: Array layout with 12 PV panels for 2680 Wp

VI. CONCLUSION

A study of an assessment of Photovoltaic water pumping in dry areas has been carried out in this research. Two types of data were used in this research which are historical meteorological and experimental. A PVsyst simulation has been carried out for nine combinations. The results found in this study are highly significant not only in terms of irrigation water requirement, and irrigation planning, but also in terms of power requirement for the entire system. The power generation of PV array and the pump sizing was carried by the PVsyst software which gives the best power required by the pump under the nine combination systems which is the DC positive displacement pump combined with the MPPT converter. Results obtained also showed that using Photovoltaic water for irrigation in small scale is technically and economically feasible for anywhere in dry areas worldwide. Moreover, the results showed consistency with previous published studies in literatures.

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