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Design of Smart Solar Water Pumping-Case study

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Abstract

One strategy to increase crop yields is irrigation, but not all agricultural areas have access to enough water for this to be effective. Diesel is also less efficient when used to irrigate agricultural land. Developing a solar-powered water pump system is an environmentally beneficial alternative that uses solar energy. Agriculture and food production consume one-third of the world's energy, which results in greenhouse emissions. Converting from traditional sources to renewables is crucial. Egypt is considered an agricultural country; agriculture is a key sector in the Egyptian economy. In 2021, it contributed 11.83% of the country's gross domestic product (GDP) and accounted for 28% of the total employment. To overcome problems resulting from traditional sources, a complete optimal design of a solar pumping system is carried out in this paper by using PVSyst software to meet the demand for irrigation of farms in Kharga Oasis, which results in an eco-friendly, low-cost design whose lifetime span is 25 years. Also, this paper includes monitoring the water level in the storage tank by using a water flow sensor controlled by an Arduino UNO and soil moisture to schedule irrigation time.

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Keywords: Renewable Energy, Photovoltaic System, Water pumping, Irrigation , PVSyst.

List of Abbreviations

GDP	Gross Domestic Product
PVsyst	Photovoltaic System Software
GHG	Greenhouse gas
CH4	Methane
N2O	Nitrous Oxide
Co2	Carbon Dioxide
UN	United Nations
COP27	Conference of the Parties 27
PV systems	Photovoltaic systems
PV Planner	Photovoltaic planner software
Meteo	Meteorology
NASA	National Aeronautics and Space Administration
SAM	System Advisor Model Software
GPS	Global Positioning System
PVGIS	Photovoltaic Geographical Information System Software
TDH	Total dynamic Head
Meteonorm	Software provides meteorological data and weather generation
MPP	Maximum Power Point
STC	Standard Test condition
IAM losses	Incidence angle modifier losses
PV modules	Photovoltaic modules
PR	Performance ratio

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List of Symbols

Q	Flow rate
V	Volume
t	Time
F	Friction Factor
L	Pipe Length
V	Velocity
D	Pipe Diameter
g	Acceleration Gravity
k_s	Minor Loss Factor
p_h	The hydraulic power of the water pump
ρ	Density Of Water
h	Total Dynamic Head

1. INTRODUCTION

Global emissions from the food sector accounted for 34% of all greenhouse gas (GHG) emissions in 2015. Agriculture and land use/change accounted for 71% of this, with supply chain activities accounting for the remaining portion. In 2015, the pre-farm gate emissions accounted for 39% of total emissions, with land use and lane use change accounting for around 32%. These emissions included emissions from agriculture, aquaculture, and fisheries as well as emissions from the manufacturing of inputs like fertilizers. The importance of greenhouse gas emissions from agriculture differs throughout nations. Methane (CH4) and nitrous oxide (N2O) can be major greenhouse gas emissions in pre-farm gate agriculture, in contrast to most sectors where carbon dioxide (CO2) is the primary GHG. Among the key industries that contribute significantly to the global economic development of a country is agriculture. Global population growth and rising living standards have increased demand for nutritious food and, in turn, cleaner energy sources to sustain such food production in the agriculture sector [1]. It is predicted that by 2050, about 80% of the world's population would live in cities [2]. This is crucial, as the world's population would expand by 3 billion people, requiring a 70% increase in agricultural productivity. It is known that a sizable portion of Egypt is used for agriculture [3]. Since agriculture produces food, which is essential to human life, and makes a substantial contribution to the GDP, it is the backbone of most economies in developing nations [4].

Egypt is one of the countries where the majority of people work in agriculture with 28% of total employment. For irrigation, Egyptian farmers use a diesel generator. However, diesel pumps have numerous disadvantages, including high operating and maintenance costs, inconsistent fuel supply, the abundance of spare parts, and greenhouse emissions. As we all know, the world's fossil fuel resources are depleting at an alarming rate. In accordance with statistics, such resources will soon run out. Fossil fuels result in climate change action; the world is in a crucial decade. The UN's Intergovernmental Panel on Climate Change states that in order to keep global warming to 1.5°C or less, greenhouse gas emissions must peak before 2025 at the latest and then be cut by 43% by 2030. The goal of limiting global temperature rise to 1.5°C above pre-industrial levels was reaffirmed by nations at COP27. That means the global economy must "mitigate" climate change by reducing or preventing greenhouse gas emissions in order to get to where science indicates we need to be by 2030. As a result, Sharm el-Sheikh launched a mitigation work program with the immediate goal of stepping up mitigating goals and implementation. The work schedule will start right away and run until 2026, at which point it will be reviewed to see if it should be extended. As a result, it is urgent to switch back to natural resources, which are renewable technologies, and to use fewer non-renewable energy sources. One of the most widely used renewable energy generation techniques is solar based [5].

Solar energy is unbounded and unrestricted by any means because of the sun. Egypt aims to reach 60% renewable energy by 2040. The prices of renewable energy in Egypt are among the cheapest in the world, given the country’s vast resources in the solar and wind energy sectors, which makes investing in Egypt economically feasible. Maintaining and enhancing the security of food and energy production is a major challenge to developing resilience in the face of a changing and unpredictable environment. Such attempts are impeded, in part, by a conventional understanding of land use that claims a 'zero-sum-game' of rivalry between various sources of renewable energy—particularly solar PV installations—and agricultural food production [6]. In this study, we take Ezbet Tulieb as a case study to design a smart water pumping system, as in kharga oasis in Egypt fill with wells. By using PVsyst to illustrate the design of water pumping system and its performance and selection of pump, pipes, PV modules, and inverter. There is various software used for designing PV systems such as Homer, PV planner, and PVsyst. In this paper, PVsyst is used as it is known for its accuracy and dependability for studying, sizing, and analysing data from full PV systems such as grid-connected, standalone, pumping, and DC grid. Shade and spectrum analysis, module temperature computations, and comprehensive reporting are only a few of its capabilities. Homer software does not generate IV curve data or perform shading analysis.

Due to a lack of weather and module data, the PV electricity generation report is also less thorough and detailed. Many loss issues that occur during PV power generation are not considered in the computation. PV planner has no access to meteo data types, such as NASA, SAM, or user-recorded data that cannot be imported to PV planner. Also, you cannot perform near-shading analysis or put-up surrounding structures. It is only available online, so an internet connection is required. So PVsyst preferred to be used in this paper. A water level sensor is created during the initial stages of design in order to precisely sense the water level. By using a microcontroller to automatically control the entire system, the complexity of the design and control is decreased. The sensor unit, which uses to sense the water level, provides input to the microcontroller. Following the processing of the input variables, the resultant output determines whether to turn on or off the water pump based on the tank's current water level [7]. The second step is that automatic irrigation system must be able to continuously detect the soil's moisture level in order for this design to work. When the necessary amount of moisture is reached, the system will be able to react appropriately by irrigating the soil and then cutting off the water supply. The PV water pump system is executed through the utilization of the PVsyst 7.4 simulation software tool. This software aids in the design of the system and illustrates the impact of various parameters on the system's performance outcomes. It is imperative to carefully select the PV system, controller, pump, water supply network, and other components in order to fulfil the design prerequisites [8].

2. THE AGRICULTURE SYSTEM DESIGN

In order to accomplish the required daily water discharge in m^3 and prevent system oversizing, the solar water pumping system must first be correctly identified, along with the required water volume during various seasons [9]. factors for an accurate solar water pumping system are described in this section, including technical, economic, and weather factors. The configuration of the solar water pumping system is shown in (Fig. 1) which consists of solar modules, hydraulic pump, tank and well. The sizing of the smart solar water pumping system is shown in (Fig. 2) [10].

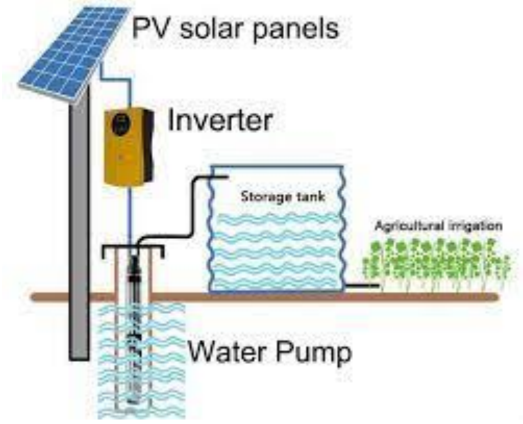

Fig. 1. The configuration of solar water pumping system.

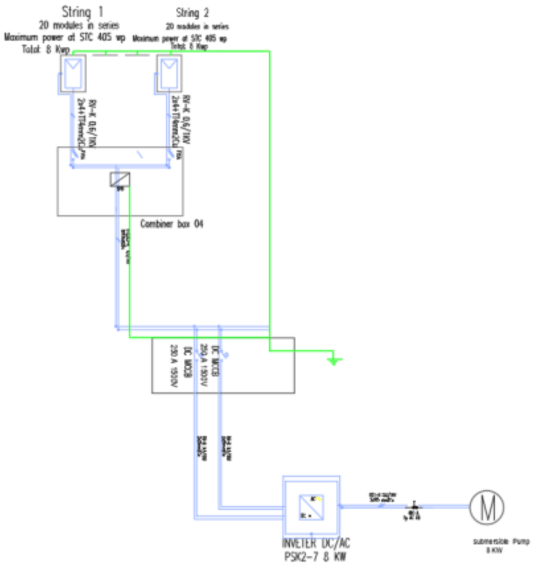

Fig. 2. Smart solar water pumping single line diagram.

2.1 Site Location

Ezbet Tulieb is located at (GPS Coordinates Latitude 25.69, longitude 30.62). It is farmland which has nearby wells which can be used for irrigation purposes. (Fig. 3) illustrates the location of the Ezbet Tulieb. The optimal tilt angle is 30° and the azimuth angle is 0° [10].

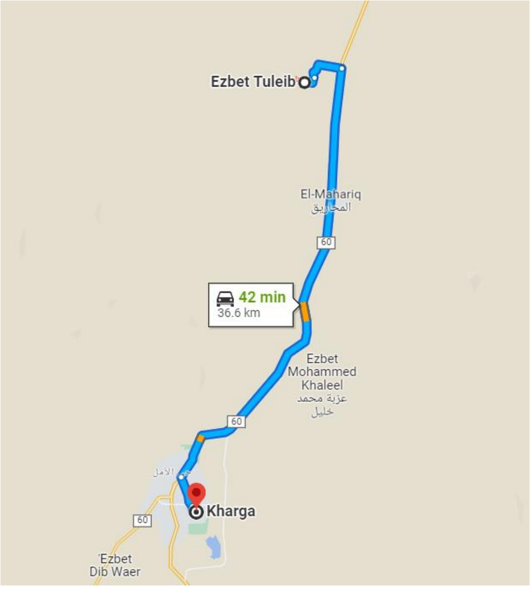

Fig 3. Location of Ezbet Tulieb on Google Map.

2.2 site irradiance

A location's viability depends heavily on how much sun irradiation it receives. It is the quantity of solar energy that is measured coming from the sun at a specific area. Solar radiation is available year-round [11]. The solar radiation incident on Ezbet Tulieb range from 6.3KWh/$\boldsymbol{m^2}$/day and 7.61KWh/$\boldsymbol{m^2}$/day and it's obtained by Photovoltaic Geographical Information System (PVGIS). (Fig. 4) illustrates the amount of solar radiation incident on Ezbet Tulieb throughout the months of the year.

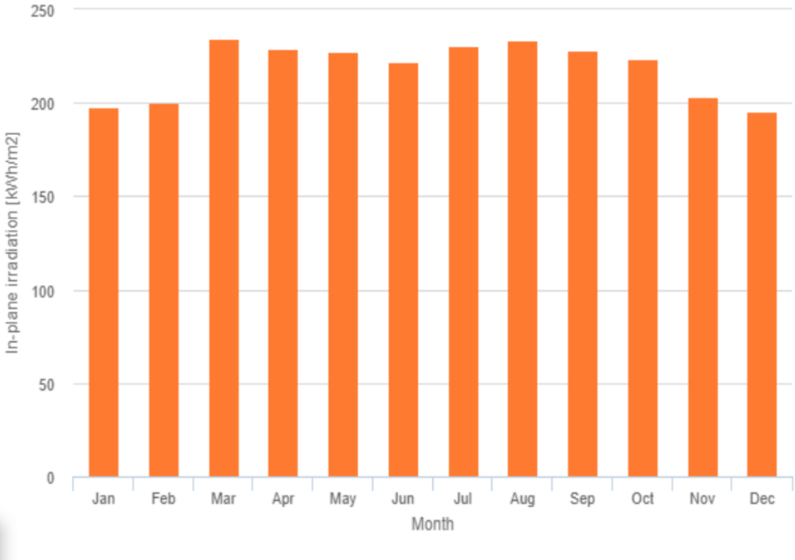

Fig. 4. Monthly irradiation incident on Ezbet Tulieb.

2.3 Water needs

The first stage in sizing a solar-powered water pump system is figuring out how much water is needed overall. Crop type, period, season, and growth all affect how much water is needed for each type of crop [11]. Other considerations that influence system design include the kind of soil and the climatic characteristics. We consider the requirement of water is 300m^3/day and one autonomy day.

2.4 The Flow rate

The required flow rate is calculated by the equation [12]

$$Q = \frac{V}{t} \tag{1}$$

Where:

Q is the flow rate m^3/sec
V is volume m^3
t is time sec

2.5 Well characteristics

The groundwater is regarded as the only supply of water in EI-Kharga Oasis, Egypt, and it serves a variety of functions. The well case of study is located in Ezbet Tulieb [13], where
Static level=30m
Draw dawn=0.09m/m^3/h
Pump depth=50m
Borehole Diameter=20cm

2.6 The total dynamic head

The heights to which the water is pumped are added together with the head losses caused by the water flow inside the pipe to determine the overall head [14].

$$TDH = Static\ Height + \ Static\ Lift + \ Friction\ Loss \tag{2}$$

The friction loss is calculated by the equation

$$Friction\ Loss = \frac{flv^2}{2Dg} + \frac{k_s v^2}{2g} \tag{3}$$

Where:
F is the friction factor
L is the pipe length
V is the flow velocity
D is the pipe diameter
g acceleration gravity
k_s minor loss factor

2.7 Pump selection

A mechanical or electromechanical device called a solar-powered water pump uses solar phenomena to create a pressure differential in order to transfer water through pipes or hoses. Positive displacement pumps and centrifugal pumps are the two most prevalent types of water pumps. Compared to internal combustion engine-powered pumps, a solar-powered pump can be more environmentally friendly and cost-effective to operate. The following elements influence the pump's selection. The quantity and quality of water needed, the number of vertical head required, the pipe's length, and the water's temperature and quality. The chosen pump depends on the design is a solar Submersible pump Lorentz_PSk2_9_CS_F_20_7 for 6’’ wells with a maximum total head of 50m and flow rate of $42m^3$/h. The rated maximum power is 8KW and the maximum input voltage is 850 V [11] [15].

The hydraulic power of the water pump (p_h) is calculated as

$$p_h = \rho g h \frac{Q}{3600}\ w \tag{4}$$

where:

ρ, density of water
g, acceleration gravity
h, total dynamic head
Q, flow rate

2.8 Solar module Selection

The photovoltaic effect is the result of the sun's photons hitting the solar panel and striking an electron, and since we know that an electron in motion produces current, this process is what causes the photons to hit the electron. The primary elements used to power the solar pump are solar panels. Interconnections are built using series or parallel combinations to achieve the desired voltage and power for the pump. We select Tongwei solar manufacturer with model is TWMPD-54HS405 solar module as it is characterized by its high efficiency which reach 20.7%and half cut technology. The Solar pumping system design results in 2 strings, each string consisting of 14 modules. Table 1 shows the specification of TWMPD-54HS405 at STC.I-V curve illustrates the maximum voltage increases with raising in radiations and decreases with raising in temperature while current increases with raising in radiations and slightly increases with increasing in temperature, overall, the power increases with raising in radiations and decreases with raising in temperature as shown in (Fig. 5) [16] [17].

TABLE 1. SOLAR MODULE SPECIFICATION

Specification	Parameter
Type	TWMPD-54HS405
Rated Maximum Power(W)	405
Open Circuit Voltage(V)	37.23
Maximum Power Voltage(V)	30.73
Short Circuit Current(A)	13.87
Maximum Power Current (A)	13.18
Module Efficiency(%)	20.7

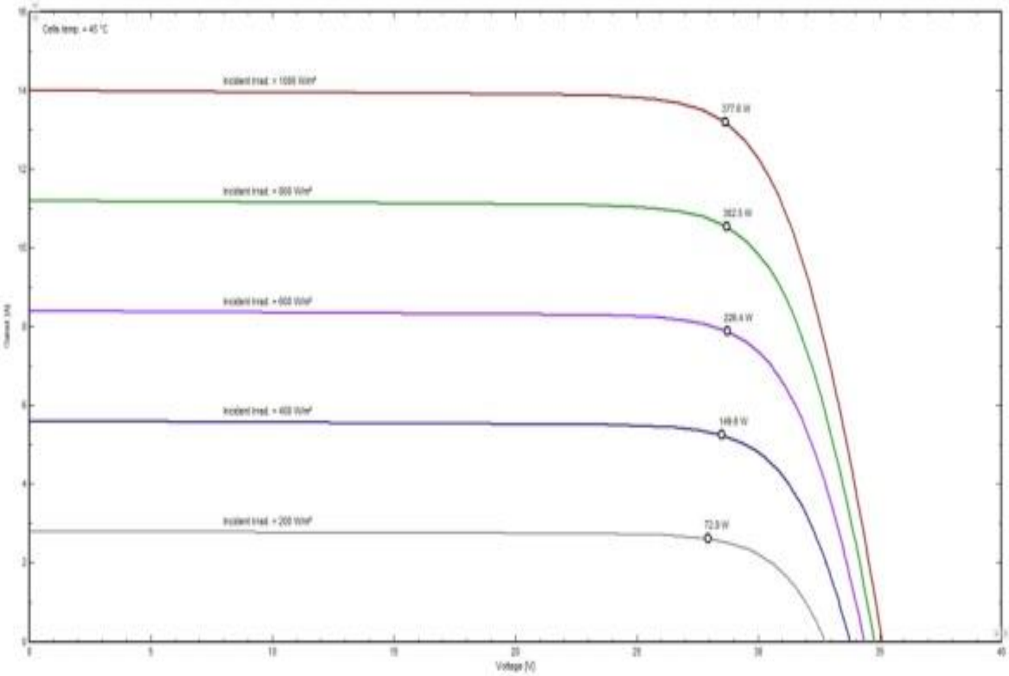

Fig.5. I-V curve under different radiations and temperature.

2.9 Inverter Selection

The inverter is also a critical component of the solar pumping system. The power from photovoltaic modules is converted into AC power via an inverter. The output of the inverter should be the same as the output of the pump. Table 2 shows the specification of Lorentz PSK2-7 centrifugal pump Inverter [10]-[14].

TABLE 2. INVERTER TECHNICAL DATA

Technical Data	Value
Rated Power	8KW
Input String	2
Max. Input Current of Each String	17A
Max. DC Input Voltage	850V
Recommended MPP Voltage	575-720V
Adapting Motor Power	5.5-7.5KW
Adapting Motor Voltage	380-440V
Rated AC Output Current	11.8A
Output Frequency	0-50/60Hz
MPPT Efficiency	98%

2.10 Storage tank selection

Because solar yield is not continuous, we integrated a storage tank in the design. For gravity-based water distribution, the storage tank is elevated above the ground in a way that maximizes static pressure. The size of the water storage tank is determined by daily water use and water to be pumped. Water storage capacity should be sufficient for days of autonomy. We have accurately defined all of the parameter such as storage volume, tank diameter, water height, and alimentation mode in the PVsyst software [11]- [18].

2.11 Automatic irrigation system

The automatic irrigation system must be able to detect the level of the irrigation water in the storage tank and soil's moisture level continuously in order to function properly under this configuration. When the required amount of irrigation water in the storage tank is measured by the water level detection sensor and it results in the level of water in storage tank is low, the system will be able to turn on the feeding pump and also it is able to measure moisture of the soil by soil moisture sensor, the system will be able to respond correctly by watering the soil and then shutting off the water supply. Figure 6 shows the flowchart diagram which illustrates the basic operation of both water level detection sensor and soil moisture sensor used in this automatic irrigation system. First water level detection sensor measures the level of the irrigation water in storage tank at intervals, sends the data as a digital signal to the micro controller then micro controller decides if the level of water in storage tank is high or low. If the level of irrigation water in storage tank is lower than pre-set value, the micro controller actuates the feeding pump. The soil moisture sensor measures the resistance of the soil so when moisture sensor measures the soil resistance is higher than pre-set value, the micro controller actuates irrigation pump. (Fig. 7) shows a part of the code used in programming the Arduino Uno [19-21].

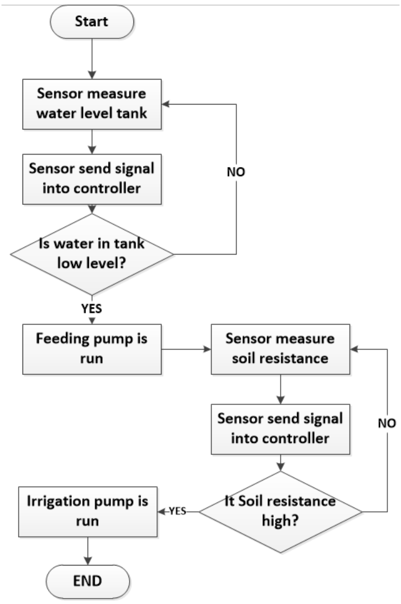

Fig.6. Flow chart of solar water pumping framework.

```
#define feedingpump          4  //D10
#define valve                6  //D10
#define PumpRelay            5   //D5
#define ModeSwitchPin        8   //D8
#define UpTankLevelHigh      9   //D9
#define UpTankLevelLow       10  //D10



bool IndicatrLED;
bool toggleState_1;
String val;
int soilmoisturevalue=0;
int percentage=0;
void setup() {
  // put your setup code here, to run once:
 Serial.begin(9600);
  pinMode(PumpRelay, OUTPUT);
  pinMode(ModeSwitchPin, INPUT_PULLUP);
  pinMode(UpTankLevelHigh, INPUT);
  pinMode(UpTankLevelLow, INPUT);
  pinMode(feedingpump,OUTPUT);
  pinMode(valve,OUTPUT);
   }

void loop() {
  // put your main code here, to run repeatedly:
  if(digitalRead(ModeSwitchPin) == HIGH )
```

Fig. 7. Implementation code of smart solar water pumping.

3. RESULTS AND DISCUSSION

The simulation by PVsyst results in a photovoltaic system that affords amount of water for irrigation equals to 109250m^3yearly. The overall efficiency of the system is calculated to be 80.1 percent, while the efficiency of the pump is 49.2 percent.

3.1 Ezbet Tulieb Geographical Site Parameters

Ezbet is located at latitude 25.69 °N and longitude 30.63°E which is Ideal for solar energy choice. PVsyst software database offers Meteonorm monthly irradiance data as shown in Table 3 with the data it calculates the average peak sun hour as shown in (Fig. 8) which illustrates the position of the sun during the day around the year.

TABLE 3. METEONORM MONTHLY IRRADIANCE DATA

Mon	Global horizontal irradiation (KWh/m^2.mth)	Horizontal diffuse irradiation (KWh/m^2.mth)	Temp ° c	Wind Velocity m/s
Jan	129.6	36.3	14.4	2.19
Feb	142.7	41.0	17.0	2.50
Mar	190.8	57.5	21.5	3.10
April	207.9	74.4	26.2	3.31
May	224.7	86.0	30.9	3.30
June	230.2	74.1	33.0	3.40

July	233.2	73.7	34.2	2.90
Aug	219.9	74.9	34.1	2.89
Sept	190.6	62.2	31.2	3.40
Oct	160.9	60.1	27.5	3.29
Nov	132.7	40.6	21.2	2.59
Dec	120.9	37.7	16.0	2.29
Year	2184.1	718.5	25.6	2.9

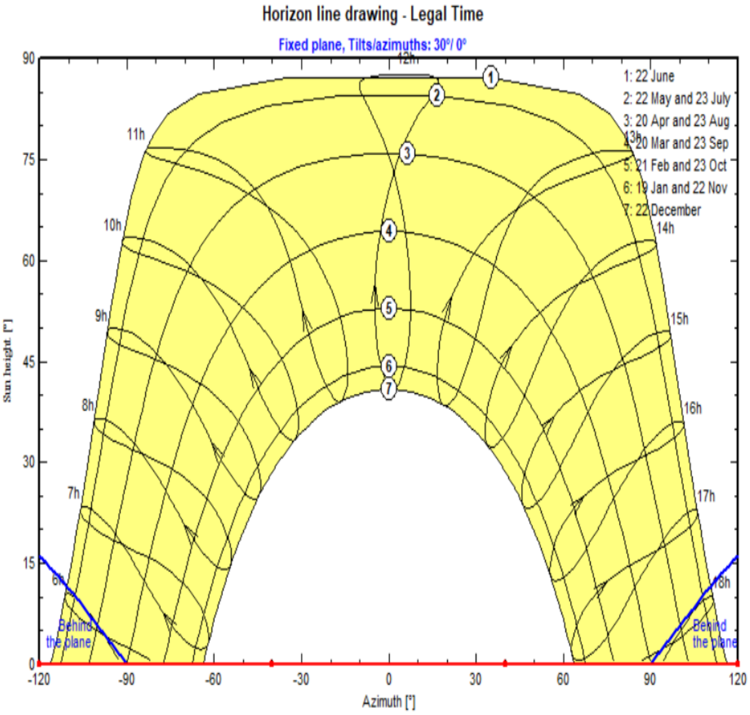

Fig. 8. Sun Path.

3.2 Normalized production

The normalized energy production per Kilowatt is installed for solar water pumping system. Normalized energy generation is almost high all around the year, the lowest value recorded at (May-July) as it is summer season and characterized by high temperatures. The effective energy at pump, system losses which include (converter, threshold), collection losses (PV array) includes (thermal, wiring, module quality, mismatch, IAM losses, shading, dirt, MPP, regulation losses) and unused energy (full tank) are 4.42 KWh/KWp/day ,0.89 KWh/KWp/day, 0.98 KWh/KWp/day and 0.25 KWh/KWp/day respectively. As shown in (Fig. 9) , the unused energy of solar water pumping system recorded its minimum value, however collection losses and system losses seem to be higher because designed solar water pumping produce maximum amount of the water (m^3) per day by using all of its available energy. When water production reaches its maximum, system faced maximum losses. While if we try to minimize the volume of water produced by the solar water pumping system per day, we can minimize the system and collection losses but this will lead to unused energy will increase.

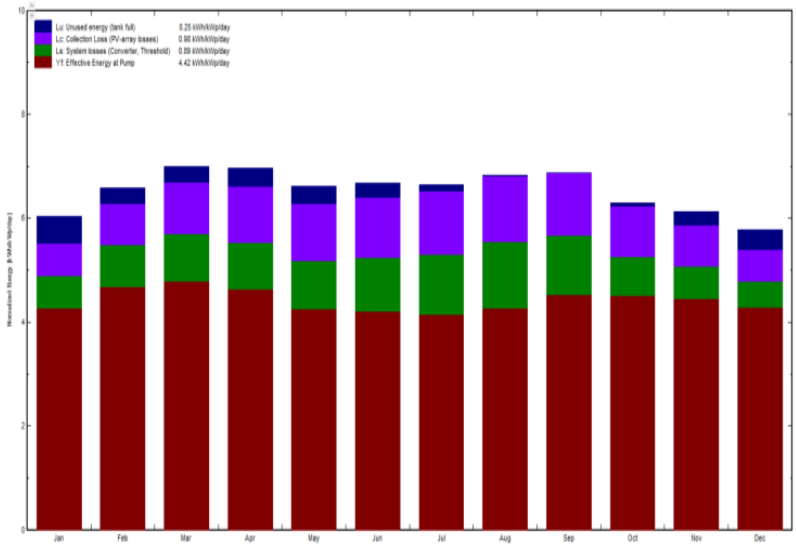

Fig. 9. Normalized Production.

3.3 Performance Ratio

The designed system's monthly variance in performance ratio (PR) is shown in (Fig. 10) . One of the most important aspects in determining the efficiency of a photovoltaic (PV) system is the PR. The ratio of actual energy production to the theoretical energy production is known as the performance ratio (PR). The Performance ratio is an indication of photovoltaic system performance that takes various environmental conditions (such as temperature and irradiance) into account. Throughout the year the performance ratio changes. The PR in October, November, December, January and February was relatively high, while it was rather low in May and June. The designed solar water pumping system has average annual performance ratio 67.6%.

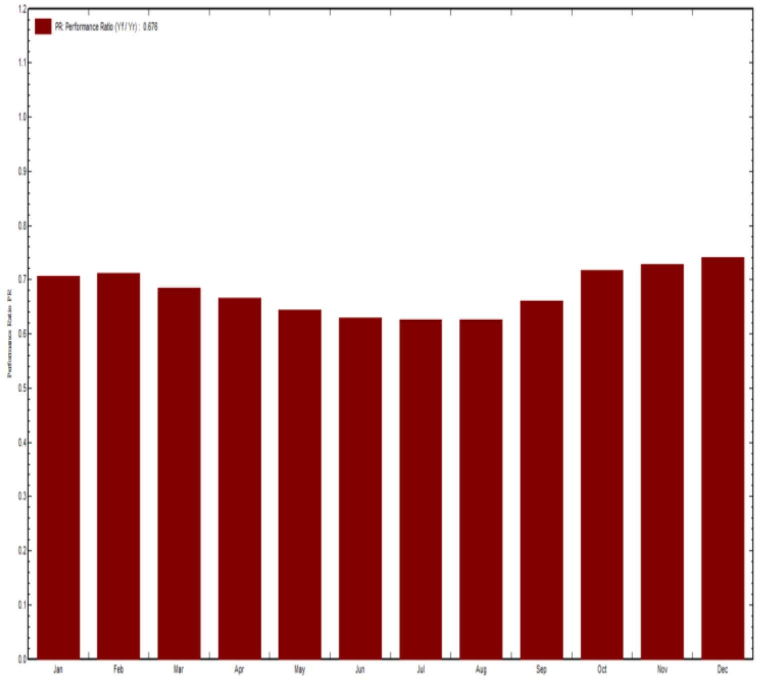

Fig. 10. Performance Ratio.

3.4 Designed System Loss Diagram

Overall loss diagram is shown in (Fig. 11). the horizontal global irradiance 2184 KWh/m^2. The effective irradiance that incident on the collector is equal to 2346 KWh/m^2. The PV converts the sunlight into electrical energy. As a result of conversion, the PV array nominal energy equals 38008 KWh. The chosen

PV module has a high efficiency equal to 20.75% at (STC). Because of thermal losses which are losses due to increasing of module temperature above standard test condition of 25°c , which are which is equal to 11.12% makes the MPP virtual energy drops to 32630 KWh. The output energy equals to 26125 KWh due to electrical losses. The pump efficiency is 49.2%. The total water pumped is 109250 m^3 which is equal to 99.7% of water needs that declared to the PVsyst software.

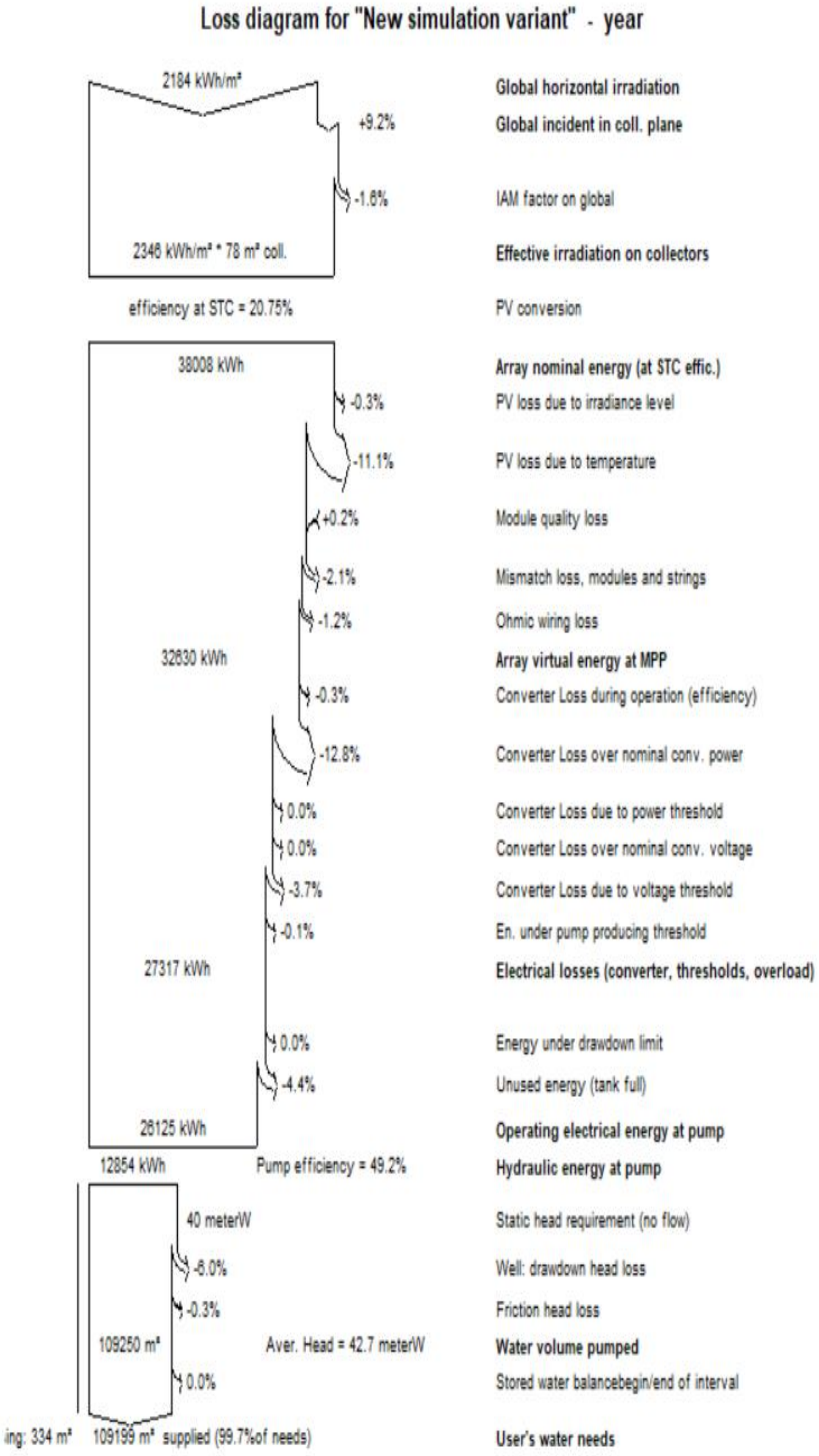

Fig. 11. Designed System Loss Diagram.

4. CONCLUSION

This paper highlighted the importance of expertise in the accurate design of solar pump systems. The researchers documented various design rules, optimal options and best practices. PvSyst software provides a platform for estimating water pump systems to maximize efficiency by collecting available information. The software uses Meteo files to provide several options for designing systems that meet daily needs, technological requirements and the number of solar panels required. By selecting the appropriate technology and assessing the efficiency and economic analysis of the photovoltaic system, this software simplifies the process. study achieved its purpose. The PVSyst Simulation results predicted a pump efficiency 49.2% and 99.7% of water needs for irrigation purposes which is sufficient percentage. The designed solar water pumping system is working properly even without batteries which reduces initial cost. This will lead to enhance environmental impacts as it reduces the greenhouse emission from the traditional irrigation system with diesel generator. Crops irrigated with PV systems are more useful and suited for long-term investment than diesel engines because PV systems have a 20-year life cycle.

The Arabian governments should encourage implementations of solar system by providing loans and other services to the framers. The Arabian governments should take advantage of its desert land, sunny weather, and underground water resources for agriculture. As we know water is an essential necessity for all living organisms, and its significance cannot be undermined. Regrettably, a substantial quantity of water is squandered as a result of unregulated consumption. In an attempt to address these issues, we endeavored to develop an effective automated system for monitoring and controlling water levels. The primary objective of our research was to establish a versatile, cost-effective, and user-friendly system capable of mitigating the issue of water loss. Also, the soil moisture sensor will inform the farmers of the soil moisture level, so that they can track what is happening on the farm without the need for physical presence. In forthcoming studies, PVsyst software can offer significant advantages in the facilitation of solar applications. The application layout allows for the predefinition of cost analysis and system efficiency, while the manipulation of parameters and configurations enables the evaluation of system performance. Furthermore, this software can be effectively utilized in grid-connected applications. By selecting various configurations of the submodules, one can identify the optimal solution for future endeavors. Besides that, the focus will be on enhancing the accuracy and efficiency of soil moisture sensors, as well as evaluating the effectiveness of the irrigation control system when compared to traditional irrigation scheduling approaches.

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