Design of a Solar Water Pumping System for Sukkur, Pakistan

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***Abstract*— Pakistan is an agricultural country, and agriculture contributes 18.7 % of the total GDP. To meet the needs of crops, diesel engines are widely used for water pumping. The rising price of diesel, along with carbon emissions, is producing economic as well as environmental complications. To overcome these issues, the economic feasibility of one experimental setup has been studied in this paper for a site in Sukkur Pakistan. To carry out the optimal analysis of the PV system for the fulfilment of electrical requirements, the NREL tool HOMER Pro is used. After feeding the site data, load details, and market prices, it used a complex algorithm to calculate the sizing results of a PV system. The finding indicates that designed PV system can meet the demand of solar water pumping irrigation system and the system has a life span of 25 years. The results indicate that the designed system is low-cost, eco-friendly solution for that site.**

Keywords—photovoltaic system, solar water pumping, homer, solar energy.

I. Introduction

The use of fossil fuels to generate electricity is one of the primary contributors to climate change caused by carbon emissions as well as to air pollution [1]–[3]. The development of sustainable sources of clean energy has become more important in many regions of the globe as a result of factors like as increasing prices for fossil fuels and the need to achieve energy self-sufficiency. The use of solar-powered (SP) pumps for agricultural irrigation has been proposed as a potential application since it is an energy-intensive activity that lends itself well to being implemented using renewable energy sources [4]–[7]. SPP irrigation, like any other use of alternative energy, must be technically and economically feasible before it can be considered a viable option. SPP irrigation systems have a negligible impact on the surrounding ecosystem and require minimal maintenance [8]–[11]. Irrigation in Pakistan is often accomplished with the use of non-renewable sources like diesel engines [12]. However, using these non-renewable sources is not only impractical from a financial perspective but also detrimental to the natural ecosystem [13]–[16].

In this study, we propose a solar-powered water pumping system to be installed in the city of Sukkur, Pakistan. This system would serve as a practical alternative to the other systems that are already in place in Pakistan. As can be seen in Fig. 1 [12], the lower area of Pakistan receives a disproportionately large amount of solar radiation as compared to other parts of the country. Therefore, SPP irrigation is preferable to other renewable and nonrenewable sources. By using *Photovoltaic System (PVSysyt)* [17], a model of SPP irrigation system is proposed. After that, by utilizing *HOMER Pro* [18], feasibility and cost analysis that considers the project's technical aspects as well as its financial and economic aspects.

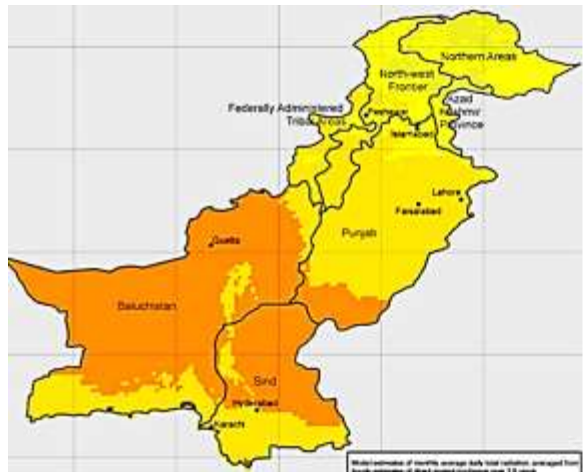

Fig. 1: Pakistan global horizontal solar radiation [4]

Section II will go through the specifics of the site. In the Section III, the details of proposed design produced by PVSyst and HOMER PRO are discussed. Section IV discusses the simulated results and Section V concludes the paper.

II. Site Details

A. Selected Site

As the site for the project, a farm that spans 20 acres and is in the tehsil of Saleh Pat in the district of Sukkur has been selected (GPS coordinates 27.481784, 69.051130). Figure 2 illustrates the location of the facility as it appears on Google

Fig. 2: Location of the Site on Google Map

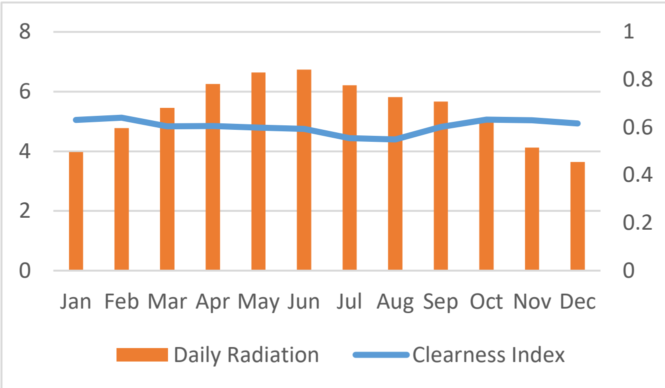

Fig. 3: Irradiance and Clearance Index of the Site

Maps. The area is covered with date palm plants separated by 20 feet by 20 feet. On the farm, there are around one thousand plants in various stages of growth. Fig. 5 shows the available setup on the site.

B. *Selected site solar insolation details*

The amount of solar irradiance a location receives is an essential factor in determining its viability. It is the amount of solar energy that is measured at a certain location from the sun. Solar radiation is accessible at all times of the year, as shown by Fig. 3, and its levels range between 3.64 and 6.73 kWh/m^2/day. The index of clearance is the metric that is used to assess the clarity of the atmosphere. Fig. 3 also demonstrates this for the specified place. Its value is never more than one and ranges from 0.550 to 0.640 during a year.

C. *Calculation of Load for Water Pump*

For the solar water pump load, site data collected is as follows:

Water required by date palm tree = 287 L/day [17]

Water required by 1000 date palm trees = 287 m^3/day

Flow Rate for 24 hours = 11.958 m^3/h

Since, the optimum solar insolation per day is 6-8 hours. Therefore, a higher flow rate is required to run the pump for 6-8

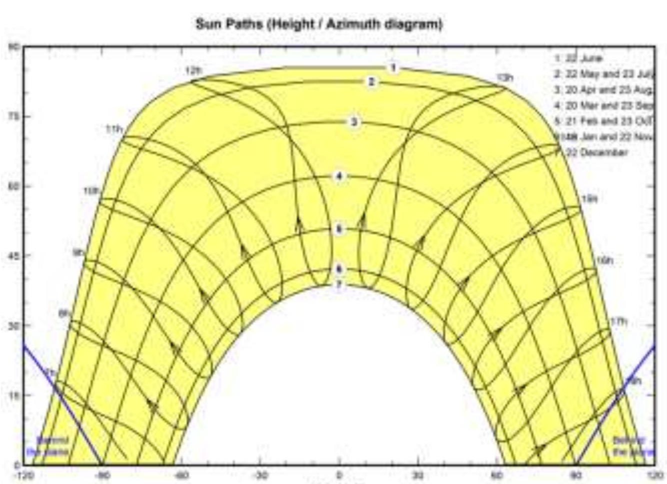

Fig. 4: Sun Horizon line at the project location.

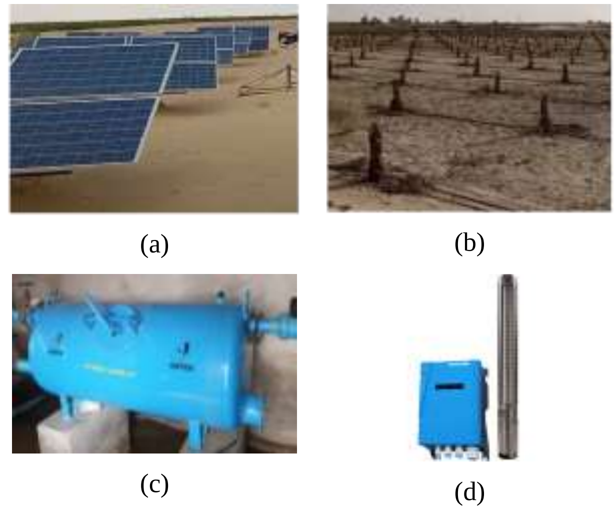

Fig. 5: (a) PV module, (b) Project Site, (c) Water Storage Tank, (d) Submersible pump

hours to achieve the required water. Computation for increased flow rate will be 24 hrs./6 hrs. = 4 times. So,

Flow Rate = 11.958 * 4 = 47.8 m^3/h

Water Depth = 100 feet = 30.48 m

Total Dynamic Head = 35 m

Hydraulic power of the water pump (P_h) is calculated as:

$$P_h = \rho \times g \times h \times \frac{Q}{3600} = 4557.5\,W$$

Where ρ = density of water, g = gravitational acceleration (m/s^2), h = dynamic head, Q = water flow (m^3/hour).

Motor efficiency (η) is estimated to be 80%. So:

$$Motor\ Power\ (P_m) = \frac{p_h}{\eta} = \frac{4557.5}{0.8} = 5696.82\,W$$

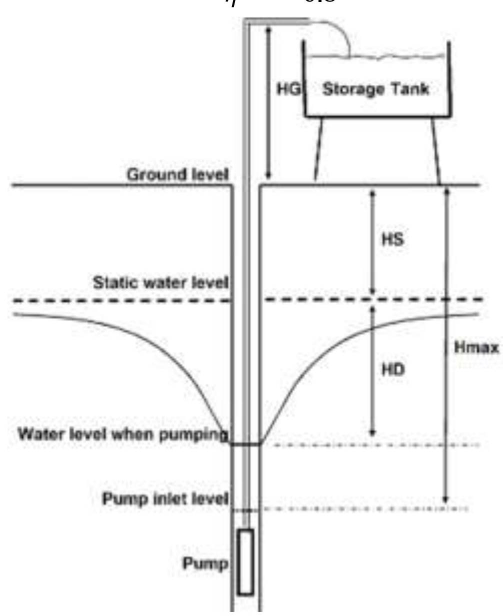

Fig. 6: Schematic of deep well system [4]

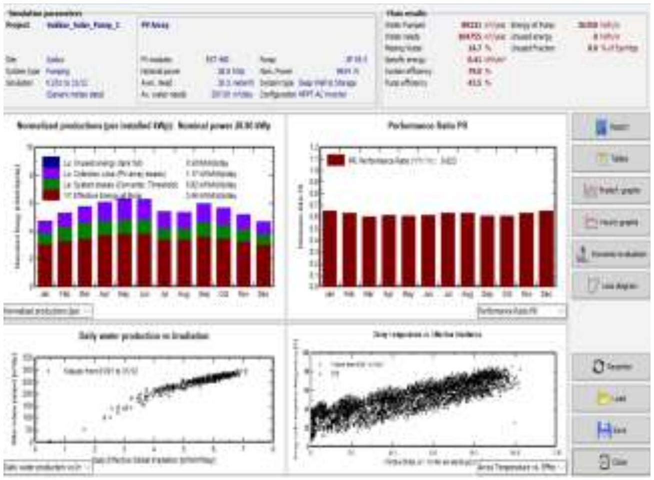

Fig. 9: Simulation result of proposed system in PVSyst.

Pump efficiency is estimated to be 50%, so:

$$Required\ Power\ (P) = \frac{5696.82}{0.5} = 11.394\ kW$$

Since, a motor is required in horsepower, therefore the required pump is estimated to be 15.27 hp.

III. DESIGN OF PV BASED WATER PUMPING SYSTEM

The Photovoltaic Systems (PVSyst) software [18] was used in the design process for the PV-based water pumping system that would be used for irrigation. Modeling, sizing, simulation, and analysis of photovoltaic (PV) systems are the primary objective of PVSyst. After that, an estimate of the cost of the design is generated using the program known as the Hybrid Optimization Model for Electric Renewables (HOMER). For the purpose of optimizing the financial and economic costs of the proposed system, the HOMER program is used [19]. The upcoming sub sections will go into further depth on each of these designs.

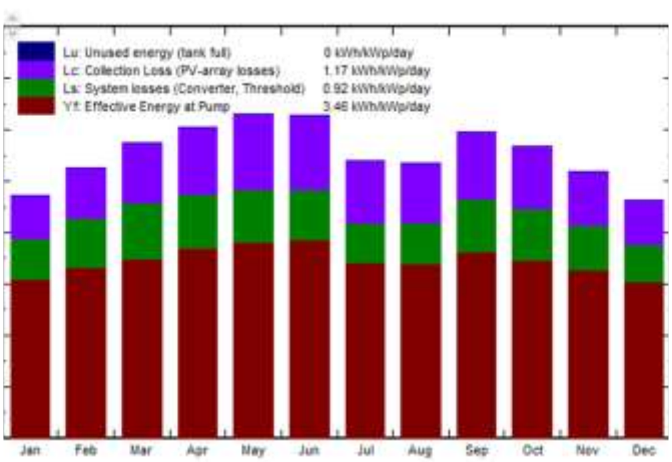

Fig. 7: Monthly normalized water productions per installed kW over the period of one year (kWh/kWp/day).

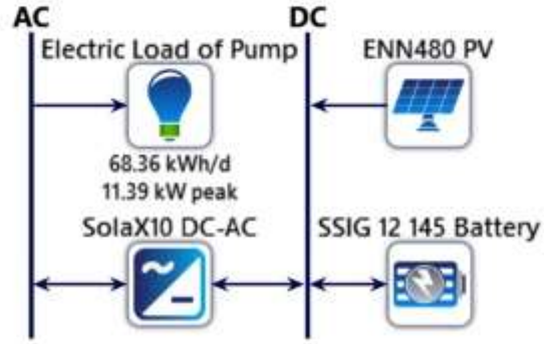

Fig. 8: System block diagram in HOMER.

A. *PV and Pumping system design in PVSyst*

Along with the solar irradiance data that comes from the Meteonorm database, the location along with its GPS coordinates are given to PVSyst in order to calculate the system's output. For the specified location, the years 1996 through 2015 are spanned by the data. Fig. 4 is a representation of the sun horizon profile at the site of the project. After that, the details of the required amount of water are provided, together with the compatible characteristics of the PV modules and the hydraulic pump. The details of these requirements are discussed further below:

1) *Water and pumping requiremnt*

The water in the well is static at the depth of around 100 feet (30.5m), has a drawdown of 1 $m/m^3/h$. A submersible pump is required with the depth of 90 m. Since, the average daily demand for water throughout the year is 287 m^3/day, therefore, a water storage tank with an estimated capacity of 574 m^3 is also required for 2 days of autonomy.

2) *Proposed Water Pump*

Fig. 6 shows the proposed deep well pumping system. To fulfil the needed level of water production, it has been suggested to use a submersible centrifugal multistage deep well pump. The model of the proposed pump is *Grundfos SP 95-3*. This pump is

Fig. 9a: Simulation result of proposed system in HOMER.

TABLE II: DETAILS OF ENN SOLAR ENERGY480EST-480

	Value	Unit
Rated Capacity	29.9	kW
Mean Output	5.51	kW
Mean Output	132	kWh/day
Capacity Factor	18.4	%
Total Production	48,271	kWh/year

Centrifugal Multistage, deep well pump with tri-phased AC motor.

3) Proposed PV System

The electrical power calculated is 11.39 kW, however, PVSyst proposed a 13 kW AC pump. Therefore, the suggested PV system to be installed is 15.36 kW to compensate for any electrical losses. However, this resulted in 54% water missing. Therefore, the suggested PV system to be installed is 28.8 kW. This improved the water missing issue from 54% to 14.7%. The proposed photovoltaic (PV) system will consist of 60 modules of solar panels with 480 W each. The model of the proposed PV is *ENN Solar EST-480*. The module would be connected in 4 Strings x 15 in series. The proposed tilt angle is 14º for summer and 44º tilt for winter seasons. It has been determined that the azimuth angle should be 0. In addition to it, an AC-MPPT (Maximum Power Point Tracking) converter is required with max efficiency of 97%.

B. System Configuration in HOMER

In the programme, the electrical load data provided to HOMER as a comma separated values (CSV) file. Based on this data, HOMER will done the sizing for the PV module and battery storage. At the end of the process, HOMER will provide a grade to the configuration that was selected. This rating will

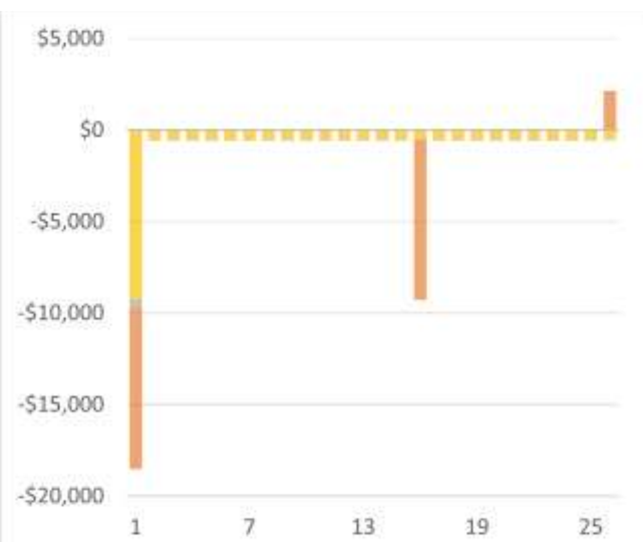

Fig. 10: Cash flow of the proposed system for over the priod of 25 years.

TABLE III: DETAILS OF TROJAN SSIG 12 145

	Value	Unit
Batteries	90	Qty.
String size	30	batteries
String in Parallel	3	strings
Bus Voltage	360	Volts
Autonomy	44.3	hours
Nominal Capacity	158	kWh
Annual Throughput	3,059	kWh/year
Lifetime Throughput	43,650	kWh
Expected Life	14.3	years

be based on the levelized cost analysis in addition to the Net Present Cost (NPC). Fig. 8 shows the model designed in HOMER. The same PV system is simulated for the nominal load of 11.39 kW. The pump is expected to run for 6 hours daily, so total load per day is estimated to be 68.36 kWh/day. A battery backup is also attached to the design.

IV. RESULTS AND DISCUSSION

A. PVSyst Design Result

The simulated outcomes for the photovoltaic system that is connected to the water pump are provided by the PVSyst. The amount of water that will be generated by the proposed system over the period of a year is predicted to be 89,321 m^3. The normalized water output per installed kW is shown in Fig. 7 throughout the period of one year. It is calculated that the overall system efficiency is 79%, whereas the efficiency of the pump is 43.5%.

B. HOMER Design Result

HOMER Pro is simulated with commercially available set of resources. The PV system is based upon same system as used in PVSyst, i.e., *ENN Solar Energy480EST-480*. A battery backup is also attached with the system to find out the feasibility of using a backup system. The battery system is designed upon commercially available *Trojan SSIG 12 145*. The details of both systems utilized in HOMER are given in Table III and Table IV, respectively. The electric load is estimated to be 68.36 kWh/day assuming the pump runs for 6 hours per day (from 10AM to 4PM) with the nominal load of 11.39 kW. The system created in HOMER is illustrated in Fig. 8.

The design can be realized that consists of one Alternating Current (AC) bus and one Direct Current (DC) bus. DC bus is coupled to a photovoltaic (PV) system and a battery backup system. AC bus relates to the pump and DC-AC converter. The photovoltaic system has a capacity of 29.9 kW, whereas the battery backup system has a capacity of 158 kWh with the autonomy of 44.3 hours. The proposed battery backup system is designed upon *Trojan SAGM 12* 145 battery. The batteries are connected in 3 strings in parallel with string size of 30. A DC-AC power converter is also proposed and designed upon *SolaX*

Fig. 11: Cost summary of the proposed system.

X3-hybrid10. The rated capacity of the converter is 17.6 kW while maximum output is 11.4 kW.

The NPC has a valuation of $29,142.90, and it is estimated that the operating expenses will be $820.68 each year, with an initial investment cost of $18,534. The Levelized Cost of Energy (COE) is estimated to be $0.09036/kWh. Fig. 8 and Fig. 9 show the cost summary and cash flow of the proposed system, respectively. Based on cash flow analysis, the initial cost is $18,533, with the battery replacement cost of $8,714.36 every 15th year. After 25 years, the salvage value will be $2,163.64.

V. Conclusion

This paper presents a design for a water pump powered by renewable energy for irrigation. We exhibited the design of a submersible AC pump based on the water requirements of a location in Sukkur, Pakistan. Using the PVSyst software, a reliable model of both the pumping system and the PV modules was developed. Following the finalization of the proposed system's technical design, an estimate of both the initial and recurring costs were determined using HOMER Pro. The system will require a 29.9 kW photovoltaic source, which will be fulfilled by a network of 60 photovoltaic panels placed in 4 Strings x 15 in series combination, and 90 batteries connected in 3 Strings x 30 in series, each 12V 145Ah are required for excess electricity storage. Following a thorough study and subsequent optimization of the system using HOMER Pro, it was determined that the operating and maintenance expenses are relatively affordable when compared to non-renewable resources.

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