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Techno-Economic Feasibility Assessment of Solar PV Water Pumping System: Case Study in AlKharj – Saudi Arabia

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Abstract

This paper presents an inclusive investigation of the utilization of a large-scale solar photovoltaic (PV) water pumping system in KSA. The system that has been applied is irrigating a vast farm with 1400 m3/day water consumption as an average. This study is providing the techno-economic of the water pumping system. The system size is 107.74 kW with a 170 m deep well, and 7210 palm trees with water storage 2800 m3. The technical analysis of the solar PV pumping system performance has carried out by utilizing PVsyst simulation software. As for the economic feasibility analysis, calculations have been applied for different economic indicators such as; Present Worth (PW), salvage value, total components expenses, Life Cycle Cost (LCC), Levelized Cost of Energy (LCOE), Levelized Cost of Water (LCOW), and Simple Payback Time (SPBT), to determine the system feasibility, including Balance of the System (BOS) and maintaining a solar PV system during its life period. The economic analysis has been applied on three scenarios. First, without exporting the excess energy at all. Second, with exporting the excess energy with considering the current agriculture electricity tariff in Saudi Arabia (7 Halalah/kWh). Third, with an assumed higher exporting electricity tariff as 20 Halalah/kWh.

Keywords: Solar PV, Pump, Cost, PVsyst Software.

* Introduction

The population growth in the planet is continually rising; the population growth for the next decades is predicted to increases so fast. The energy of the human kind needs are expected to increase even faster, but at the same time there will be an increase in the amount of energy that can be generated by electrical sources. According to a recent study, electric motors used in various pumping systems applications consume more than thirty percent of the electrical energy utilized around the world. Coal, petroleum, and gas are the primary sources of energy today; they are highly utilized by the existing global population and are predicted to deplete before they can be supplied. Furthermore, the potential for those fuel sources to have a large detrimental impact on the environmental exists. Short-lived trace gases like CO2 are produced when fossil fuels and biomass are partially burned. CO2 is one of the most important gases found in the atmosphere. Furthermore, CO2 is one of responsible parts of the global warming. This problem is intricately connected to the state of the planet's ecosystem, and the continued quest for alternate sources of green energy may help to alleviate it, at least in part, as well as adaptive methods aimed at minimizing the detrimental effects these environmental changes, Solar radiation is among the most potentially alternative green and sustainable sources of energy nowadays [1]. According to H. Kazem et al. [2], either the utilization of the solar water pumping systems for irrigation or residential, solar pumping systems are crucial parts for water storage and distribution, it has been practiced all over the world for a considerable amount of time to utilize photovoltaic (PV) panels to supply the electrical needs of these pumping systems. In addition, the end-user can benefit from the implementation of optimization sizing approaches to such systems by reducing costs in terms of both cash and time and energy.

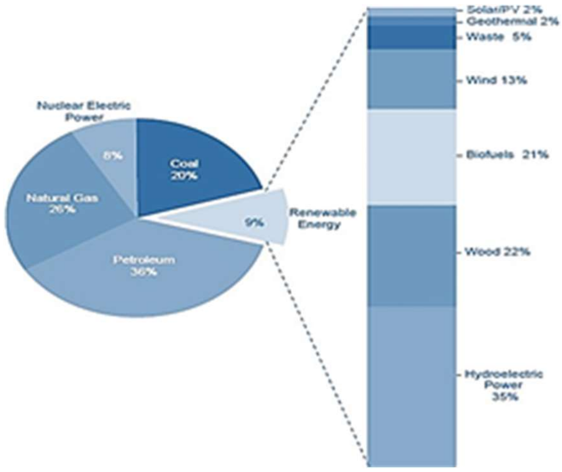

Fig 1. Consumption of Renewable Energy [3].

According to a study by Daud et al. [4], in many of Saudi Arabia's desert regions, people still rely on the traditional methods of irrigation, which involve drawing water from wellbores with the use of internal combustion equipment such as diesel pumps. Despite being easy to install, many pumping systems, especially those that use diesel fuel, have demonstrated to have major limits, due to the fact that they need frequent site repairs as well as fuel replenishment, however, diesel fuel is typically not available in such regions.

*** Methodology and Input Data**

1- Determining water requirements: The amount of water required each day to irrigate a farm with around 7200 palm trees has been obtained. About 95% of the water usage each day is consumed by these trees. Every palm tree consumes 184.4 l/day as a daily average according to a research has been implemented in the gulf region [5]. The daily average requirement of the farm can be expressed as:

$$\frac{\textbf{Number of palm trees} \times \textbf{Consumed water per a tree}}{\textbf{0.95}} \quad (1)$$

2- Determining Total Dynamic Head (TDH): The pump size is determined in a different manner for each type of irrigation method; it depends on a calculating the total dynamic head (TDH) to pump the water for pumping water. Some mechanical frictions and the pipes length are considered.

The calculation of the THD can be expressed as: -

TDH = Pump depth (m) + [Distance between the storage tank and the well (m) + (3 elbows x 90o elbow friction)] x safety factor (%)+ storage tank height (m) (2)

3- Solar PV System Sizing: Table 1 display the specifications of the solar PV module that have been utilized in the simulation. Water tank has been selected for storing the excess water.

Table 1. Solar PV Module Specifications

PV module, mono-crystalline type, model (jkm405m-72h), manufactured by Jinko Co.	
Peak Power	405 W
Open circuit voltage	48.7 Voc
Short circuit current	8.22 A
Maximum power voltage	39.8 Vmp
Maximum power current	7.72 Imp
Module efficiency	20.13 %
Operating Temperature	- 40 ℃ ~ + 85 ℃
Pout Degradation/year	0.55%
Temp. Coefficient	- 0.35%
Dimensions	200 ×100 cm
Ns	14
Np	19

The shading on the system is around 2% because of the fence, the lights poles at the corners and any other temporary shading. The PV system has been applied in Sketch up software and imported it to the PVsyst software to be computed and analyzed the shading in the area. Figure 2 shows the detailed losses of the system and it must be considered and taking into account in the system sizing.

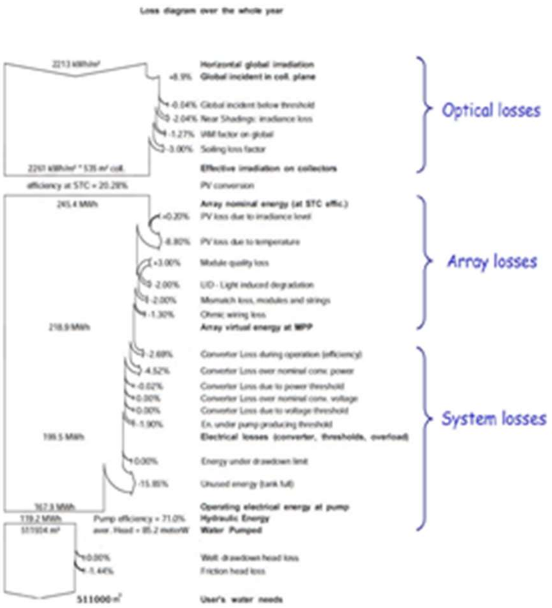

Fig 2. Solar PV system losses (from PVsyst software)

4- Solar PV Pump Sizing: The calculation of the pump size is outright, it can be expressed as [6]: -

$P_{hyd} = \rho g H Q$ (3)

$P = P_{hyd}/\eta = \rho g H Q/\eta$ (4)

(P_{hyd}) is the hydraulic power (kW)

(g) is the gravitational constant (9.81 m/s^2)

(ρ) is the water density (1000 kg/m^3)

(H) is the total head (m)

(Q) is the flow rate (m^3/s)

(P) is the shaft power (kW)

(η) is the Pump efficiency (%)

5- Water storage tank sizing: The autonomy days are two days only where there is cloudy days. However, the tank sizing will be expressed as: -

The size for the tank = Cloudy Days x Average Daily Water Amount (5)

6- Economic Parameter: The economic analysis will be applied on three scenarios. First, without exporting the excess energy at all. Second, with exporting the excess energy with considering the current agriculture electricity tariff as shown in the table below. Third, with a higher exporting electricity tariff as an assumption (20 Halalah/kWh). The monthly consumption is above 6000 kWh. Therefore, the agriculture electricity tariff in Saudi Arabia for this consumption will be used (20 Halalah/kWh).

The expenses of installing systems and equipment are included in the economic element of the inputs. Table 2 shows the costs of the solar PV pumping system as they are applied.

Table 2. Costs of installing the system's equipment

Item	Value
PV modules	181000 SAR
BOS*	267000 SAR
O&M / year	8000 SAR
*BOS includes everything other than the PV modules such as: inverter, pump, pipes, storage tank, system design and planning, infrastructure development, mounting structures, installation cost, DC cabling, fencing transportations. Etc...	

* Result and Discussion

1- Technical Evaluation: The annual Performance Ratio (PR) is 0.659, this value of PR is reasonable with taking in consideration the circumstances on the PV system such as conduction loss, thermal loss or, for example, defects in components. As showing in Table 3, the exploitation factor (EF) annually is 84.1 %. Next is the annual yield factor (YF) of consumed energy is 1558, this number means that the PV array in the location and under its weather conditions is capable to generate an electrical energy equals to its rated power for 1558 times in the year. With comparing this value of yield factor with grid-connected PV systems worldwide, it seems to be reasonable such as; 1861-1922.7 in Kuwait [7].

Table 3. Summary results of performance indicators

System Efficiency	76.7 %
Operation time	2555 h/year
Water pumping	511000 m^3
Annual Expected Energy	199.500 MWh
Annual Consumed Energy	167.900 MWh
Annual Excess Energy	31600 MWh
Annual YF of Consumed energy	1558
Annual CF of Consumed energy	17.8 %
Annual PR of Consumed energy	65.9 %
Annual EF of Consumed energy	84.1 %
Expected energy during Life cycle	4671.8 MWh
Consumed energy during Life cycle	4197.5 MWh

2- Economic Evaluation

The main indicators for the economic: -

Levelized Cost of Energy (LCOE) can be expressed as [8]: -

$$LCOE = LCC / \Sigma E_{generated} \quad (6)$$

LCC: The total costs of the PV pumping system during its lifetime.

$\Sigma E_{generated}$: The total amount of produced energy during its lifetime.

Levelized Cost of Water (LCOW) can be expressed as: -

$$LCOW = LCC / \Sigma Q_{Life\_cycle} \quad (7)$$

LCC: The total costs of the PV pumping system during its lifetime.

ΣQ_{Life_cycle}: The amount of water production during the life cycle of the system (m^3).

Simple Payback Period Time (SPBT) can be expressed as [9]: -

$$\textbf{SPBT (years)} = \frac{\text{Initial Cost(\$)}}{(\text{Egenerated (Kwh/year)} \times \text{Value(\$/kWh)} - \text{O\&M(\$/year)})} \quad (8)$$

Based on the calculations with the highest consumption tariff which has been used in our case, the calculations of the economic indicators results that the Simple Payback Period (SPBT) for the first scenario is 14.48 years, but for the second scenario the SPBT will be decreased to 11.8 years which is in case of exploiting the excess energy and export the energy with using the current ex-porting tariff. Unfortunately, even with selling the excess energy in the second scenario, it still a long time to get the money back because of the exporting tariff is very low and it is not encouraging. For the third scenario, the SPBT will be decreased even more to 6.06 years with considering the exporting tariff (20 Halalah/kWh) as an assumption to have a vision if Saudi Electricity Company (SEC) planned to enhance the tariff prices of exporting the energy and it seems to be feasible and encouraging to install and invest. Table 4 shows the main economic indicators for the three scenarios.

Table 4. The economic indicators for the three scenarios

	Scenario 1 (Without Exporting Excess Energy)	Scenario 2 (With exporting Excess Energy)	Scenario 3 With exporting Excess Energy assuming the tariff (20 Halalah/kWh)
LCOE	0.057 SAR/kWh	0.045 SAR/kWh	0.008 SAR/kWh
LCOW	0.019 SAR/m^3	0.015 SAR/m^3	0.003 SAR/m^3
SPBT	14.48 years	11.8 years	6.06 ears

* Conclusion

As a conclusion, this study found that installing solar PV pumping system in Saudi Arabia is technically feasible only for remote areas where there is no grid connection nearby. On the other hand, the economic seems to be unfeasible because of the high initial cost of the system and long pay back time. So, when user wants to install a solar PV system, a balance must be considered between sizing the system and the load, taking into account that the extra amounts of energy is not exported to the grid, which is damaging to the profitability of the project due to the low exporting tariff. The results of the approach on the case study showed that it is easy to apply in case of intending to do other technical-economic analysis. Nevertheless, using water storage tank rather than batteries storage in Saudi Arabia has several advantages such as; the initial cost is around 25% of the batteries expenses. Also, they need to be replaced on a certain time. In addition, it is not affected by weather changes, in contrast batteries need to be preserved resulting to more O&M cost.

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