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Solar Powered Water Pumping System for a Rural Village

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ABSTRACT
This research presents the study, design and simulation of solar powered water pumping based system. The work starts with a general overview on solar pumping systems leading to the selection of a particular system and design to be studied and analyzed. The study will reveal its efficiency and optimum point of operation. Simulation will be carried out on PVsyst software in order to evaluate both electrical and mechanical aspects. This work aims highlighting the state of art of solar powered water pumping systems in a rural village and representing a complete study that allows understanding the overall behavior and interest of such systems.

Keywords: solar powered water pumping system; PVsyst software; rural village.

INTRODUCTION

Background

Water is one of the essential resources for human and plant life. According to the National Aeronautics and Space Administration (NASA), all living organisms on earth depend on water for survival, from the tiniest microorganism to the largest mammal [Toll et al., 2020]. Due to the importance of water and the difficulty in transporting water from the source to the destination, a pump was invented to transport fluids by mechanical action, which is converted from electrical energy into hydraulic energy. Many techniques were used to supply the electricity to operate the pumps such as grid energy, generators or even renewable energy sources [Devan et al., 2020c; Senthilgavaskar et al., 2021].

In the recent years, renewable energy started to become more and more of a feasible solution due to the high energy prices and the low costs of renewables, especially solar PV technologies [Devan et al., 2020a; Devan et al., 2020b], which provides rural residents and farmers with environmentally friendly power sources to pump water with clear competitive advantages over traditional fuel-driven generators [Vourvoulias, 2021]. Due to the large amounts of water demanded especially during summer season, solar water pumping has a huge potential in the agricultural sector in Lebanon. However, it is still not very common among farmers and people involved in the agricultural sector. Less than 30 projects are implemented in Lebanon, with more than 80% of them initiated by the technology providers rather than the farmers themselves [Shehadeh, 2015] This shows the lack of awareness among users, and there is a need for more efforts and incentives to make it a viable and applicable solution.

Project overview

One of the most appropriate uses for photovoltaic is water pumping. From crop irrigation to domestic uses to stock watering, PV-powered pumping systems meet a broad range of water needs. Most of these systems have the added advantage of storing water for use when the sun is not shining, eliminating the need for batteries, enhancing simplicity and reducing the overall cost. This project deals with converting the solar energy to electricity using a field of photovoltaic panels and supply this power directly to a pump-to-pump water for a village needs. The photovoltaic farm is designed to produce energy to ensure that the pump functions normally and to provide the needed quantity of water.

For this work, a photovoltaic direct pumping system design for a village is to be done. The main purpose is to design and size a PV system and simulate it while accounting for the pump size and system parameters (well depth, static head, etc.) for maximum production. Studying the pump head and flow over variable frequency operation and calculating the energy produced from the PV system and the water volume produced per month for one year are considered. Simulations and calculations will be done using PVsyst software.

Solar water pumping systems

In general, water pumping worldwide is dependent on conventional electricity or diesel generated electricity. The dependence on diesel, gas or coal-based electricity can be minimized by solar water pumping. Solar pumping systems are characterized by no fuel cost, low maintenance cost, and are environment friendly [Foster et al., 2009] The flow rate of pumped water is dependent on the size of PV array and incident solar radiation [Rohit et al., 2013]

Comparing PV pumping systems to conventional pumping systems, shows a significant long-term cost savings. Moreover, batteries for electricity storage can be replaced by tanks for water storage.

Solar water pumping components

Solar water pumping components are known as standard ones and are listed below:

a) Water supply source – water supply source can be a stream, pond, deep drilled well, spring, or a river. Water source must recharge faster than water pumping rate.
b) Solar pumps – solar pumps are selected as per the rated power and accessories added as filters, float valves, switches to perform efficiently [Verma et al., 2021] Solar pumps are constructed from high quality stainless steel and low lead marine grade bronze and are designed for maintenance-free and corrosion-free service even in harsh environment with long term performance and reliability.
c) Motors for PV based pumps – AC or DC Motors can be used. DC motors are most commonly used in a low power solar water pumping system. Solar pump systems below 5 kW generally use DC motors. however, AC Motors Used for high power but it needs an inverter (DC/AC) to operate.
d) PV generator – it consists of a combination of series and parallel connected PV modules as per motor voltage requirement. A PV module consists of solar cells which convert solar radiation into direct electricity [Puukko et al., 2012].
e) Solar pump driver – in case of AC Water pumping system a solar inverter is needed, solar pump inverter, also known as solar pump drive. If the source is PV (which is DC), it converts the DC current produced from the solar plant into AC current in order to run the pump.
f) Storage tank – a storage tank is used to hold and store a liquid, which is water in this project.

Solar pumping techniques

In terms of techniques that can be used to pump water using solar energy, three main techniques exist and are listed below:

- Direct coupled PV DC water pumping system:
- PV AC water pumping system.
- PV water pumping system with battery storage.

Overall system design

The overall system requires the design of both the PV system and the pumping system. Inputs as well as outputs along with the steps are presented below in Figure 4.

PROJECT SPECIFICATIONS AND DESIGN

Project specifications

Our case study is implemented in Assayra Village in Baalbek with a geographical coordinate 34.008896 and 36.249365.

Water pumping design and study

Pump and storage tank sizing

The selection of pumps must go through some steps. In our case study the water source is from a deep well with a 302 m depth underground but the pump level was selected to be on a depth of 144 m. The water demand (WD) will be about 800 m^3/day. Additionally, to prevent the lack of water during a day especially in summer, a water storage tank must be constructed to save water for 2 days' autonomy (AD) according to Eq. 1:

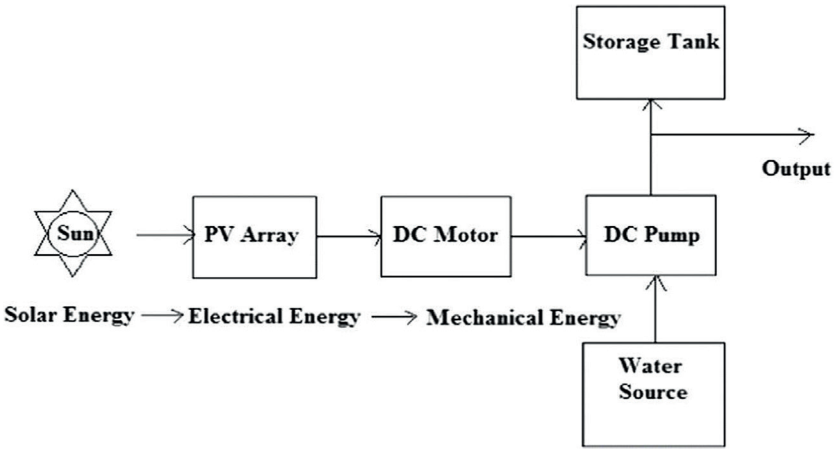

Figure 1. Direct coupled PV DC water pumping system

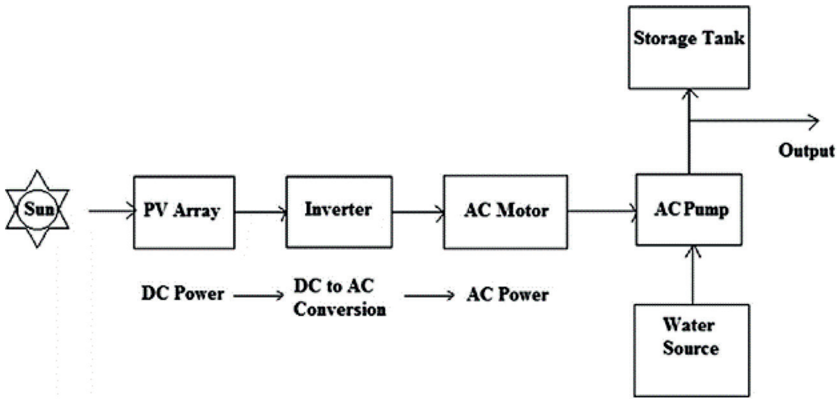

Figure 2. PV AC water pumping system

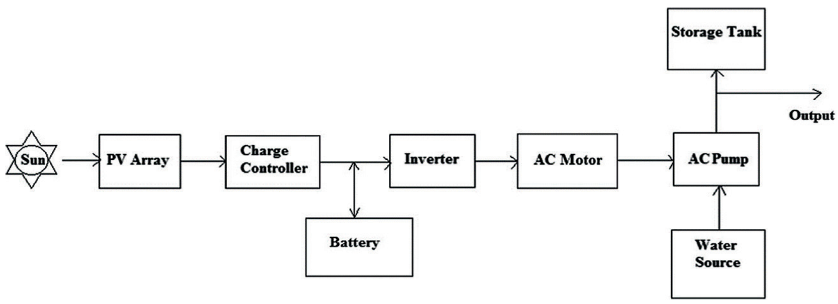

Figure 3. PV water pumping system with battery storage

$$Tank\ Capacity = WD * AD \tag{1}$$

The required storage tank volume is 1600 m^3. The storage tank capacity is constructed with a spare 20% to accommodate an 1800 m^3 with a circular shape (Figure 5). Now, we calculate the flow rate of this required pump by Eq. 2.

$$Flow\ rate\left(\frac{m^3}{h}\right) = Demand\ (m^3/day)\ \div Peak\ sun\ hour\ (day) \tag{2}$$

Which can be around 149 m^3/h. Finally, the total dynamic head can be revealed to be equal to 182 m at a 50 Hz frequency. This can be calculated according to Eq. 3.

$$Th = hG + hS + hD + hF \tag{3}$$

The elevation difference from the water pump to the inlet of the water reservoir is known as the pump head. This pump head is an important parameter in designing the pumping system [Aliyu et al., 2018]. Now selecting an appropriate pump for the project. Following a market survey, a Caprari pump E10S50N/7CD with a motor power 92 kW is selected. The

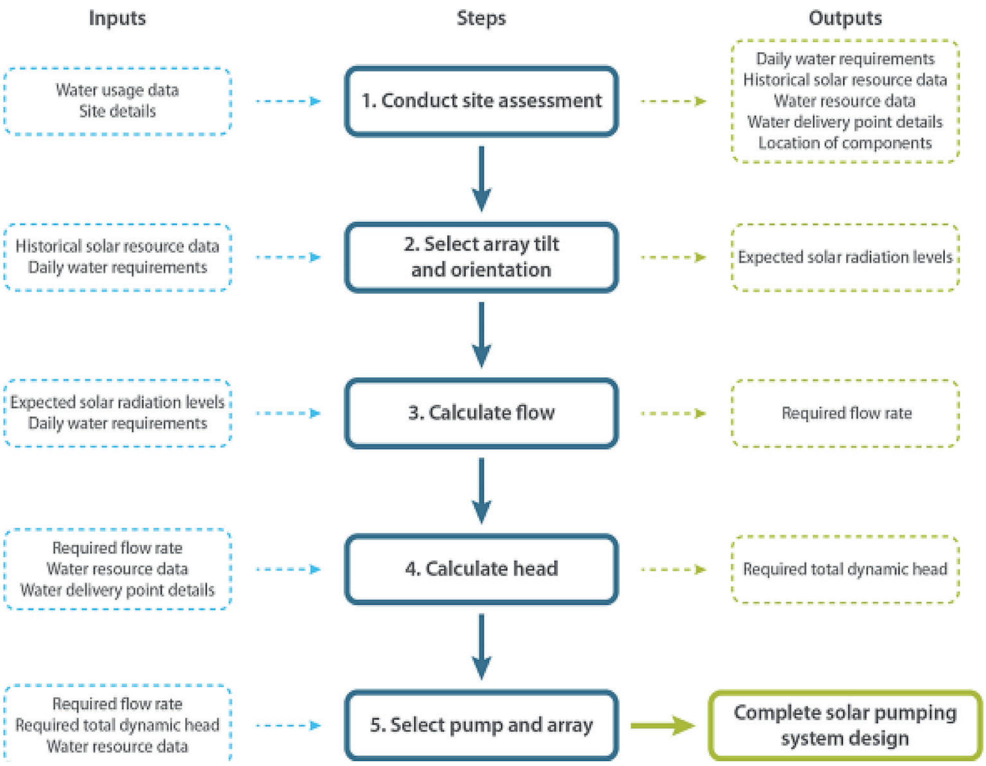

Figure 4. Steps involved in designing solar pumping

Figure 5. Circular storage tank

pump performance characteristic is presented in Figure 6.

Controller sizing

The basic function of the inverter is to change the variable Direct Current output of the solar panels into Alternating Current [Senthil Kumar et al., 2020] According to the change of intensity of sunlight, solar pump inverter system adjusts the output frequency in real time, and the provided output power is close to the sun cell array maximum power. The selection of the controller depends on the rated power of the pump and on the controller technology, for this project a controller ABB ACSM1-110kW is selected to drive the motor of the submersible pump.

The ACSM1 solar pump inverter is a low voltage AC drive of 0.3 to 355 kW rating designed

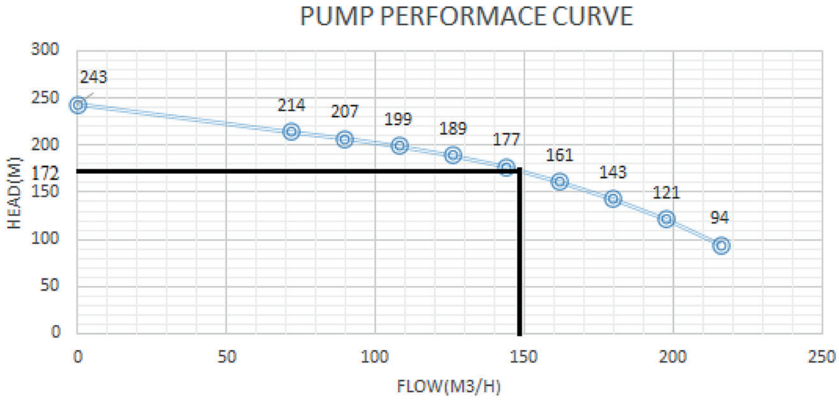

Figure 6. Caprari pump E10S50N/7CD

to operate with energy drawn from photovoltaic cells (PV). The inverter is customized to operate in dual supply mode, so the grid connected supply is used in the absence of energy from PV cells. The inverter functions with the latest in technology maximum power point tracking (MPPT) algorithm to derive maximum power from the PV cells at any instant. Using MPPT algorithm checks output of PV module, whether the output is maximum or not. If the maximum power available in PV module can convert the best voltage to get maximum current [Priya and Madhumitha, 2021]

Solar system design and study

PV capacity determination

In general, the sizing of solar energy is based on specific parameters. Firstly, the available solar energy on the project location is needed and it will be provided using PVsyst that imports the location of the project which is Al Assayra village and imports its meteorological data (Table 1). After that, choosing the orientation and the azimuth of the panels should be done. It is based into the best optimized orientation in Lebanon which is 31 degree and azimuth 0 degree.

When finishing from panels orientation, the system design and components selection will take place. Firstly, the capacity to be simulated must be defined. This parameter is based on the pump size which is 92 kW (125 hp). The solar energy sized for this pump well will be approximately ranged between 120 (30% · pump power) and 180 kWp. More than one simulation will take place in order to define the optimum solar capacity.PV determination methodology and the optimal sizing will be done using mechanical calculations (TDh, water production) and the

Table 1. Assayra meteorological data

Interval begin	GlobHor kWh/m²·mth	DiffHor kWh/m²·mth	BeamHor kWh/m²·mth	BeamNor kWh/m²·mth	Globnc kWh/m²·mth	KT	T °C	WindVel m/s
January	79.2	38.68	40.5	92.2	112.3	0.477	3.3	2.3
February	89.5	42.12	47.4	93.3	116.0	0.476	4.9	2.5
march	148.7	55.53	93.2	156.5	175.3	0.567	9.1	2.4
April	180.2	59.20	121.0	182.8	191.2	0.595	12.8	2.5
May	227.4	66.89	160.5	236.5	215.6	0.658	17.2	2.3
June	249.0	54.04	195.0	274.6	225.4	0.719	21.5	2.1
July	255.5	52.98	202.5	291.4	236.4	0.727	24.6	2.0
August	233.1	49.72	183.4	272.5	236.2	0.718	23.5	1.7
September	185.7	50.04	135.6	214.2	214.1	0.684	20.0	1.7
October	143.9	40.98	102.9	195.1	192.5	0.638	16.1	1.7
November	104.2	33.45	70.7	151.9	156.1	0.611	9.4	1.8
December	71.0	36.35	34.7	88.5	105.2	0.468	5.6	1.9
Year	1967.5	579.99	1387.5	2249.7	2176.4	0.633	14.1	2.1

PVsyst software for solar array electricity power production. For this project the optimum solar capacity to be installed is 174.08 kWp. The solar capacity estimation results are presented below in Table 2. The results show that an increase in the estimated water production levels occurs in parallel to the increase of the installed solar capacity. At 170 kWp, the water production result starts to be saturated (not much difference between 170 kWp and 180 kWp water production) so the optimum capacity is on the range of 170 kWp.

Solar system components and specifications

From the section before we get that the optimum solar capacity is on the range of 174.08 kWp. For this project the maximum DC input voltage of the chosen drive (ACSM1-110kW) is 800 V, thus the open circuit voltage of the PV strings should not exceed this limit at the minimum expected temperature. Using Suntech 320Vem the PVsyst software helps estimating the V_{oc}, and it is deduced that a maximum of 16 panels per string can be connected (resulting in a V_{oc} of 790 V at -5 °C). The power of solar energy is purely depending on intensity of solar radiations [Abhilash et al., 2021]. Since we put 16 panels of 320 Wp each per string, we conclude that each string will produce a 5.12 kWp. To reach the solar DC capacity, a 34 string must be installed with average power of 174.08 kWp. A total of 544 Suntech 320 Wp each is proposed for this project to be oriented toward south with azimuth 0 degree and tilting angle 30 degree.

When power levels exceed 50 or 100 kW, photovoltaic arrays are split into subgroups (Figure 7) to make it easier to connect the various components. Strings are paralleled on two levels. Strings in each subgroup are paralleled in subgroup PV string combiner boxes. These boxes are fitted with safety devices (fuses, disconnector switches, surge arrestor) the necessary measuring equipment and monitoring devices. The outputs of these boxes are paralleled in a PV array combiner box near the inverter.

Table 2. Solar capacity estimation results

DC capacity	Estimated water production flow (m^3/h)
120	282344.9407
140	343253.7314
160	386874.7413
170	396398.3392

Mechanical structure

The project is consisting of steel Mounted Racking, arranged in a repetitive array each array consist of 2 strings of 8 PV Modules in each string, PV modules are fixed in portrait

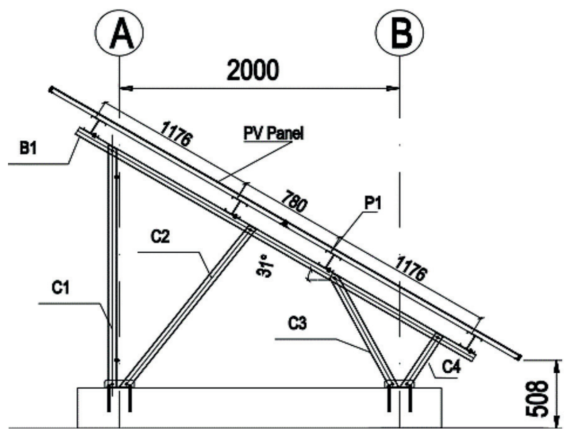

Figure 8. Solar panel design structure

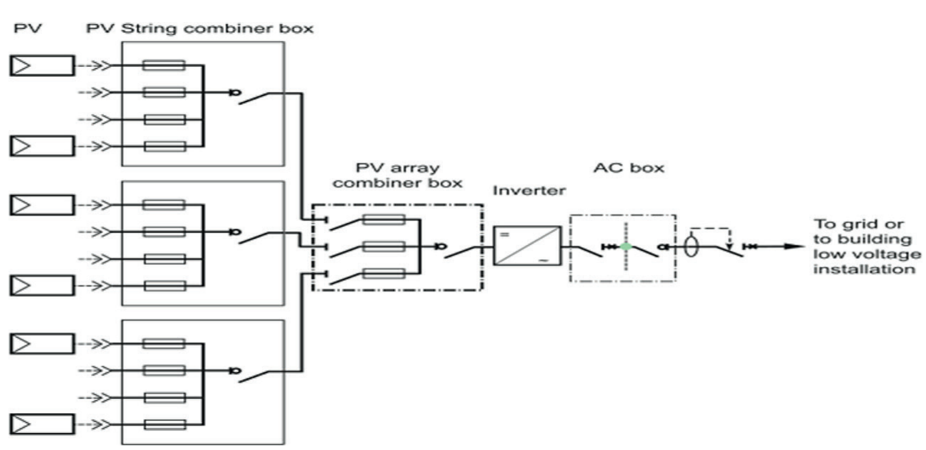

Figure 7. Arrangements of photovoltaic arrays in several groups

orientation with angle 30 degree (Figure 8). The material standards and specifications for which the structure components have been designed is Galvanized Steel Grade JIS G 3302.

Overall system design

The overall system design is presented below in Figure 9, where we can note the PV system, the storage tank, the pumping system and the well. Simulations using PVsyst and PSC will be revealed in the following section. The sizing of the main components was revealed. Results show that the PV generator capacity will be 174.08 kWp to feed a solar pump driver sized 110kW manufactured by ABB to drive a submersible caprrari pump 9 2kW to produce the daily water requirement needed by Assyara and Baalbek village.

SIMULATIONS AND ANALYSIS

In this project we have performed about 6 simulations on PVsyst software. These simulations shared some common parameters (location, orientation, solar panels type and power...). However, the planned PV array solar power (kWp) was the variable parameter. Thus the purpose, is to underline the effect of this latter.The first simulation planned array power was 120 kWp and it is increased gradually (140, 160,170, 174, 180 kWp). As different output energy will be produced from these different simulations, the optimum solar DC capacity well be chosen based on simulation results.

Simulation parameters

The parameters selected for these series of simulations are listed below in Table 3 and they concern the Assayra solar pumping project.

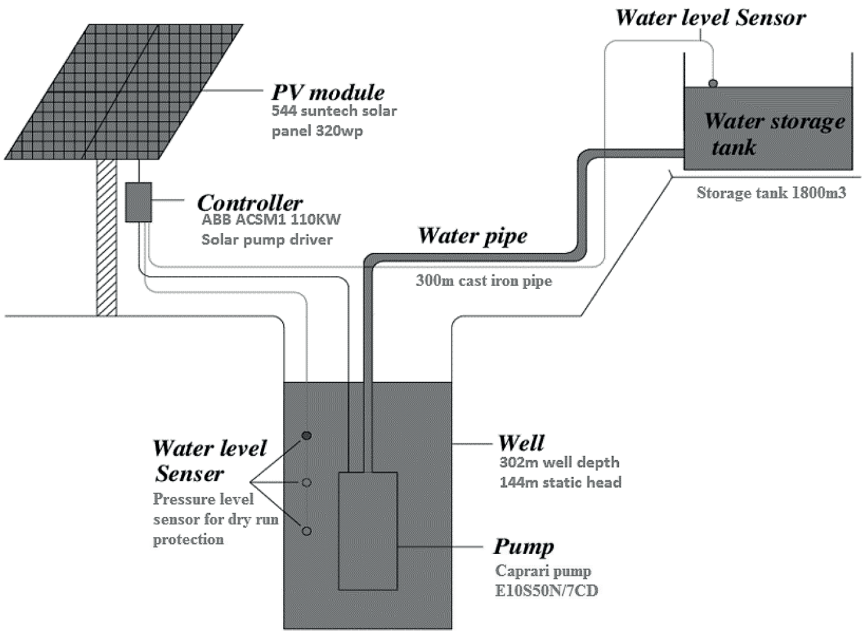

Figure 9. Overall system design

Table 3. Simulations parameters

Parameters		Sim. 1	Sim. 2	Sim. 3	Sim. 4	Sim. 5	Sim. 6
Geographical	Location (degree)	34.01, 36.25	34.01, 36.25	34.01, 36.25	34.01, 36.25	34.01, 36.25	34.01, 36.25
	Tilting angle (degree)	30	30	30	30	30	30
	Azimuth angle (degree)	0	0	0	0	0	0
System	Solar panels	STP 320-20/Wem	STP 320-20/Wem	STP 320-20/Wem	STP 320-20/Wem	STP 320-20/Wem	STP 320-20/Wem
	Selected inverter	ACSM1-110 kW	ACSM1-110 kW	ACSM1-110 kW	ACSM1-110 kW	ACSM1-110 kW	ACSM1-110 kW
	Planned DC capacity (kWp)	120	140	160	170	174.08	180

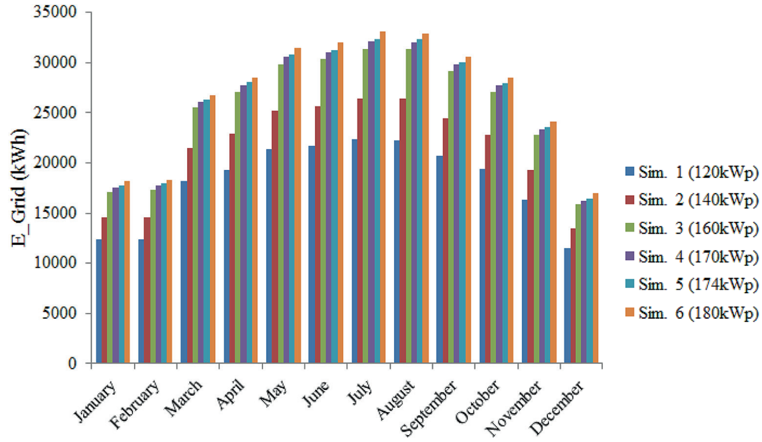

Figure 10. Monthly injected energy for different power array

Table 4. Simulation results for different array power

Months	Global Irradiation		Sim. 1 (120 kWp)	Sim. 2 (140 kWp)	Sim. 3 (160 kWp)	Sim. 4 (170 kWp)	Sim. 5 (174 kWp)	Sim. 6 (180 kWp)
	GlobInc kWh/m²	GlobEff kWh/m²	E_Grid kWh	E_Grid kWh	E_Grid kWh	E_Grid kWh	E_Grid kWh	E_Grid kWh
January	112.3	109.2	12366	14530	17081	17494	17714	18207
February	116	112.9	12424	14623	17334	17751	17921	18298
March	175.3	170.7	18155	21441	25472	26077	26308	26766
April	191.2	186	19307	22854	27087	27733	27995	28433
May	215.6	208.9	21348	25198	29835	30547	30822	31468
June	225.4	218.2	21675	25592	30294	31017	31271	31966
July	236.4	229.1	22395	26429	31303	32047	32297	33116
August	236.2	229.7	22246	26366	31290	32033	32272	32898
September	214.1	208.8	20676	24475	29094	29784	30019	30538
October	192.5	187.8	19336	22827	27029	27671	27927	28503
November	156.1	152.4	16337	19257	22807	23348	23583	24099
December	105.2	102.1	11510	13522	15881	16266	16470	16957
Year	2176.4	2115.8	217776	257114	304505	311769	314598	321248

Table 5. Calculated water production (120 to 160 kWp)

Month	120 kWp		140 kWp		160 kWp
	Seasonal production (m³/month)	Daily average (m³/day)	Seasonal production (m³/month)	Daily average (m³/day)	Seasonal production (m³/month)
January	12916.43526	416.6592019	16270.56292	524.856868	20023.68021
February	13649.14566	487.469488	16651.31605	594.689859	19485.91269
March	22515.19737	726.2966892	27525.96049	887.934209	31420.27811
April	25371.59729	845.7199096	30506.3066	1016.87689	33908.13533
May	28381.69407	915.5385184	34669.40362	1118.36786	38876.3018
June	29541.39315	984.713105	35800.05185	1193.33506	39084.07393
July	30988.28966	999.6222471	37833.07078	1220.42164	41635.78646
August	31204.73957	1006.604502	37699.57453	1216.11531	41033.0013
September	28778.0584	959.2686132	34366.83772	1145.56126	38048.73142
October	26508.9127	855.1262162	31456.77384	1014.73464	35727.90698
November	21508.68236	716.9560788	25856.33594	861.877865	29609.41755
December	10980.7952	354.2191999	14617.53709	471.533455	18021.51553
Yearly production (m³/year)	282344.9407		343253.7314		386874.7413

Table 6. Calculated water production (170 to 180 kWp)

Month	170 kWp		174.8 kWp		180 kWp	
	Seasonal production (m³/month)	Daily average (m³/day)	Seasonal production (m³/month)	Daily average (m³/day)	Seasonal production (m³/month)	Daily average (m³/day)
January	20542.55376	662.6630244	20890.99159	673.902955	21665.86037	698.8987
February	20047.89673	715.9963118	20341.82705	726.493823	21187.83523	756.7084
March	31970.19705	1031.296679	32256.42998	1040.53	32975.06901	1063.712
April	34324.5134	1144.150447	34587.94959	1152.93165	35184.56953	1172.819
May	39289.92313	1267.416875	39476.66143	1273.44069	40133.2732	1294.622
June	39439.58007	1314.652669	39633.72593	1321.1242	40114.88539	1337.163
July	42008.052	1355.098452	42158.95233	1359.9662	42647.23832	1375.717
August	41342.84243	1333.640078	41472.7653	1337.83114	41927.39803	1352.497
September	38442.75664	1281.425221	38609.26024	1286.97534	39145.69482	1304.856
October	36317.49472	1171.532088	36548.63146	1178.98811	37315.02524	1203.71
November	30167.17009	1005.572336	30425.18856	1014.17295	31217.68901	1040.59
December	18505.35922	596.9470718	18845.81389	607.92948	19787.80376	638.3163
Yearly Production (m³/year)	392398.3392		395248.1974		403302.3419	

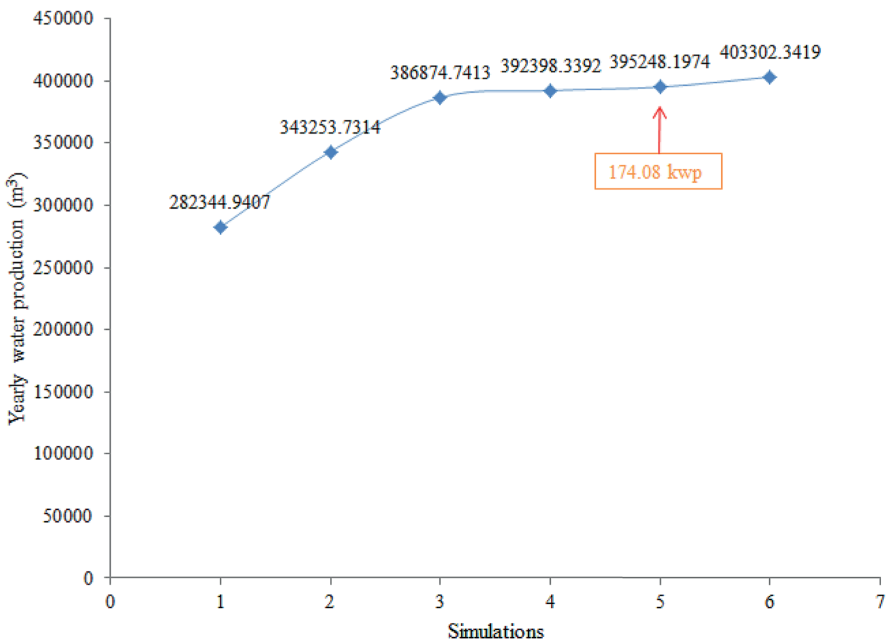

Figure 11. Water production per simulated kWp

Simulation results

The PVsyst will generate and calculate the estimated energy injected from each simulation. Table 4 will show the energy injected from the PVsyst for different simulations done at different solar array capacity (120–180 kWp). The Table 4 shows that as the solar array power increased gradually the available energy injected to the pump will increased which is one of our main goals in the thesis. Since the most optimized solar array capacity detected when the pump is fed with its rated power to reach the saturation region in pumping water. The monthly injected energy for different power array is shown in Figure 10. All the parameters inserted above are the same for all simulations done since the system and pump is fixed. The main variable parameter in our project is the solar array power in kWp. This variable as shown in the section before leads to a variation on the power and energy injected to the pump, which in turn will lead to an increase in the extracted water produced from the pump.Tables 5 and 6 show the estimated water quantity results from the multiple simulations done by comparison between the simulated solar array powers and the water volume produced. As a result, the optimum point will be detected. Figure 11 shows the estimated water production flow per the simulated kWp.

CONCLUSIONS

The solar system design and analysis of Al Assayra solar pumping project has been simulated and tested using PVsyst. First of all, we started our project design by specifying the site location and defining the well mechanical parameters. Accordingly, we sized the storage tank and the pump we used. After that an analysis study was done to calculate the average water quantity well produced from the system based on batch of simulations done on PVsyst software at different solar array capacity to determine the most efficient one. As a result of this work, A pump of rated power 92 kW was chosen we with an optimum solar capacity 174.08 kWp and a drive (ACSM1-110 kW), this solar system is divided into 34 strings each with 16 panels in series, then distributed into seven combiner boxes and finally totalized in a totalizer panel. The output of this panel will feed the solar drive input undergoes two stages of transformation/losses: first, the DC to AC inversion according to the drive efficiency, second, the AC electrical to mechanical power at the pump level. The future work needs to be related to the modeling and controlling of the system. Developing an experimental work and comparing the performance of the system with the results of our simulations and production under many scenarios. That would help understanding the behavior of such systems in different ways by the mean of data logging system should be developed based on experimental work such as writing codes for PIC and configuring the monitoring system.

REFERENCES

1. Abhilash P., Nanda Kumar R., Praveen Kumar R. 2021. Solar powered water pump with single axis tracking system for irrigation purpose. Materials Today: Proceedings, 39, 553–557.
2. Aliyu M., Hassan G., Said S.A., Siddiqui M.U., Alawami A.T., Elamin I.M. 2018. A review of solar-powered water pumping systems. Renewable and Sustainable Energy Reviews, 87, 61–76.
3. Devan P.K., Bibin C., Asburris Shabrin I., Gokulnath R., Karthick D. 2020a. Solar drying of fruits – a comprehensive review. Materials Today: Proceedings, 33, 253–260.
4. Devan P.K., Bibin C., Gowtham S., Hariharan G., Hariharan R. 2020b. A comprehensive review on solar cooker with sun tracking system. Materials Today: Proceedings, 33, 771–777.
5. Devan P.K., Bibin C., Krrishana A.G., Ashwin M., Bala Kumar K., Dinesh K.B. 2020c. A comprehensive review on solar tricycles. Materials Today: Proceedings, 33, 229–231.
6. Foster R., Ghassemi M., Cota A. 2009. Solar energy: Renewable energy and the environment. Routledge, London.
7. Priya P., Madhumitha R. 2021. Modelling and simulation for automatic irrigation system with pv solar tracking. Materials Today: Proceedings.
8. Puukko J., Nousiainen L., Mäki A., Messo T., Huusari J., Suntio T. 2012. Photovoltaic generator as an input source for power electronic converters. Paper presented at the 2012 15th International Power Electronics and Motion Control Conference (EPE/PEMC), Novi Sad, Serbia.
9. Rohit K.B., Karve G.M., Khatri. 2013. Solar water pumping system. International Journal of Emerging Technology and Advanced Engineering, 3(7), 323–337.
10. Senthil Kumar S., Bibin C., Akash K., Aravindan K., Kishore M., Magesh G. 2020. Solar powered water pumping systems for irrigation: A comprehensive review on developments and prospects towards a green energy approach. Materials Today: Proceedings, 33, 303–307.
11. Senthilgavaskar S., Karthick K., Bibin C. 2021. A review paper on solar operated ridge and furrow formation machine. Materials Today: Proceedings, 46, 3627–3630.
12. Shehadeh N.H. 2015. Solar-powered pumping in lebanon - A comprehensive guide on solar water pumping solutions. Geneva, Swiss: Federal Department of Foreign Affairs, Swiss Agency for Development and Cooperation.
13. Toll D., Doorn B., Engman E. 2020. Nasa's water resources element within the applied sciences program. Paper presented at the IEEE International Geoscience and Remote Sensing Symposium, Honolulu, United States.
14. Verma S., Mishra S., Chowdhury S., Gaur A., Mohapatra S., Soni A., Verma P. 2021. Solar pv powered water pumping system – a review. Materials Today: Proceedings, 46, 5601–5606.
15. Vourvoulias A. 2021. Pros and cons of solar energy. Retrieved 20 September, 2021, from https://www.greenmatch.co.uk/blog/2014/08/5-advantages-and-5-disadvantages-of-solar-energy