Design and analysis of a solar water pumping system for drip irrigation of a fruit garden in Iran

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***Abstract*- In this research, a solar water pumping system for a 2.36-hectare grape garden in the northwest of Iran is designed and presented. Drip irrigation is used in that area to conserve water. Lorentz Compass3 was used to select a submersible water pump and then using HOMER Pro, all system's electrical components were selected. The proposed system consists of a 2kW PV, 10, 12V 105Ah batteries, and an 883W submersible pump. The designed system dynamic modeling was done in Simulink. A system controller was also designed and analyzed successfully. The simulation results show that the designed controller can maintain MPP by operating the PV array at 178.7V and at 8.3A. System economics and a method used to calculate water needs are also presented in the paper.**

I. Introduction

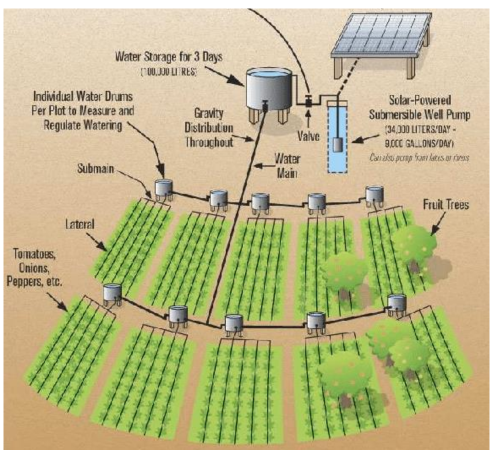


Figure 1 - Drip irrigation system with solar pumping

There are several types of irrigation systems in agriculture: flood irrigation, sprinkler irrigation, drip irrigation, etc. They are shown in figure 1. Among them, drip irrigation shown in figure 1 is the most efficient one (between 85 and 95 percent). Reason is that it provides water for the plant directly in the roots area.

The case study is a grape garden which is popular in north west of Iran with drip irrigation system. The area for the garden is 2.36 hectare which is shown in figure 2. Water needs of the garden is analyzed using CropWat. In this software, climate information, crop information and soil are given to the software, and it uses some techniques to calculate water needs for the plant in a unit area. Then, the number is multiplied by the area of the garden and results in the ovrall water requirement of the plant [1-4].

Figure 2 - The case study grape garden

II. System Sizing, Modeling and Analysis

In this project, several steps are taken to size and model a solar water pumping system. The primary step is to analyze water requirements of the garden and this is obtained using Food & Agriculture Organization (FAO) analysis software, ClimWat & CropWat. Second, total dynamic head (TDH) of the bore well is calculated. Then based on the results of the previous steps, Lorentz Compass 3 software was used to size a proper submersible water pump that can supply the water needs of the garden. With having the electrical load of the system, the HOMER Pro was used to design a complete and optimized model of solar photovoltaic (PV) system.

A. Water Requirement Analysis and Flow Rate Calculation

CropWat is the tool developed by the land and water development division of FAO that provides complete water requirement and irrigation requirement calculations of various crops on the basis of soil, climate, and crop information. [5]

In this project, Table Grape data was given as crop data, Urmia station's climate information was given as climate info and medium (loam) soil was selected. The net irrigation results are shown in table 1.

Table 1 – Irrigation requirement results

Month	Net Irrigation requirement mm/month
January	0.0
February	0.0
March	2.7
April	19.1
May	60.5
June	121.7
July	119.4
August	49.08
September	33.6
October	1.3
November	0.0
December	0.0
Sum	408.1

Graph shown in figure 3 presents the results of water requirement, effective rain and irrigation requirement for one year in decade periods.

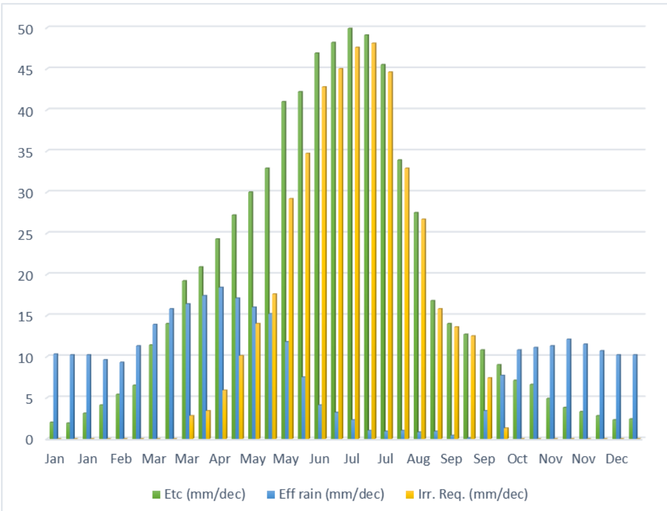


Figure 3 – Irrigation requirement (Irr.Req.), Crop Evapotranspiration (Etc), and Effective Rain (Eff rain) graph

Based on the results in table 1, total irrigation requirement is 408.1 mm in one year. Plus, the area of the selected grape garden is 23,600 square meters. Therefore, multiplication of these two numbers gives us the total amount water required for irrigation equal to 9638.14 cubic meters.

As per figure 3, only about 6 months of the year, irrigation is required. Since a water tank is used to store excess water and provide it when needed, average water flow rate required to supply per day is calculated. Table 2 shows the different irrigation schemes for the system. Based on the results, since the plant is mostly irrigated in the mid-6-month of the year, and the average hours of sunshine in the location is about 8.8 hours, the flow rate equal to 6 m^3/h was selected for the irrigation.

Table 1 - Flow rate based on different irrigation scheduling

Irrigation Period	6 months (April – September)
Average per day	52.8 m^3/day
24 h/day	2.2 m^3/h
12 h/day	4.4 m^3/h
8.8 h/day	6 m^3/h

B. Total Dynamic Head (TDH) Calculation

Head is the second important factor in selecting a submersible water pump. Several factors are important in calculation of the head such as ground water level, head losses in pipes and water tank level.

Figure 4 shows ground water levels relative to the surface of the Earth. The starred points show water level in 2019 in the bore wells for monitoring water level in the ground. Ground water depth equal to 22.01 meters in the location is achieved using data from the bore wells' in the location for 20 years and analyzing them by ArcGIS which is a software for Geographic Information System [6].

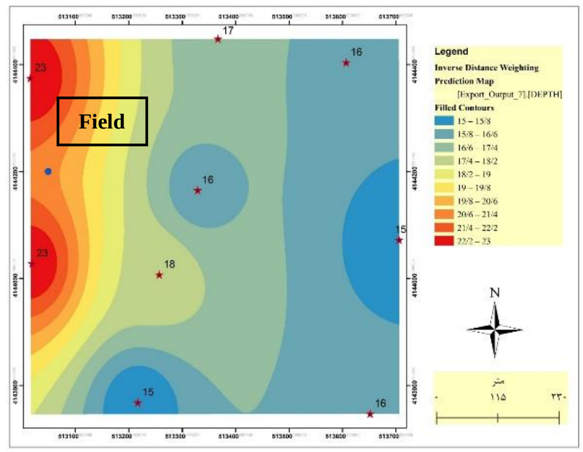


Figure 4 - Ground Water Level in the location

Figure 5 shows the schematic of the submersible pump system. Elevation head is 25.01 meters. Total friction head loss is 2.15 meters. This results in the TDH calculation of 27.16 meters [7].

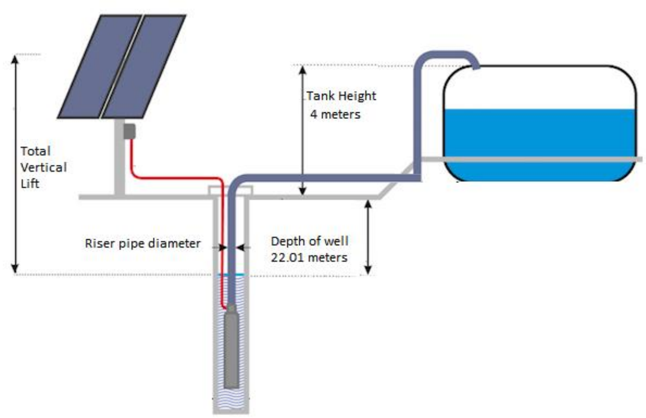


Figure 5 - Schematic of the solar water pumping system with water levels

C. Sizing of the Submersible Water Pump

In the previous sections, irrigation system and water requirement of the grape garden were analyzed. To providing this much water, Lorentz Compass3 software was used to choose an efficient submersible pump among various types of pumps the Lorentz company offers [7].

Based on the system's design, the software recommended solar water pump named Lorentz PS2-1800 C-SJ8-7. Figure 6 shows the characteristics of the selected submersible pump.

Figure 3 - Characteristics of the submersible pump

Figure 6 shows the pump curve and its performance in the calculated flow rate and head conditions. As shown in figure 6, at flow rate of 6 m^3/h and head of 27.16 m, its electrical power is 883 Watts with the speed of 2,75 rpm. These types of pumps offered by Lorentz company have a controlling unit that controls the DC motor's speed by varying the voltage.

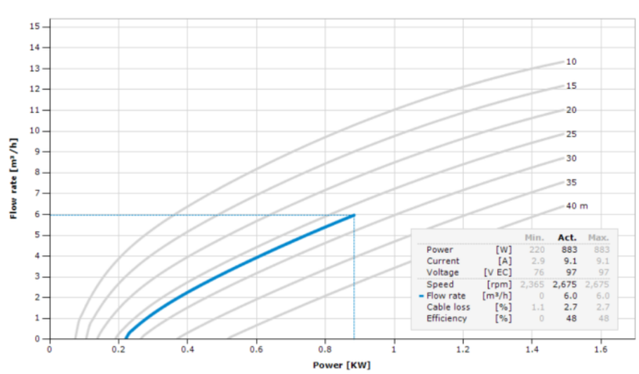


Figure 4 - Pump Curve and its performance in the calculated conditions

D. PV System Sizing and Analysis

National Renewable Energy Laboratory developed HOMER (Hybrid Optimization of Multiple Energy Resources) software and in this project HOMER Pro was used to design a PV system based on the layout shown in figure 7. The configuration of the system is presented in table 3.

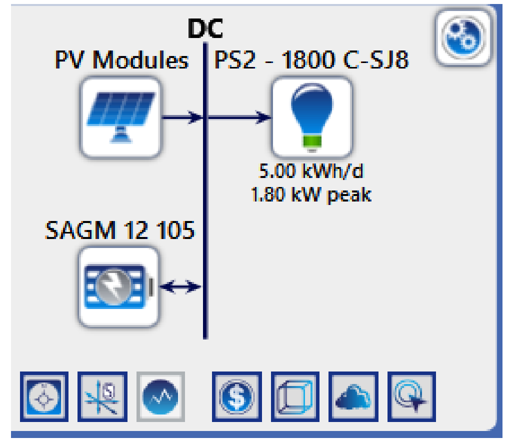


Figure 5 - Layout of the PV system

Table 3 – PV System configuration

	Model	Electrical Characteristics	Results	
Battery Storage System	Trojan SAGM 12 105	12 v, 105 Ah	10 per string, Bus voltage: 120v	Backup: 15hours
PV	Canadian Solar 300CS6X	300 W, 72 Cell, 13% Efficiency	P=2.01 kw CF= 19.6% E= 3,457 kwh/y Time=4382 hrs/y	Excess: 1607kwh/y 46.5%
Load	Lorentz PS2 1800	883w	1778 Kwh/y	

Cash flow is shown if figure 8. As shown in the results, the overall cost of the system is about 24,000 CAD.

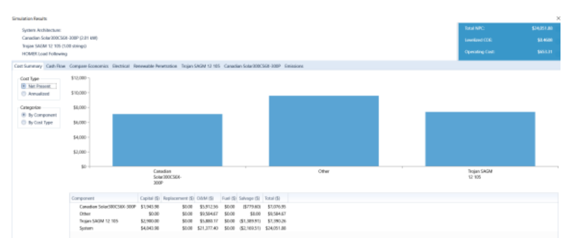
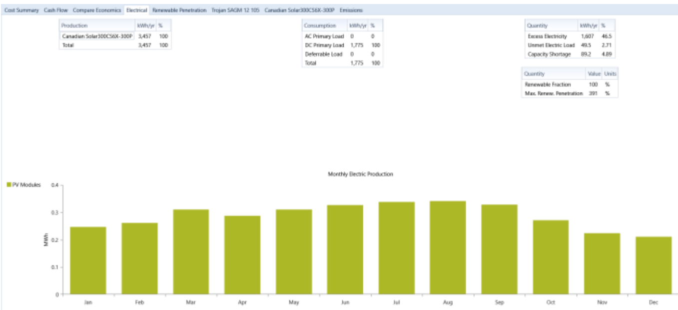


Figure 6 - Cash flow of the system

Figure 9 shows the system's electrical performance in 1 year. As it is clear, the excess energy produced by the system is about 1607 Kwh per year that is almost 46.5 percent of the total production. This can easily become zero by disconnecting the panels from the system in the period of not irrigating the plant. As mentioned before, the system works only for 6 months in the duration of the irrigating.



Production	kWh/yr	%
Canadian Solar300CS6X-300P	3,457	100
Total	3,457	100

Consumption	kWh/yr	%
AC Primary Load	0	0
DC Primary Load	1,775	100
Deferrable Load	0	0
Total	1,775	100

Quantity	kWh/yr	%
Excess Electricity	1,607	46.5
Unmet Electric Load	49.5	2.71
Capacity Shortage	89.2	4.89

Quantity	Value	Units
Renewable Fraction	100	%
Max. Renew. Penetration	391	%

Figure 7 - Electrical Performance of the system

Battery storage system's performance is shown in figure 10.

Quantity	Value	Units
Batteries	10.0	qty.
String Size	10.0	batteries
Strings in Parallel	1.00	strings
Bus Voltage	120	V

Quantity	Value	Units
Autonomy	53.5	hr
Storage Wear Cost	0.260	$/kWh
Nominal Capacity	13.9	kWh
Usable Nominal Capacity	11.1	kWh
Lifetime Throughput	12,120	kWh
Expected Life	26.3	yr

Quantity	Value	Units
Average Energy Cost	0	$/kWh
Energy In	500	kWh/yr
Energy Out	425	kWh/yr
Storage Depletion	0	kWh/yr
Losses	75.0	kWh/yr
Annual Throughput	461	kWh/yr

Figure 8 - Battery Storage system's performance

Figure 11 shows the PV modules' performance.

Quantity	Value	Units
Rated Capacity	2.01	kW
Mean Output	0.395	kW
Mean Output	9.47	kWh/d
Capacity Factor	19.6	%
Total Production	3,457	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	2.26	kW
PV Penetration	189	%
Hours of Operation	4,382	hrs/yr
Levelized Cost	0.0696	$/kWh

Figure 9 - PV Modules Performance

Last, production plots of the system are shown in figure 12. In this figure, Canadian Solar PV Modules energy generation is in yellow color, state of charge of the battery system is in red, and total electrical load served by the system is in dark blue.

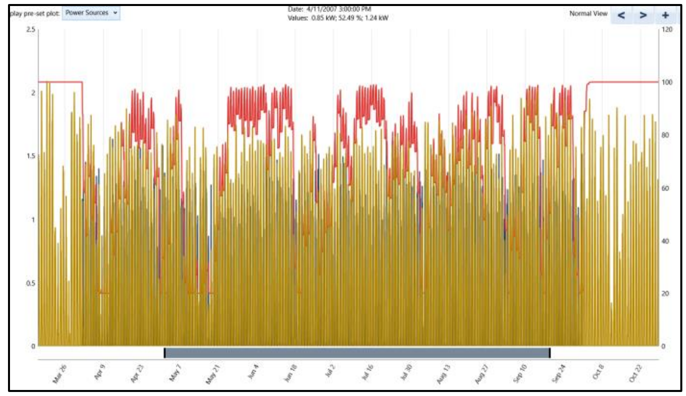


Figure 10 - Electrical output of the system, plots for SOC, Total Electrical Load Served, and power generation by PV Modules

In sum, the performance of the electrical PV system was analyzed using HOMER Pro and results showed that the system works properly with high performance.

III. MATLAB/Simulink Dynamic and Control System Design and Analysis

A. Dynamic Model Design

First, a dynamic model was designed in MATLAB Simulink to study the systems performance to meet its load demand. Figure 13 shows the Simulink model.

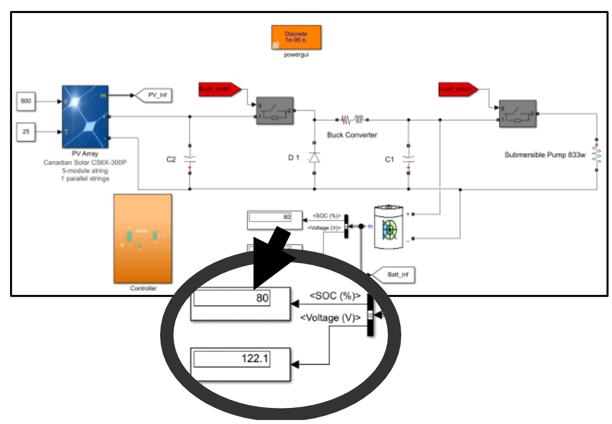


Figure 11 - Simulink Dynamic and Control Model

Figure 14 shows the PV module used in this project.

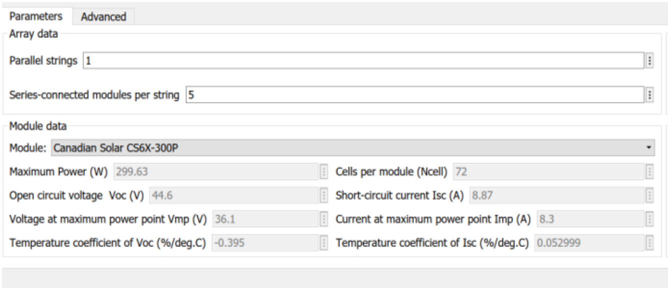


Figure 12 - PV module details

B. Control System Design

Control system consists of an MPPT controller to harvesting maximum power from the modules, a battery charge controller that can be used to protect the battery system from over charging and a load control that is used to cut the load off the system in order to prevent over discharging the battery system in situations that Sun is not available for a few days.

Figure 14 shows the performance the PV panels in various voltages and currents. The max power extracted from the panel when it works in its max point. A buck converter was used to control the MPPT of the system. Also, Perturbation & Observe method was used in this study for MPPT.

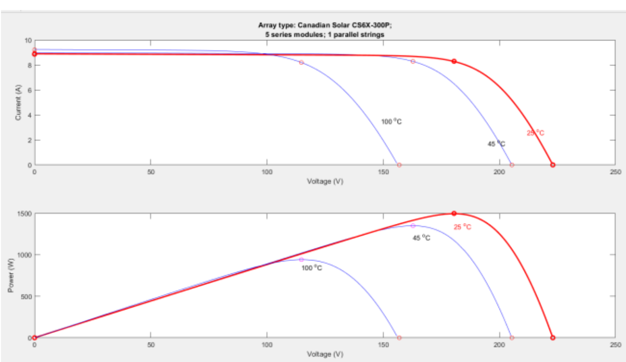


Figure 13 - PV Arrays outcome for DC bus voltage 120 v

In this model, the control Unit consists of three parts: MPPT Controller, Overcharge Controller, and Over-discharge controller to increase the performance of the system and protect the system from faults happened in the system. Figure 15 shows the control unit. As shown in this figure, the MPPT works fine. This fact is clear via comparing to the PV modules voltage and current at maximum power point.

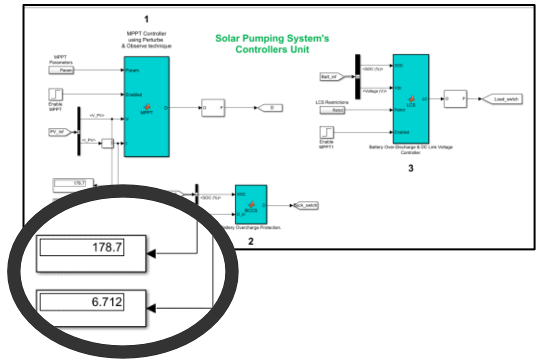


Figure 14 - Control Unit of the system

IV. Conclusion

This project was implemented successfully. It showed that a PV system design to cover energy requirements of a drip irrigation garden is feasible. Using CropWat software, water analysis was done and for the water level, GIS was used. In this project, Lorentz Compass3 was used to select a submersible water pump and then using HOMER Pro, systems' electrical components were selected. At the end, the system's controller was designed and analyzed successfully. In the simulation results, shown in figure 22, the PV Array's voltage at maximum power point was 178.7 volts. Comparing to the PV arrays plot, which shows the voltage at maximum power point for the module in laboratory conditions (25 degrees temperature and 800 W/Sq. meter irradiance) equal to 180 volts and current equal to 8.3 ampere, this is a great success that shows the MPPT controller works well.

Acknowledgment

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References

[1] "Irrigation," https://en.wikipedia.org/wiki/Irrigation#Micro-irrigation, Wikipedia

[2] C. Wilson and M. Bauer, "Drip Irrigation for Home Gardens," Colorado State University Extension fact sheet no. 4.702.

[3] Long He, Tara Baugher, 2019, "Drip Irrigation for Tree Fruit Orchards in Pennsylvania," PennState Extension

[4] "Handbook on Pressurized Irrigation Techniques," Food and Agriculture Organization of The United Nations, Rome 2007

[5] CropWat, FAO, http://www.fao.org/land-water/databases-and-software/cropwat/en/

[6] "Water resources statistics", 2017, Iran Water Resources Management Company, https://www.wrm.ir/#Info