OPTIMAL DESIGN OF A SOLAR WATER PUMPING SYSTEM WITH HYBRID STORAGE FOR A SITE IN IRAN

by

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Outline:

- Introduction and a background of electricity and water

  Consumption in Iran

- Specifications of the site in Iran

- Optimum sizing of solar water pumping for irrigation

- Optimum sizing of a hybrid storage system

- Dynamic modeling and simulation on Simulink/MATLAB

- Conclusion

Three main part:

1. Sizing the main components (using Homer pro)
2. Proposed and optimize a hybrid storage system
3. Simulation and dynamic analysis

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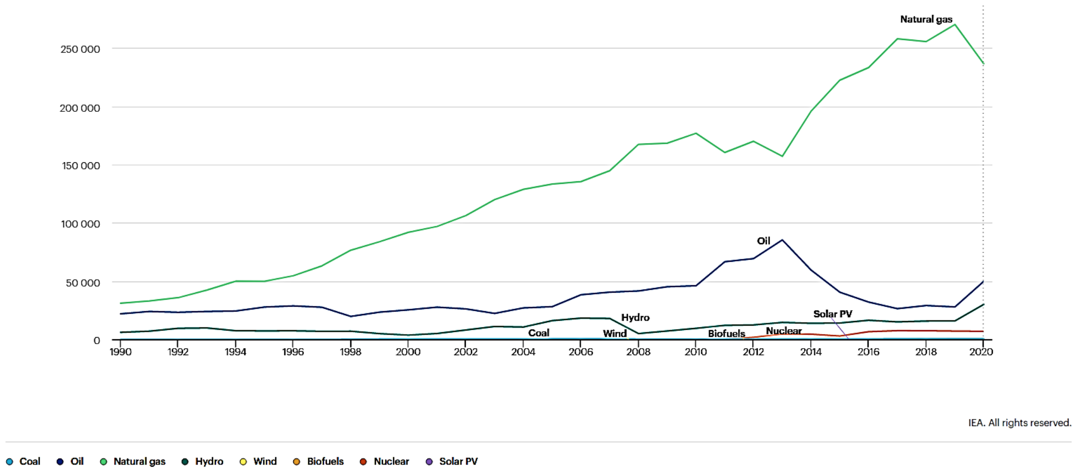
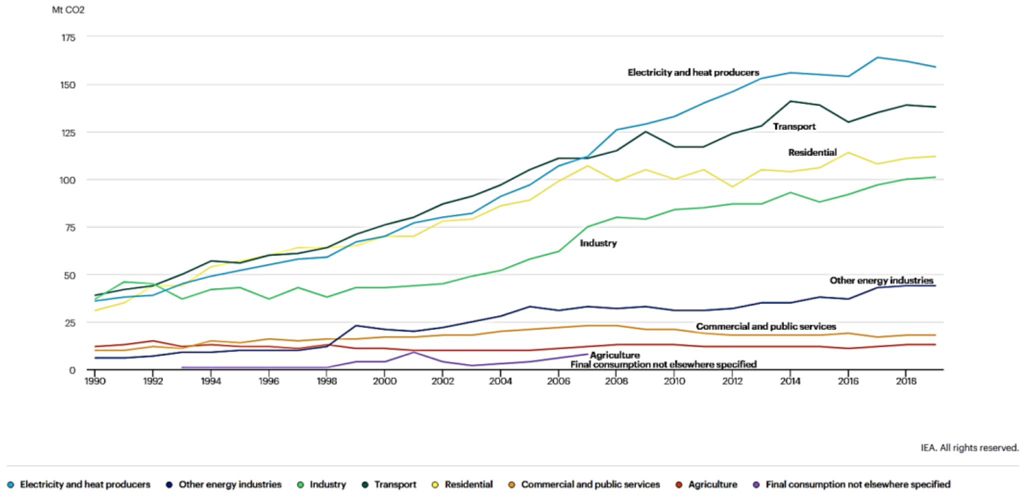
Introduction:

Iran:

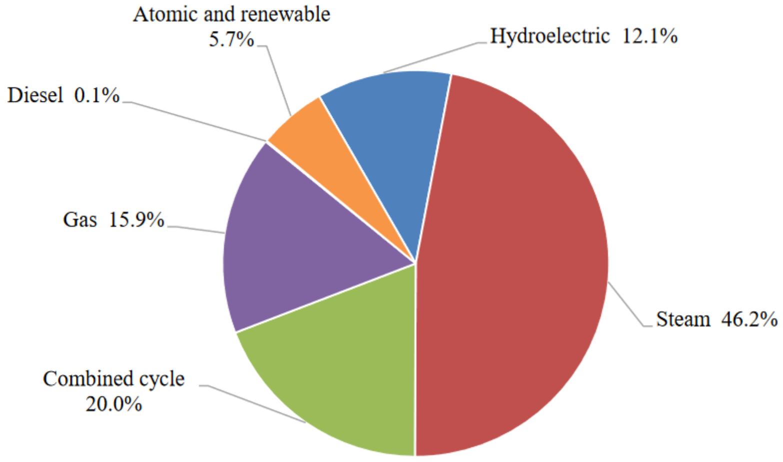
- Energy consumption in Iran is among the first 10 top countries in the world
- This energy is mainly used for electricity and heat production purposes
- Iran is one of the main oil producers. The price of oil and natural gas is lower than in many other countries.
- More than 80 percent of the electricity share belongs to fossil-fuel-based power plants
- Results in high CO_2 emission
- Design a system in a reasonable price



Electricity generation by source, Iran 1990-2020



CO2 emissions by sector, Islamic Republic of Iran 1990-2019



The share of electricity production in the years 2018-2019

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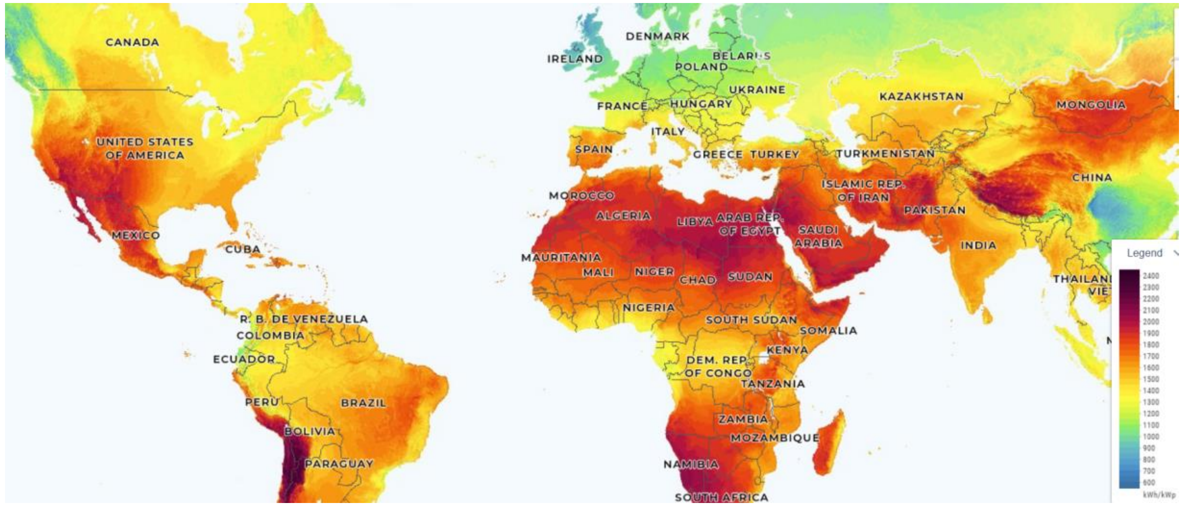
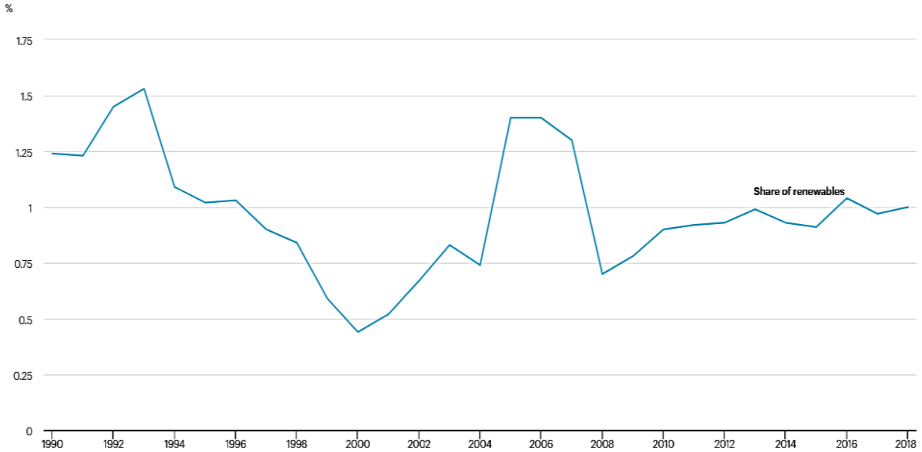
Introduction:

Iran:

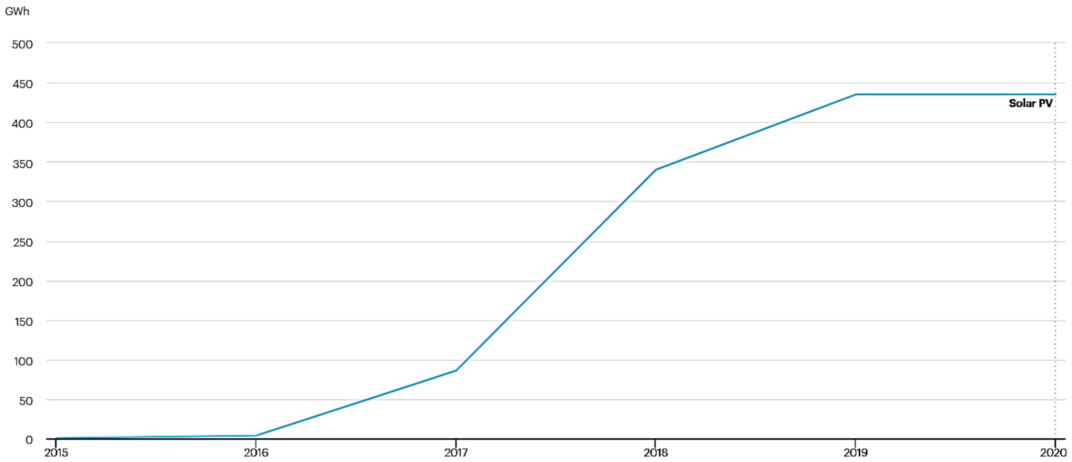
- High protentional for solar energy based systems
- the government has encouragement programs for photovoltaic (PV) systems
- Not efficient enough
- A need for more research on solar based systems



Global horizontal irradiation



Renewable share in final energy consumption (SDG 7.2), Islamic Republic of Iran 1990-2018



Solar PV electricity generation, Islamic Republic of Iran 2015-2020

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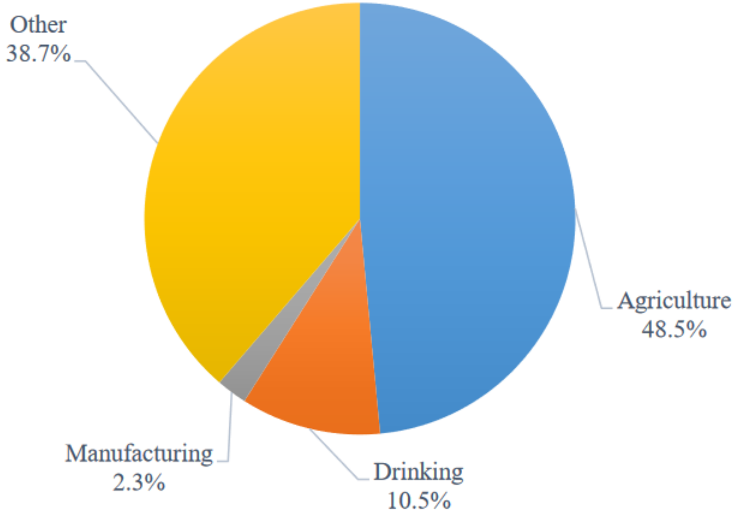
Introduction:

Iran:

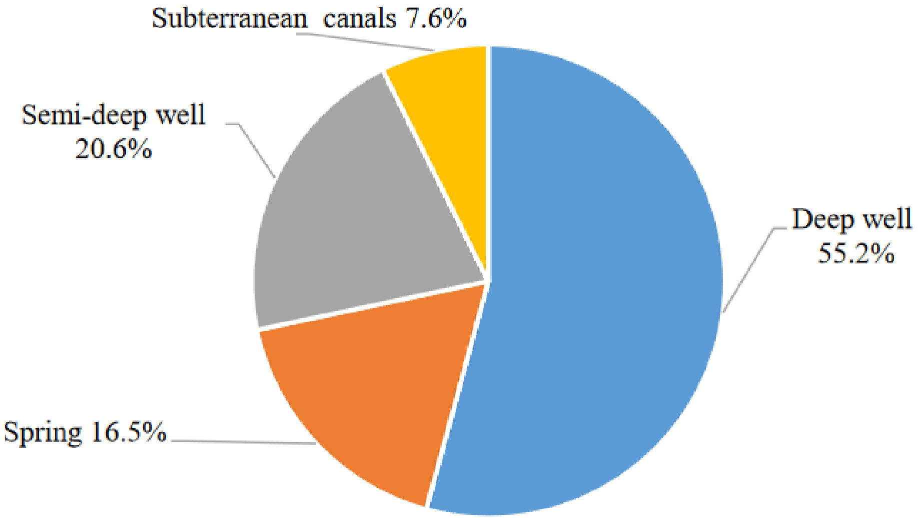
- High water consumption
- The significant share of water consumption is belonging to agriculture
- Many remote agriculture areas that need electricity for their water pumps
- Most of these pumps are for Deep and semi-deep wells

Motivate gardeners

High GHI and need for water pump in remote areas, motivate me to have a research on solar water pumping systems



water consumption by type of use in Iran, the years 2018-2019



Percentage of water withdrawn from underground water resources in the years 2017-2019

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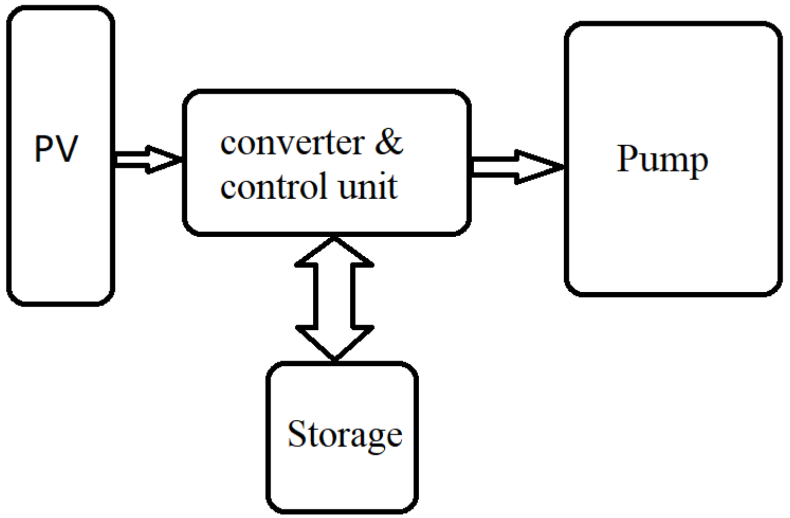
Literature Review:

Previous works on solar water pumping systems can be categorized into three groups:

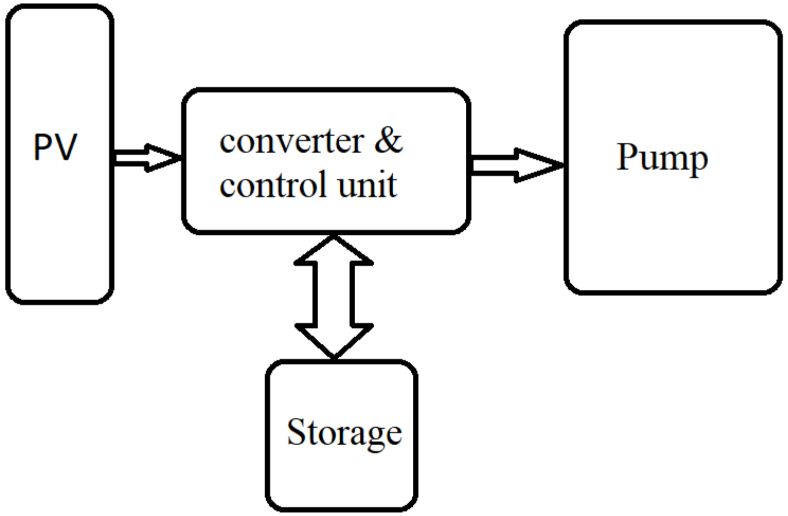
1. Stand-alone solar pumping systems without storage (such as [1-3]). These researchers focused on designing a system consisting of only PV modules and water pumps connected directly or through an inverter.



Main parts of a solar water pumping system

Literature Review:

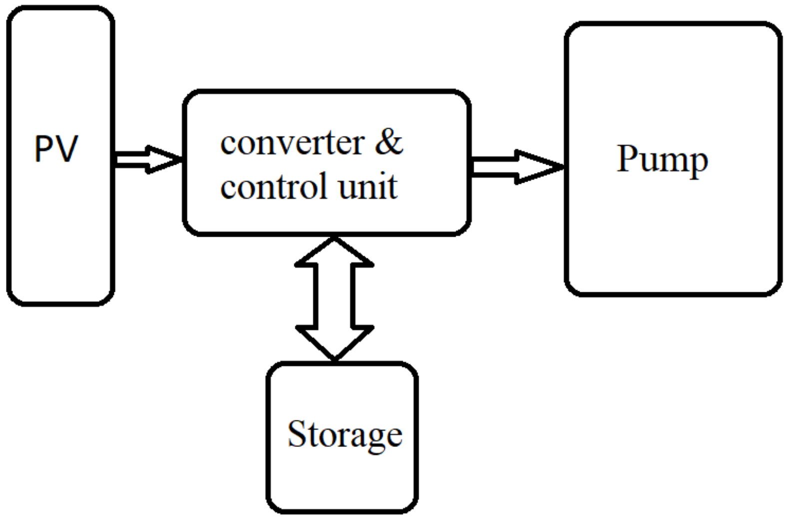
2. battery as storage (like [4,5]). These researchers considered a battery bank as a back-up for solar water pump, which provides power for water pump when there is no enough solar irradiation.



Main parts of a solar water pumping system

Literature Review:

3. Stand-alone solar pumping systems with water tank as storage (such as [6-9]). These researchers proposed a water tank as a back-up to store water directly in the tanks and whenever they need water, the stored water in the wank can be used for irrigation.



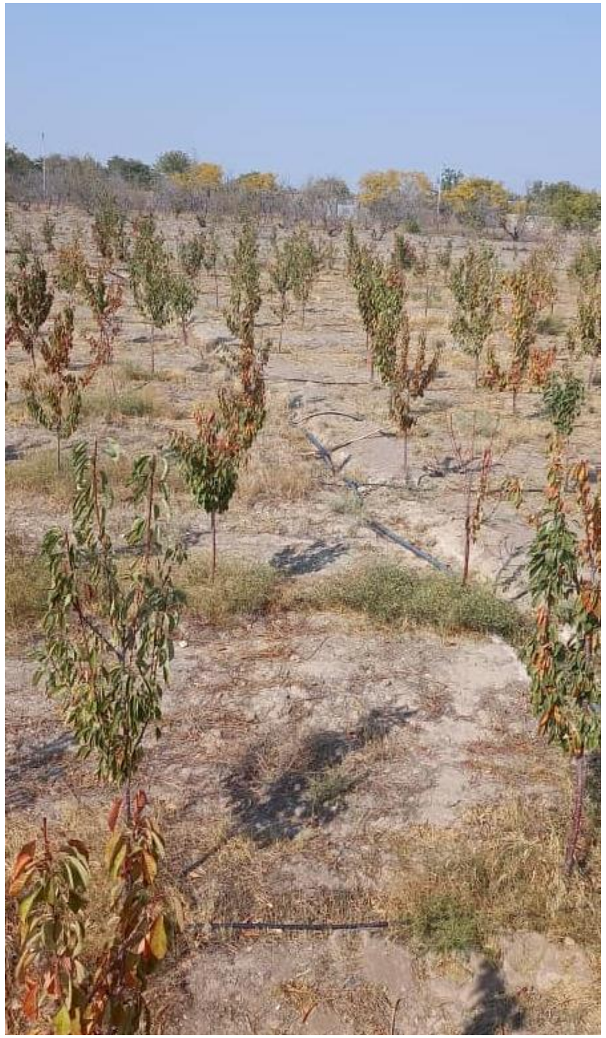
Main parts of a solar water pumping system

Site specifications:

Location:

- Site is Located at 30 km from Mashhad, Iran
- The total area of this site is approximately 220000 m^2
- many apple and cherry gardens
- area comprises about 20 smaller gardens with shared water well
- Surface irrigation/now dripping irrigation

Satellite image of the site location

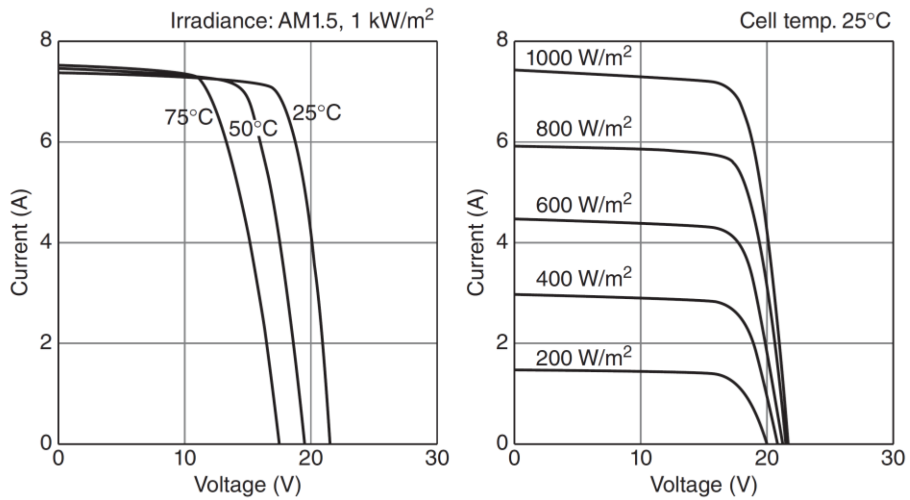


Cherry garden

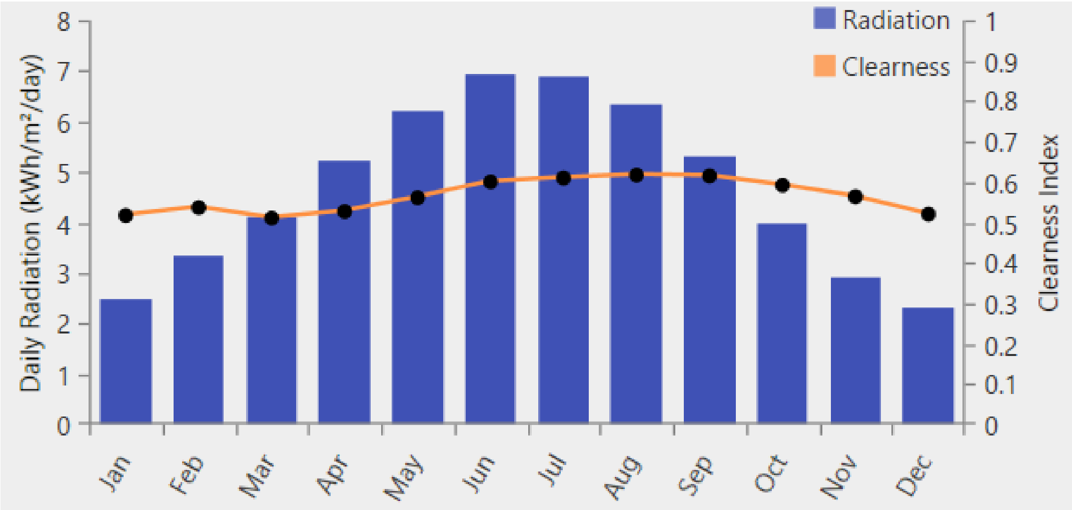
Site specifications:

Ambient condition:

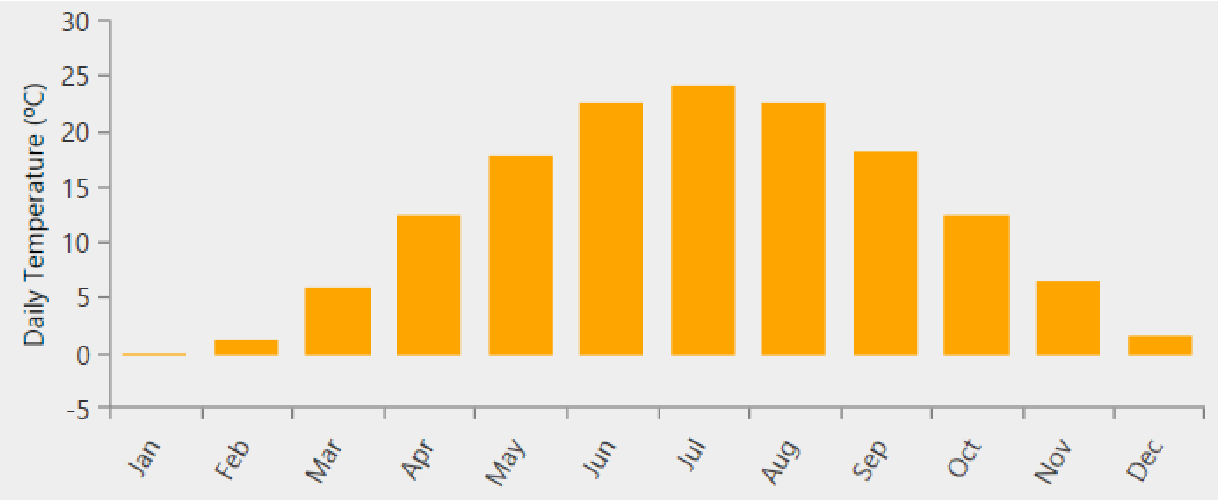
- Solar irradiation and ambient temperature are two main factors in designing a PV-based system
- An increase in cell temperature results in a decrease in open-circuit voltage, and reduce in solar irradiation results in a drop in short-circuit current



Impact of changes in temperature of solar cell and sun irradiance in output voltage and current of a PV module



Mean daily radiation and clearness index of the site



Mean daily temperature of the site

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Site specifications:

Current running system:

- This site uses two diesel generators one as primary and another as auxiliary
- Gasoline is stored in two fuel tanks which are refilled regularly by a fuel truck
- Operating for more than 20 years, nearer to its expected life span
- The maintenance cost has an increasing trend and notable system interruptions

Best time to propose

Mean daily temperature of the site

Fuel tanks

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Site specifications:

Water well and Total Dynamic Head (TDH):

- TDH (Total dynamic head) is the equivalent height which water should be pumped.

$$TDH = H_D + H_V + H_F + H_R$$

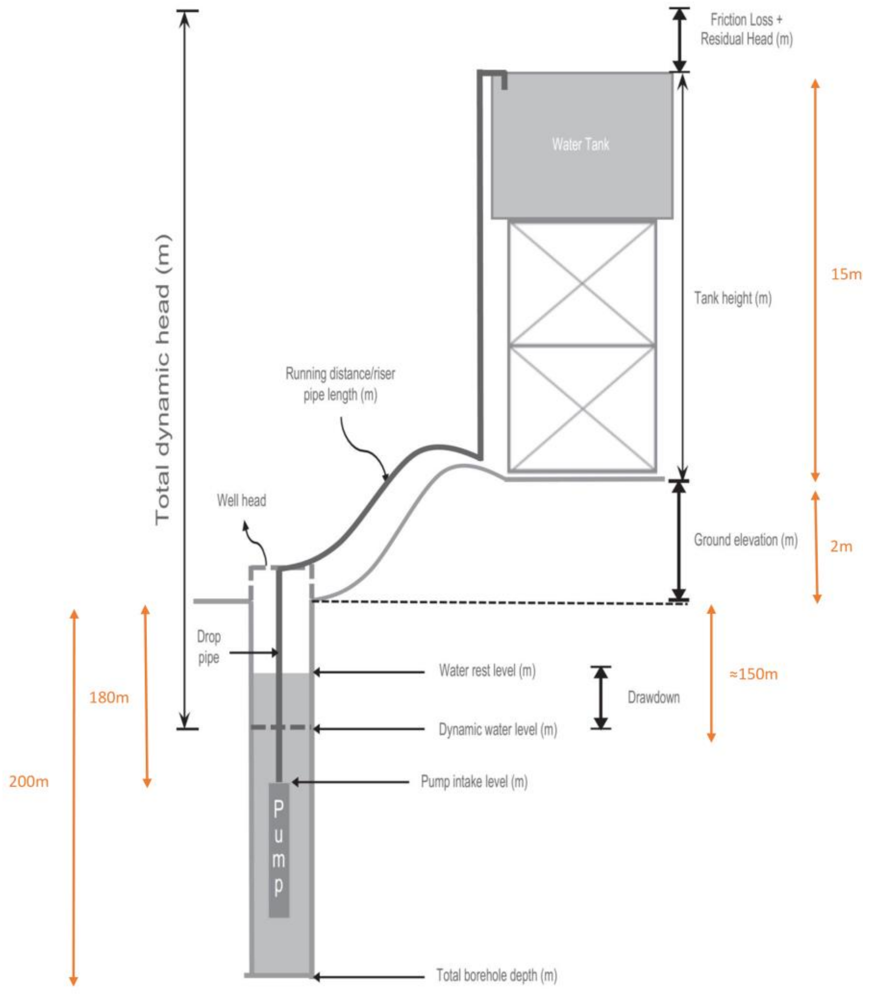
where:

H_D = the height from dynamic water level to borehole surface

H_V = the height from borehole surface to tank inlet

H_F = the fraction lost because of pressure drop in piping

H_R = residual head, which is the additional height from tank inlet to delivery point



TDH calculation

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Site specifications:

Water demand profile:

- based on a local survey, gardeners need 6 m^3 of water per 1000 m^2 of the field
- every day, just a part of these gardens is watered, and the water cycle turns every seven-day
- water which is needed for every seven days:

$$220 \times 6 = 1320 \text{ m}^3$$

- minimum needed water for irrigating for one day:

$$1320 \div 7 = 188.6 \text{ m}^3/\text{day}$$

- If the pump works 7 hours a day:

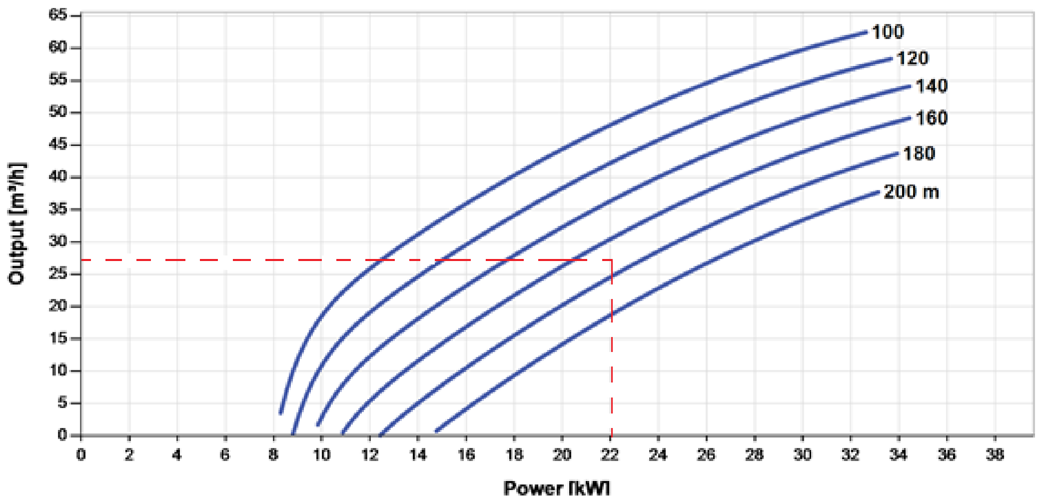
$$\text{Flow rate} = 188.6 \div 7 \cong 27 \text{ m}^3/\text{hour}$$

System sizing:

Selecting solar water pumping system components :

Pump:

- Lorentz PSK2-40 is considered
- Satisfy the minimum needed water flow (27 m^3 /hour) and TDH (170 m)
- the pump needs about 22 KW power for a well with 170 m of TDH and 27 m^3 /hour of water flow,



Lorentz PSK2-40 curves

Lorentz PSK2-40

Min Power should be provided

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System sizing:

Selecting solar water pumping system components :

PV panels:

- JC-340-72P is considered
- **Poly PV module**
- **with 340 W maximum power in Standard Testing Condition (STC)**
- the module dimension is 1.002×1.979 meter

Batteries:

- GP200-12 is a 200Ahr **Gel battery**
- **High life span**

Inverter:

- Growatt 33000TL3-S
- **MPPT solar inverter**
- **33 KVA apparent power and 30 KW rated power**

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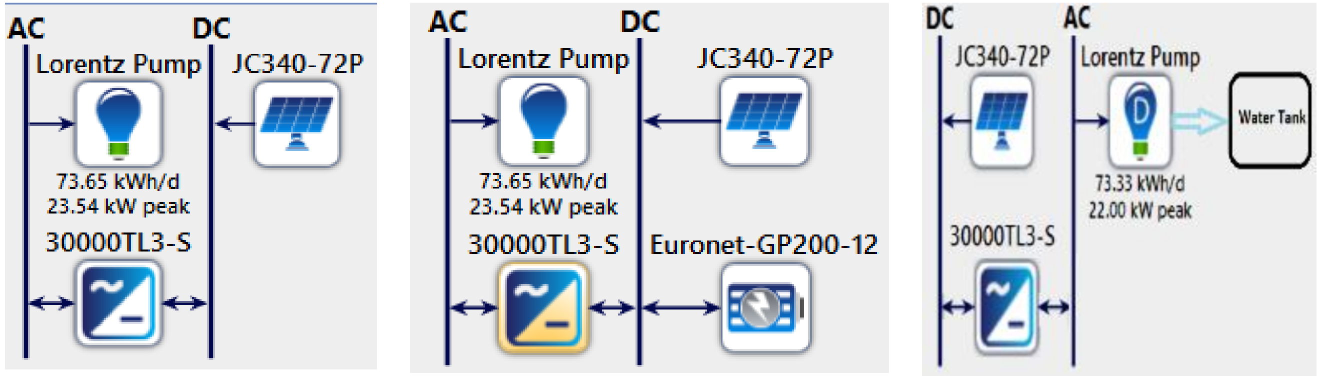
System sizing:

Optimum solar pumping :

There are three typical storage for solar water pumping:

1. Without storage
2. With battery storage
3. With water tank storage



a b c

different storage configuration: a) without storage b) battery storage c) water tank storage

Compare different storage configurations

Configuration	Cost (CA$)	Advantages	Disadvantages
Without storage	30,000	Low cost	Unreliable
Battery storage	72,800	Provide a constant power to pump, which results in a higher life span of the pump	Replacement and maintenance cost
Water tank storage	56,000	High life-span	Difficulty in build and installation of high-capacity water tanks

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System sizing:

Optimum solar pumping :

Without storage :

- a system without storage is the simplest configuration which is used to reduce the project expenses due to the high initial cost of storage systems

- The sizing of these systems are quite straightforward :

Site irradiance
Panel specification
min needed energy

→

# of panels

Panel area = 1.002 × 1.979 = 1.98 m^2
Max power (STC) = 340 W
Irradiance (STC) = 1000 W/m^2
Panel efficiency = 340 / (1000 ×1.98) × 100 = 17.17%
Solar irradiation in the site location is 4.67 KWh/m^2 per day
So we need 7×22KWh = 154 KWh/day
Arraysize=(154KWh/day)/(4.67KWh/(m^2 .day)×0.1717×0.7)= 274.37m^2
Number of modules= [(274.37m2)/(1.98 m2)]=139
Power of each modules is 0.34 KW, so:
Total power = 139×0.34 = 47.26 KW
The cost of each module in Iran is about 150 CA$, so **the cost for PV panels will be:**
139 × 150 = 20,850 CA$
The price of the inverter is about 3000 CA$ in Iran, which should be replaced after 10 years; thus, to cost **the inverter for project lifetime (25 years) is:**
3000 × 3= 9000 CA$
As a result, the total cost of the project is:
20,850 + 9000 ≈ 30,000 CA$

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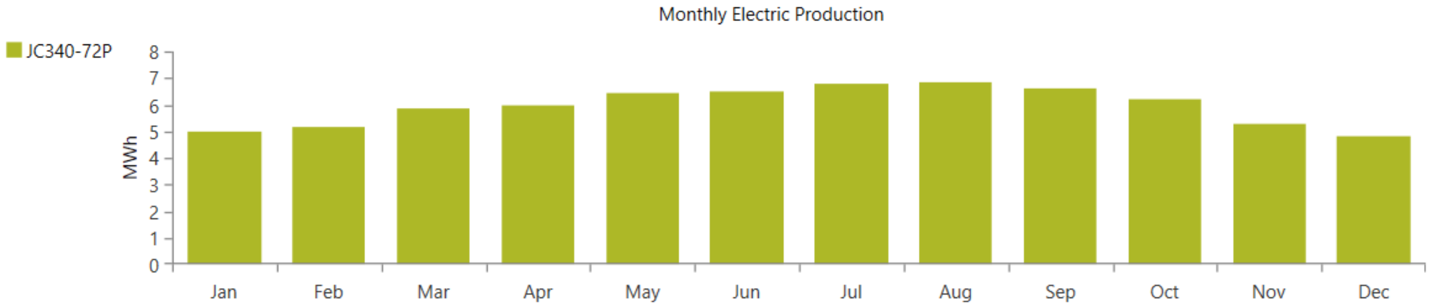
System sizing:

Optimum solar pumping :

optimum solar pumping with battery storage :

- The sizing is done using Homer Pro
- 43.2 KW solar panel, five strings of 20 batteries (100 batteries in total), and a Growatt 30000TL3-S inverter
- most electricity production is during the summertime, which perfectly matches the load demand during the same period of time



Electrical power flow

System Architecture: Growatt 30000TL3-S (30.0 kW)
Sunrise JC340-72P (43.2 kW) HOMER Cycle Charging
Euronet 200Ahr (5.00 strings)

Total NPC:	$72,761.24
Levelized COE:	$0.2095
Operating Cost:	$1,530.25

Production	kWh/yr	%
Sunrise JC340-72P	71,401	100
Total	71,401	100

Consumption	kWh/yr	%
AC Primary Load	26,868	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	26,868	100

Quantity	kWh/yr	%
Excess Electricity	43,153	60.4
Unmet Electric Load	14.2	0.0528
Capacity Shortage	22.2	0.0825

Quantity	Value	Units
Renewable Fraction	100	%
Max. Renew. Penetration	206	%

Homer Pro analysis results

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System sizing:

Optimum solar pumping :

optimum solar pumping with water tank storage:

For sizing of this systems these steps should be taken:

- the minimum needed water for irrigating for one day in this site is about 188.6 m^3 /day, so a tank with 188 m^3 is needed
- It takes about 7 hours to fill this tank with the water pump at 22KW power
- as a result, 22KW × 7 = 154 KWh is storage capacity required.
- the water pump will be defined as a deferable load with 154 KWh storage capacity in Homer Pro
- Homer proposed at least 53.2 KW PV panel and a 30KW inverter for the electric part of the system
- the total project cost is about 40,000 CA$, which should be added to the price of the water tank. A 200 m^3 water tank (four number of 50 m^3 water tanks in series) in Iran is about 16,000 CA$; thus, the total project cost will be approximately 56,000 CA$.

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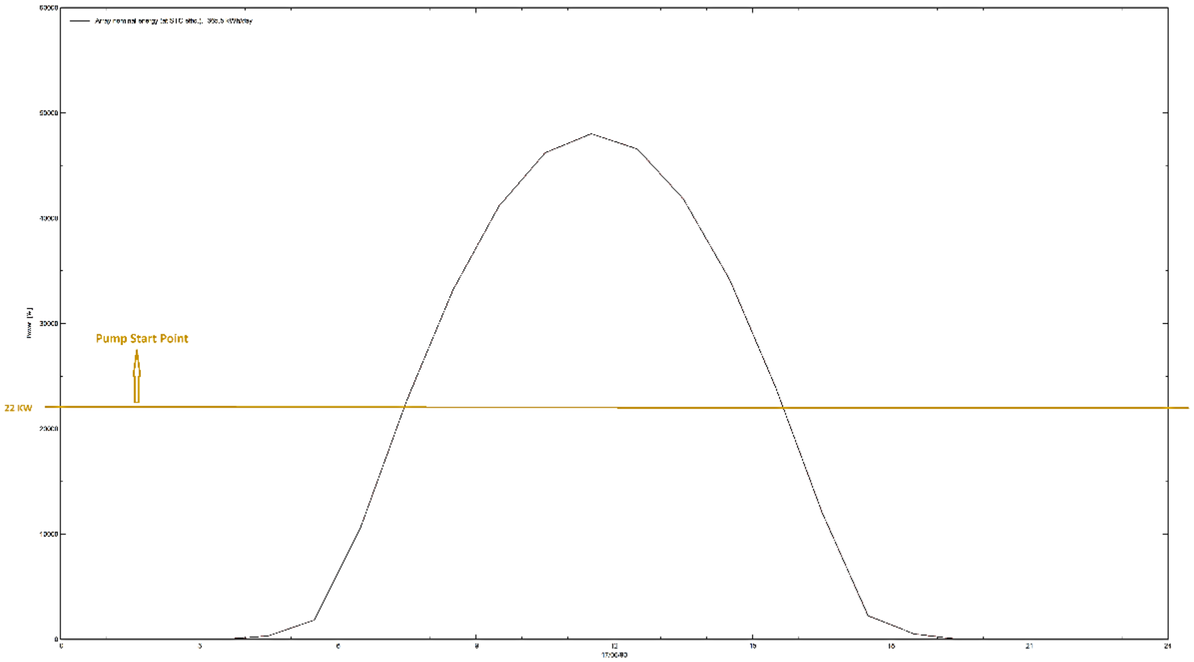
hybrid storage system:

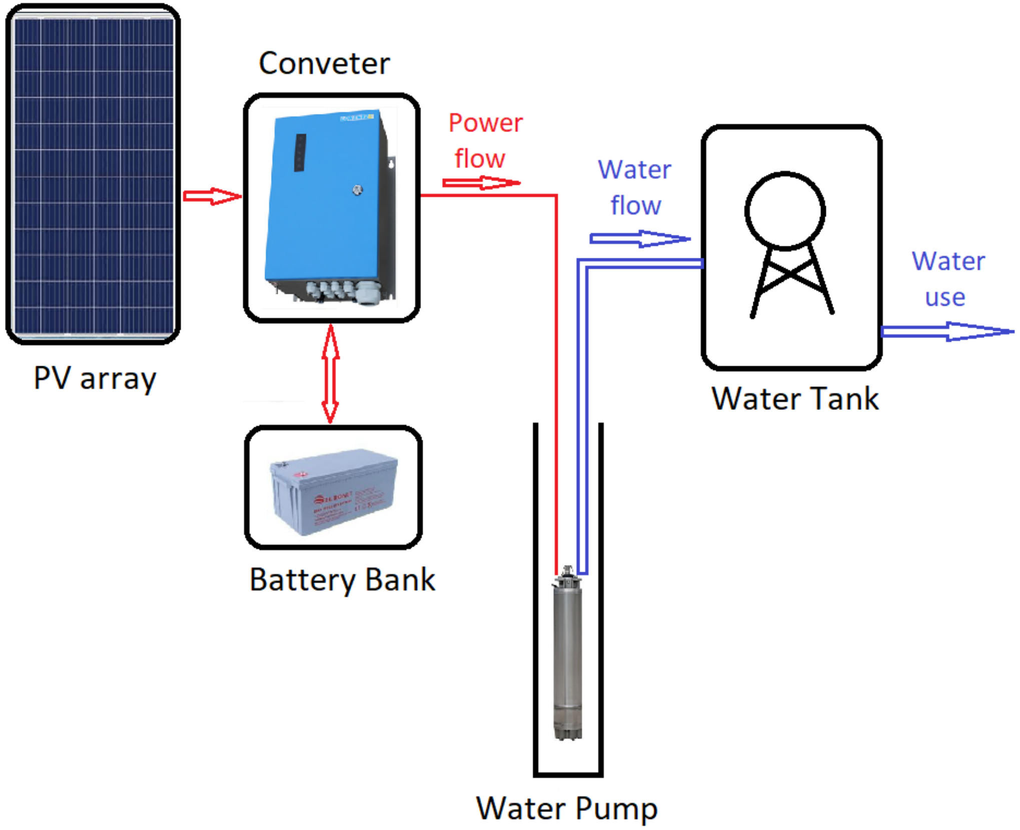
A hybrid storage system consist of:

1. Battery
2. Water tank

- ❖ Take advantage of both configuration
- ❖ Decrease the project cost
- ❖ Increase the reliability
- ❖ Technical advantage



Nominal output array power for the site in Iran (for June 17th)



Schematic of a water pumping system with a hybrid storage

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hybrid storage system:

Question?:

- what is the most optimum size of the battery bank and what is the best capacity for the water tank to reduce the system cost while meeting the minimum needed back-up for solar water pumping to guarantee the system reliability
- This is an optimization problem

Like any optimization problems:

✓ objective function
✓ Constraints

Cost function:

Life-Cycle Cost Analysis (LCCA) is considered as the cost function:

$$LCCA = C_C + C_{O\&M} + C_R$$

Where:

- C_C=Capital cost
- $C_{O\&M}$=Operation and maintenance expenses
- C_R=Replacement cost during the project lifetime

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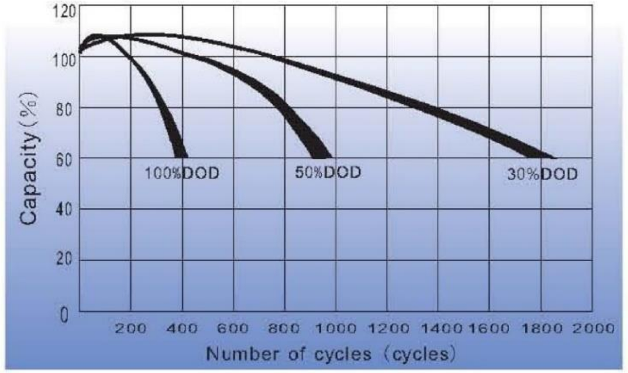
hybrid storage system:

- According to Homer pro simulation for this site in Iran, the **mean battery depth of discharge is approximately %15**. Also, based on the battery manufacturer company, if %15 of battery capacity is used, the battery lifetime will be more **than 2000 cycles**. Since the operation period in this site is about five months per year, <u>there is no need to replace the batteries during the project lifetime</u>



Life characteristics of cyclic use for Euronet Gel Battery

Quantity	Value	Units
Autonomy	68.5	hr
Storage Wear Cost	0.133	$/kWh
Nominal Capacity	263	kWh
Usable Nominal Capacity	210	kWh
Lifetime Throughput	228,510	kWh
Expected Life	54.7	yr

Results of Homer pro battery analysis

The water tanks are last long, and there <u>is no need to replace them during the project lifetime</u>. So, the term CR can be omitted in the LCCA function.

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hybrid storage system:

- used batteries are gel batteries which unlike the conventional lead-acid batteries, they do not need to charge after each period of use. Also, the water tanks have no specific operation or maintenance cost. As a result, the term CO&M is relatively small, so that it can be omitted as well.

- For this specific site in Iran:

$$Cost\ fuction = P_B + P_T\ ; \begin{cases} P_B = Price\ of\ batteries \\ P_T = price\ of\ water\ tanks \end{cases}$$

hybrid storage system:

Constraints:
The only constraint in this problem is that stored energy in water tank and in batteries should meet the minimum needed energy.

Based on Homer:

1. Homer suggestion for total size of the battery bank for the site in Iran is 240 KWh
2. Just 80% of the battery capacity is allowed to use (min SoC is 20%); also, the efficiency of this battery is 85%

The minimum needed stored energy is:

$$minimum\ needed\ stored\ energy = 240\ KWh\ \times 0.80\ \times 0.85 = \mathbf{163.2\ KWh}$$

It is found that this solar water pumping in Iran needs at-least 163.2 KWh of stored energy:
The constrain for this optimization problem is:

$$((E_B + E_T) - 163.2) \leq \varepsilon$$

Where:

- E_B is the stored energy in batteries
- E_T is the stored energy in water tank
- ε is a small positive number. In this research, it is considered as five

percent of the minimum needed energy to ensure daily water demand is satisfied.

$$\varepsilon = 163.2 \times 0.05$$

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hybrid storage system:

Method:

- ❑ The search area is big → Classic optimization methods cannot be used →Evolutionary algorithms are the solution
- ❑ Among evolutionary algorithms → Imperialist Competitive Algorithm (ICA) is used → faster and easier to implement in compare with widely use methods (Genetic Algorithm GA)

Imperialist Competitive Algorithm (ICA) :

- Proposed by Esmaeil Atashpaz-Gargari in the year 2007
- inspired by imperialist competition on their properties
- algorithm starts with a random initial point called "country"; countries are divided into two groups, imperialists and colonies which each colony belongs to an imperialist.
- During the run of this algorithm, imperialists start a competition with other imperialists to take power over more colonies.
- In the end, the most powerful imperialists take control over all countries and converge them to an optimum global point.

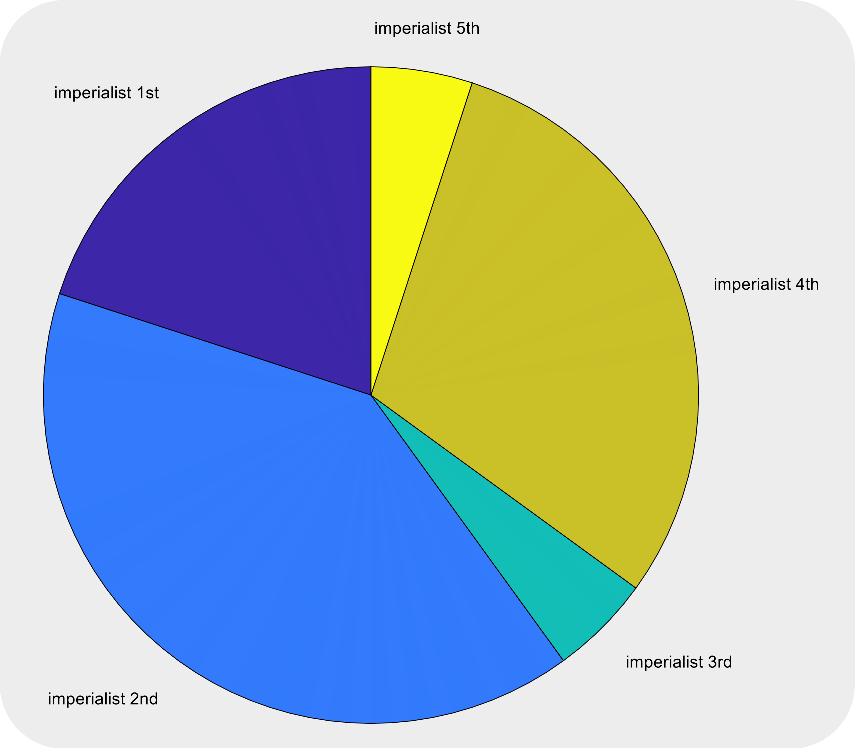
hybrid storage system:

Imperialist Competitive Algorithm (ICA) :

Initialization:

- Generates a number of random initial countries which most powerful countries will be imperialists and the rest colonies.
- to divide colonies among imperialists, the Roulette Wheel selection is used.
- This wheel is like a pie divided into different partitions, representing the normalized power of an imperialist.

- A random number between 0 and 100% is generated to select an imperialist and allocate a colony to that imperialist.
- In this way,an imperialist with a higher power has a higher chance to be selected; as a result, an imperialist with a higher power has more colonies.



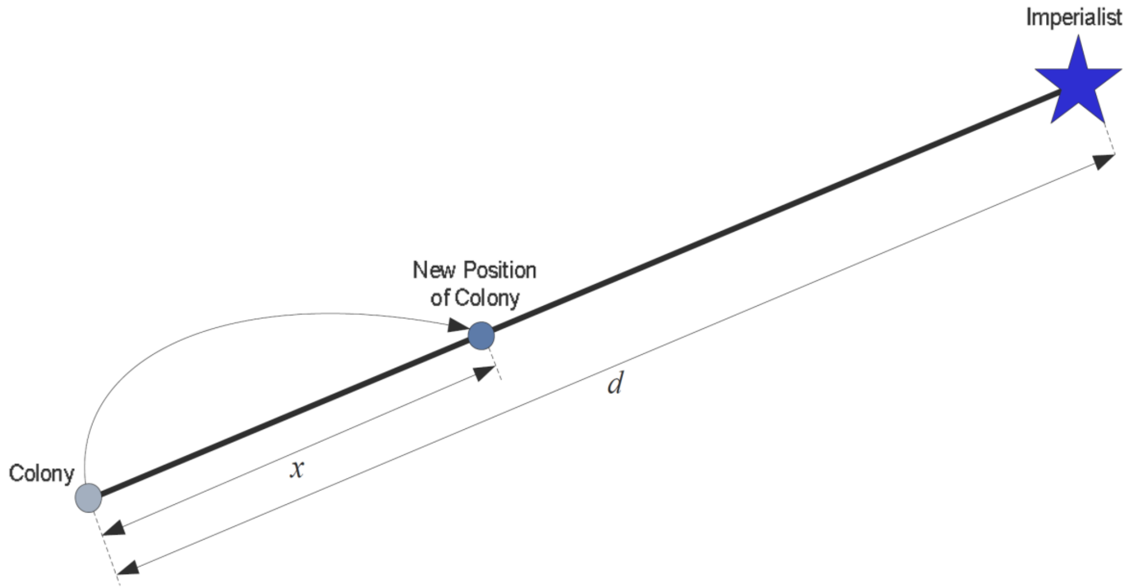
The nominalized probability of imperialists

hybrid storage system:

Imperialist Competitive Algorithm (ICA) :

Colonies moving toward their imperialist:

- Imperialists try to make their empire more powerful by moving their colonies toward themselves.
- the total power of the empire will rise

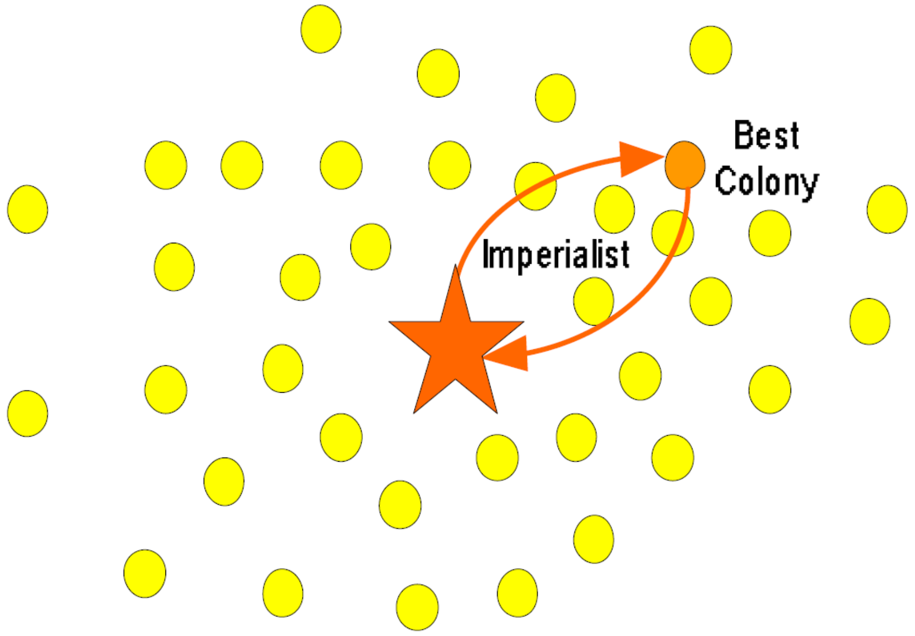


Colonies moving toward their imperialist

hybrid storage system:

Imperialist Competitive Algorithm (ICA) :

Exchange the position of a colony with its relevant imperialist:
After a colony moves toward its imperialist, it may find a better location in the search area with higher fitness than the imperialist; in this scenario, the position of the imperialist and that colony will be switched



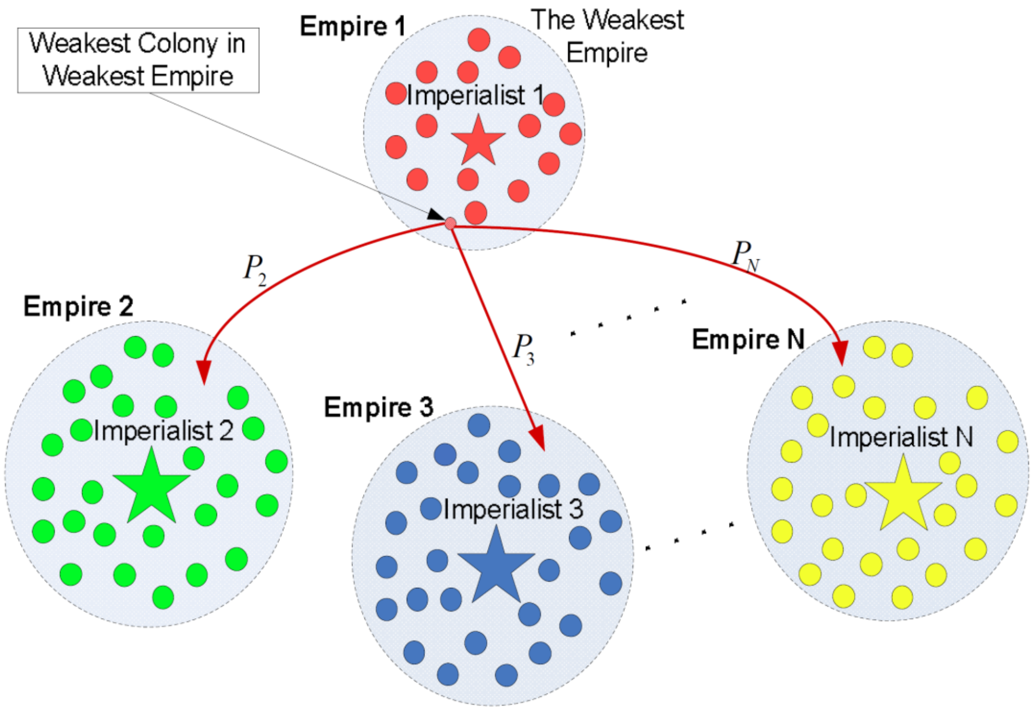
Exchange the position of a colony with its relevant imperialist

hybrid storage system:

Imperialist Competitive Algorithm (ICA) :

Imperialist competition:

- In this algorithm, the weakest colony in the weakest empire is picked. It is given to the selected empire using the roulette wheel, which means that an empire with the most total power has more chance of owning the weakest colony



Imperialist competition

hybrid storage system:

Imperialist Competitive Algorithm (ICA) :

Eliminating the powerless imperialist:

- During the run of the algorithm and after a couple of loops, an imperialist might lose all of its colonies; in this case, the relevant empire will be collapsed, then imperialist will be considered a colony and it will be assigned to one of the rest empires with roulette wheel selection.

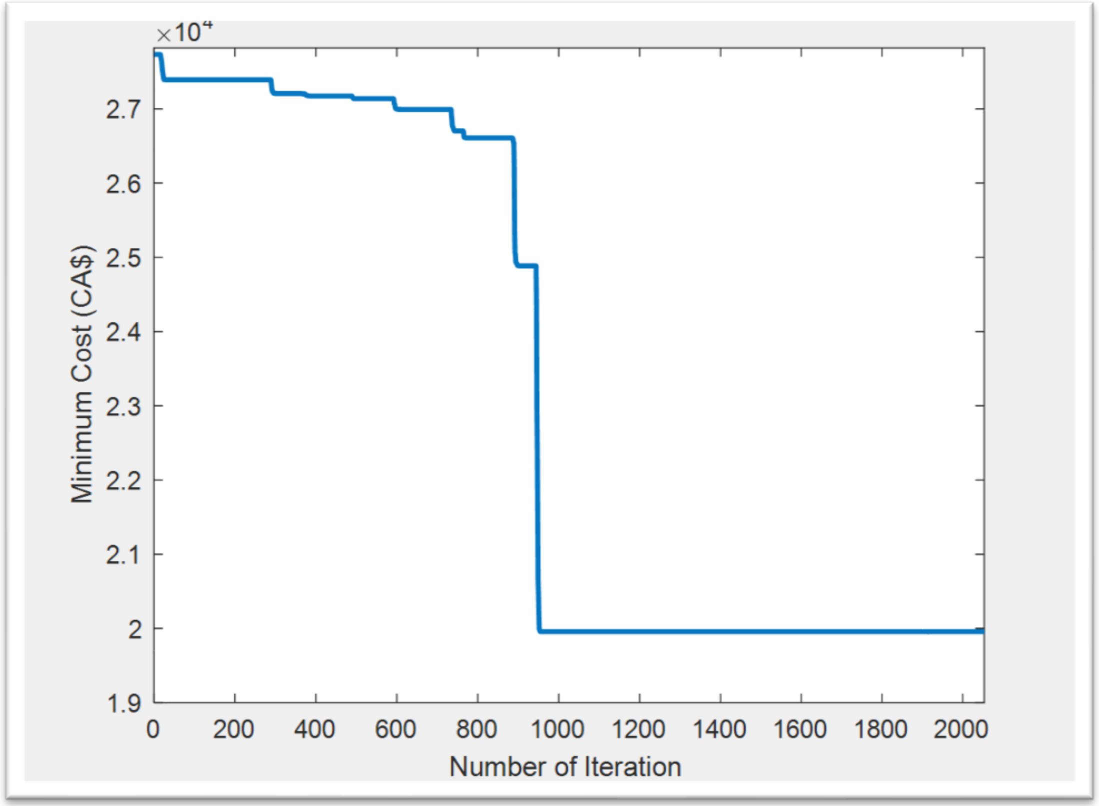
Stop criteria

- Stop criteria can be defined in different ways. In this research, reaching a specific number of algorithm loop (generation) is considered a stop criterion.

hybrid storage system:

Results of Implementation of ICA for Optimum Size of Hybrid Storage :

The algorithm suggestion for optimum size of storage system for this specific solar water pumping system in Iran is as follows:



The cost of best imperialist during the run of algorithm

the output results of ICA

storage	Value
Number of batteries	40
Water tank (m^3)	140

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hybrid storage system:

Results of Implementation of ICA for Optimum Size of Hybrid Storage :

To justify the output result of ICA, the following table is prepared with a couple of battery and water tank combinations:

Some feasible size of the hybrid storage system

# of batteries	Water tank capacity (m^3)	Total Price (CA$)
130	9	26562
120	24	25509
110	39	24483
100	55	23757
90	68	22760
80	82	21860
70	97	21366
60	112	20699
50	128	20448
40	140	20041
40	141	20342
40	142	20644
40	143	20945
30	156	22862
30	158	23464
20	170	24905
20	171	25188
10	184	26540
10	185	26740

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hybrid storage system:

Comparison :

- cheaper than the two other configurations.
- is not significant, the hybrid system boosts system reliability and can provide sufficient water during the hours of operation.
- In case of failure

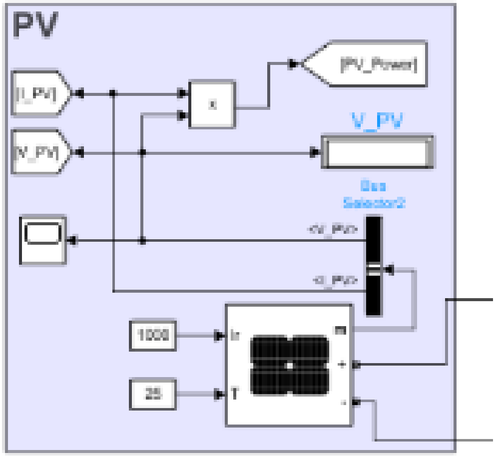
comparison of storage methods

Storage type	capacity	Cost (CA$)
batteries (Number of 100 Ah battery)	200	40,000
Water tank (m^3)	180	23,800
Hybrid	Batteries: 40 × 100Ah and Water tank: 140 m^3	20,041

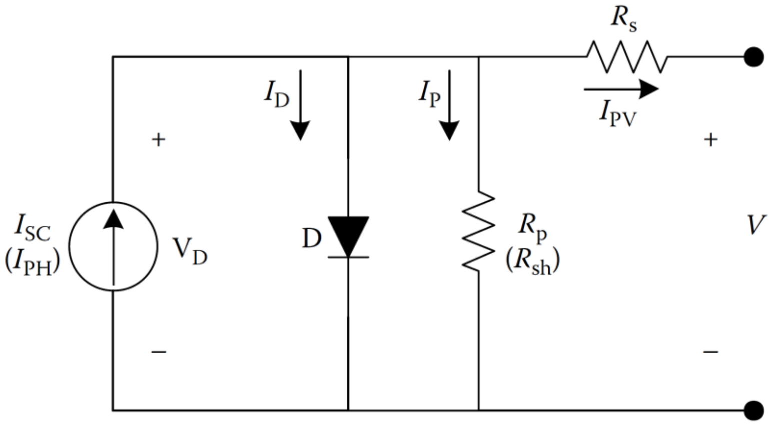
Dynamic modeling and Simulink:

Photovoltaic cell: Common single diode model

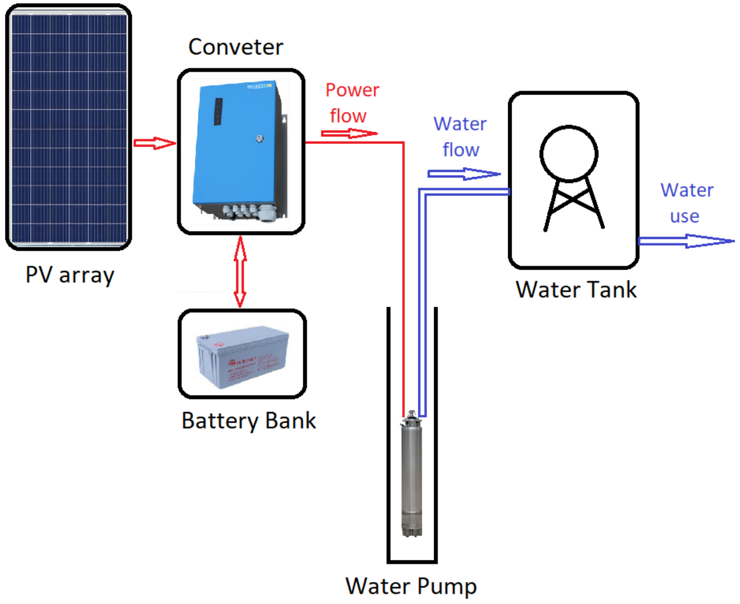
- Inputs: cell temperature (direct impact on output)
- Outputs: Voltage and current



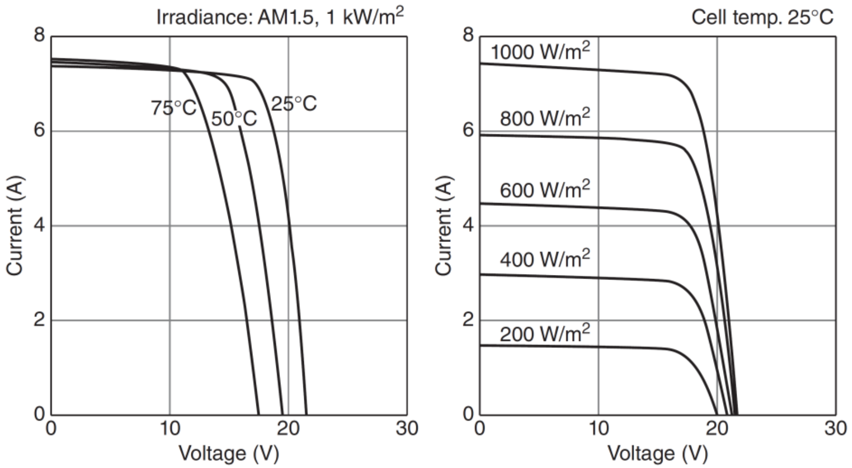
the Simulink model of PV



PV cell single diode equivalent circuit



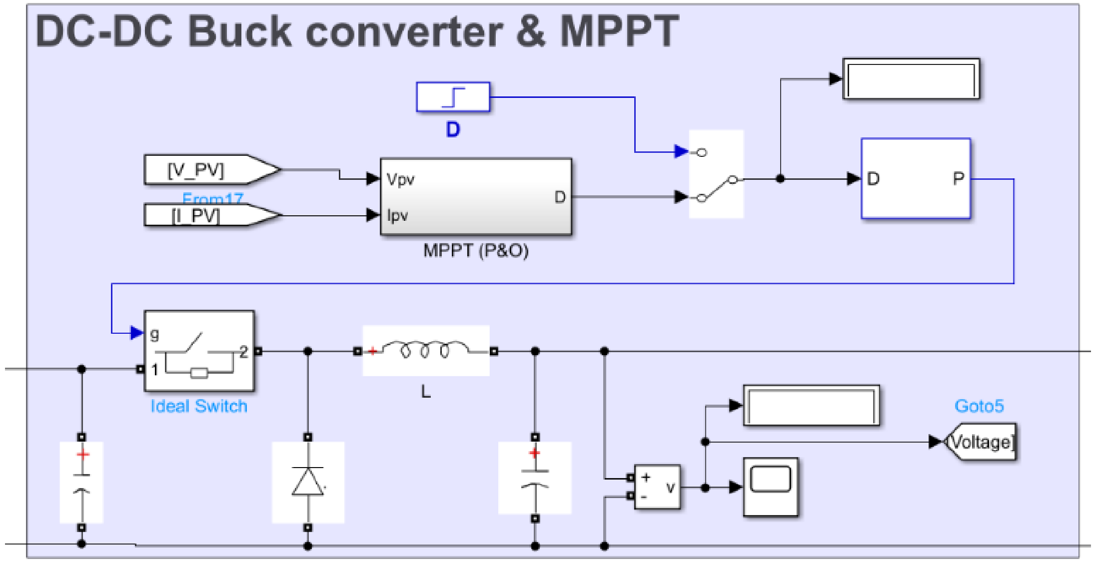
Solar water pump with hybrid storage



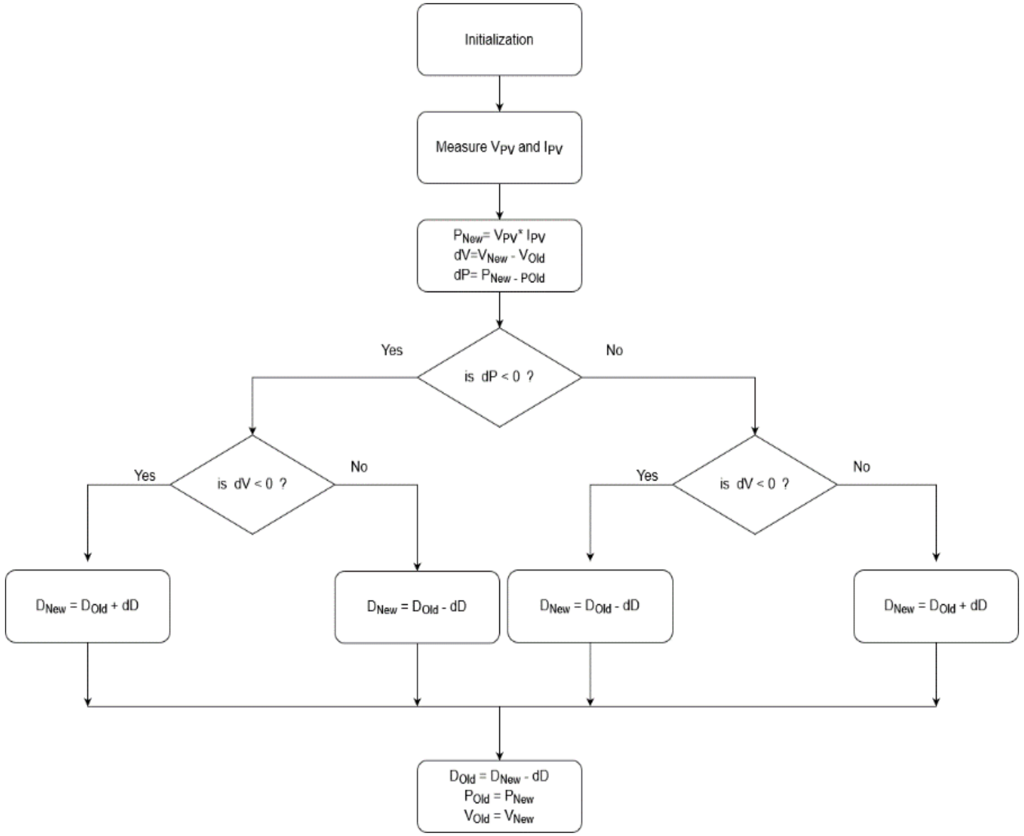
Impact of changes in temperature of solar cell and sun irradiance in output voltage and current of a PV module

Dynamic modeling and Simulink:

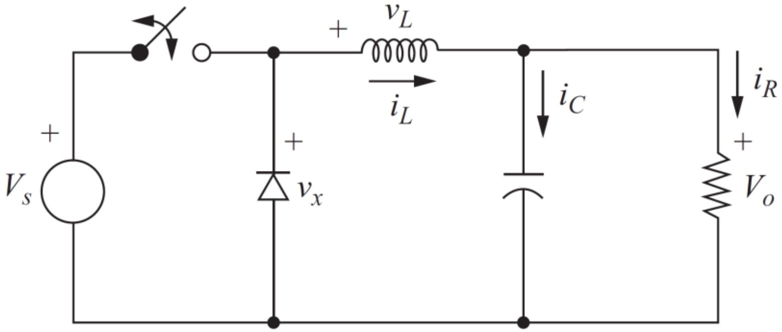
DC/DC converter and MPPT: buck converter
Perturb-and-Observe (P&O)



Simulink model of DC-to-DC buck converter and MPPT



P&O flowchart



Buck converter topology

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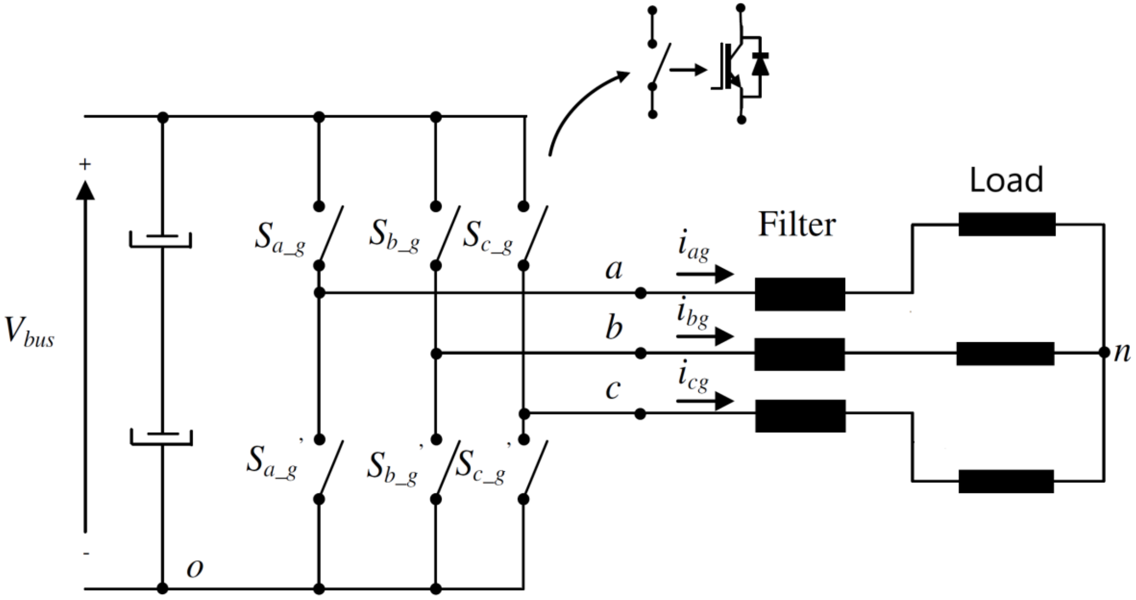
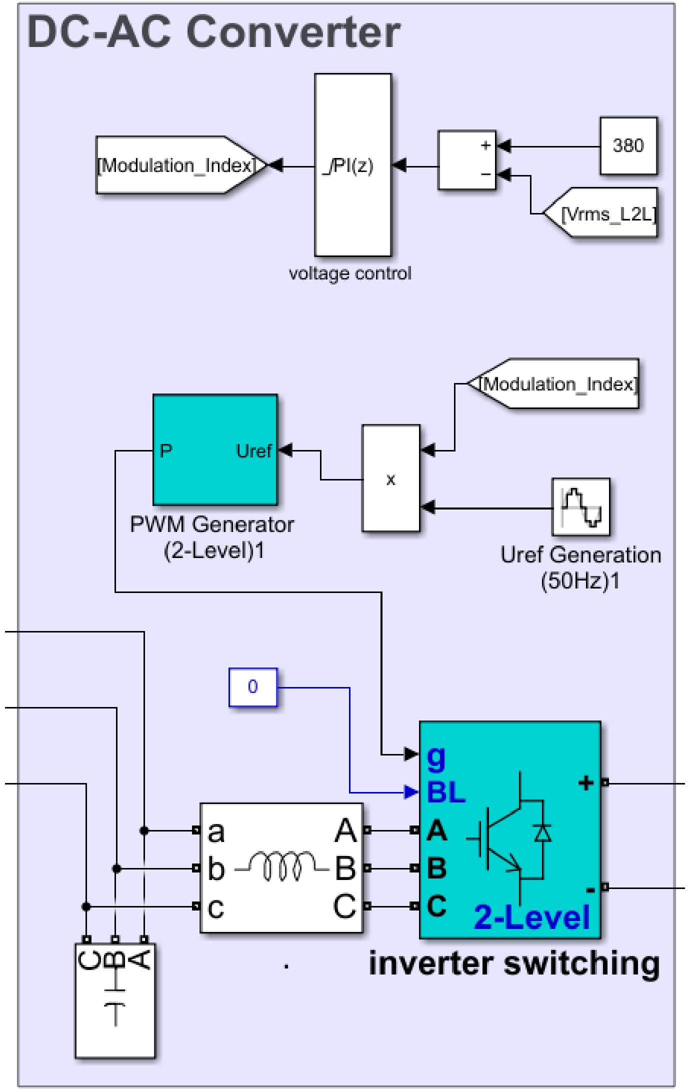
Dynamic modeling and Simulink:

DC/AC converter : two-level 3-phase inverter

- Inputs: DC voltage
- Outputs: 3phase AC voltage



Two-level 3ph inverter

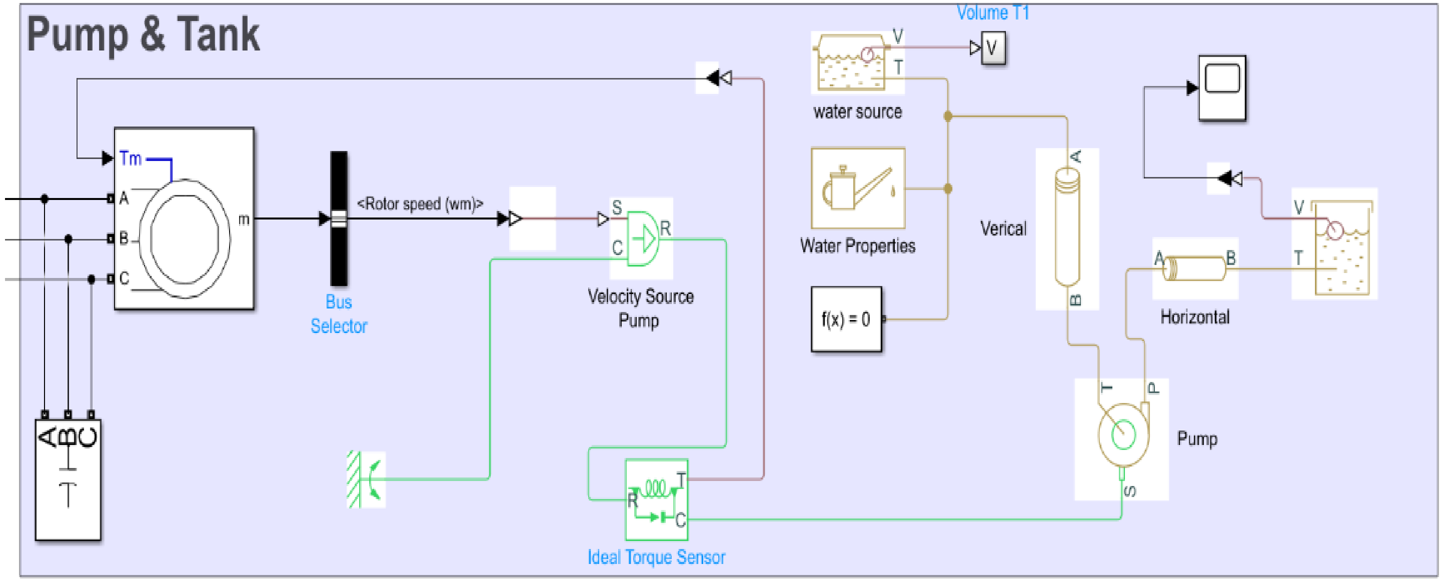


the Simulink model of two-level
DC to AC inverter

Dynamic modeling and Simulink:

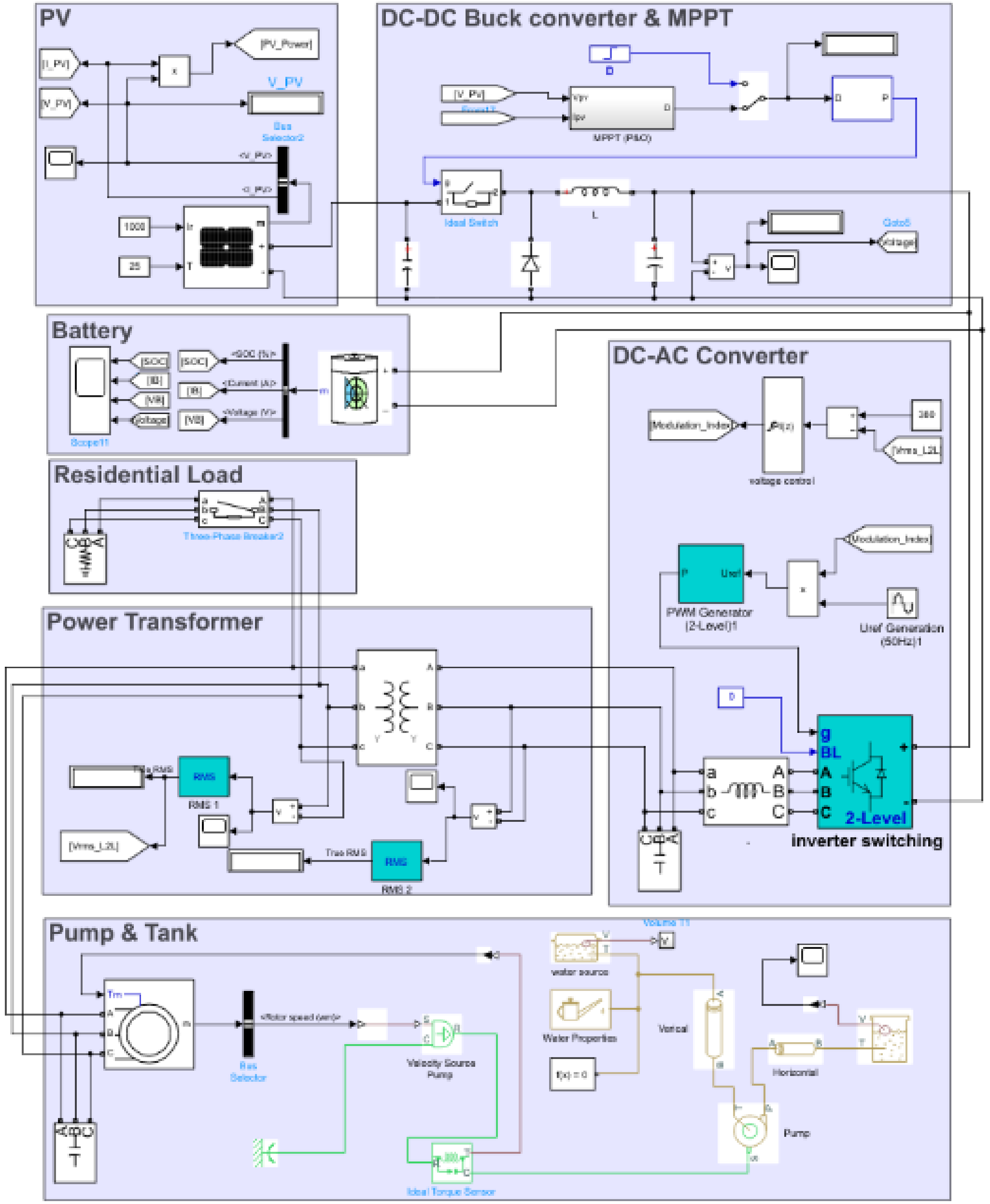
Water pump and Water tank

- Inputs: 3phase AC voltage
- Outputs: level of water tank



Simulink model of water pump and water tanks

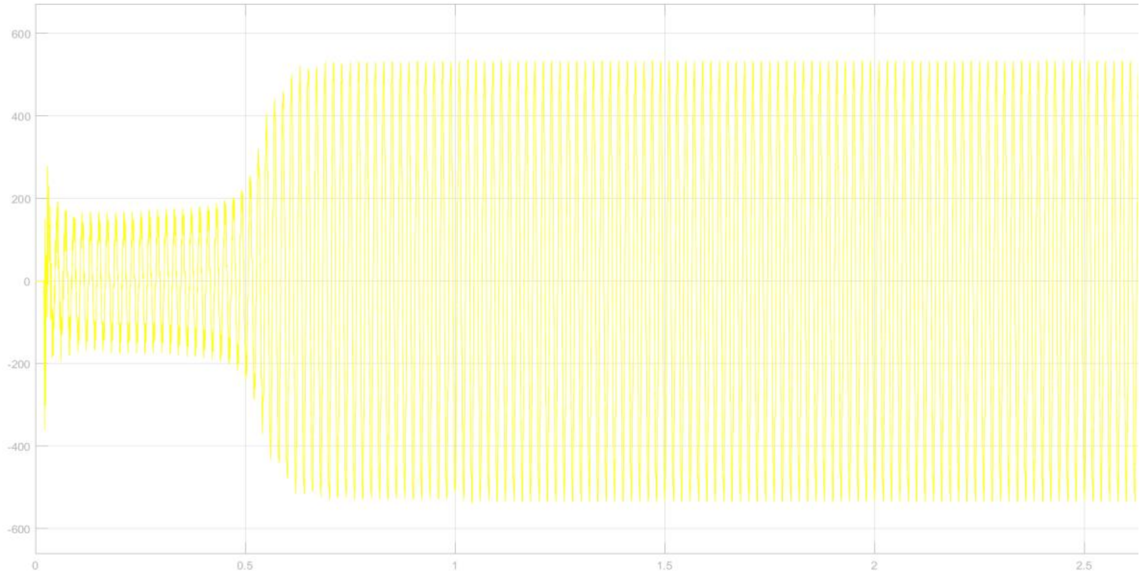
Dynamic modeling and Simulink:



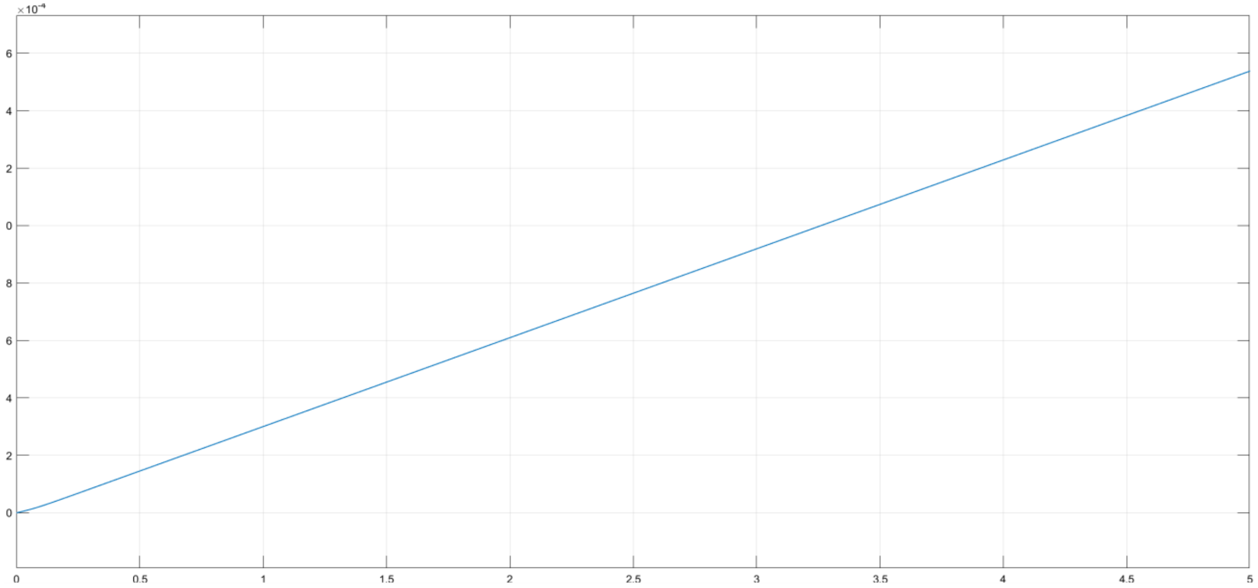
the complete model of solar water pump system with hybrid storage system in Simulink

Dynamic modeling and Simulink:

At Standard Test Condition (STC) that cell temperature is 25 Celsius and irradiance is 1000 w/m2



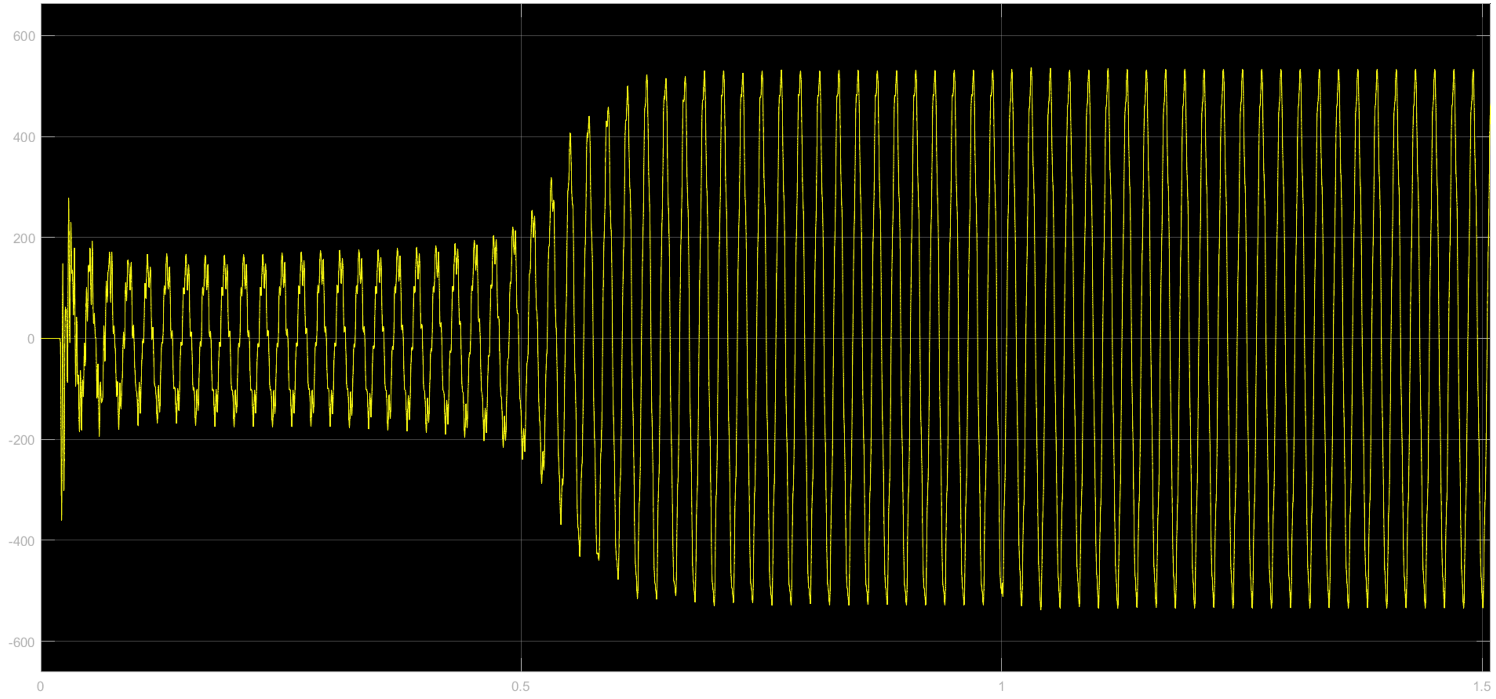
VL-L phase b and c



Water level in the tank

Dynamic modeling and Simulink:

At Standard Test Condition (STC) and a small active load (3 KW) switched at second one

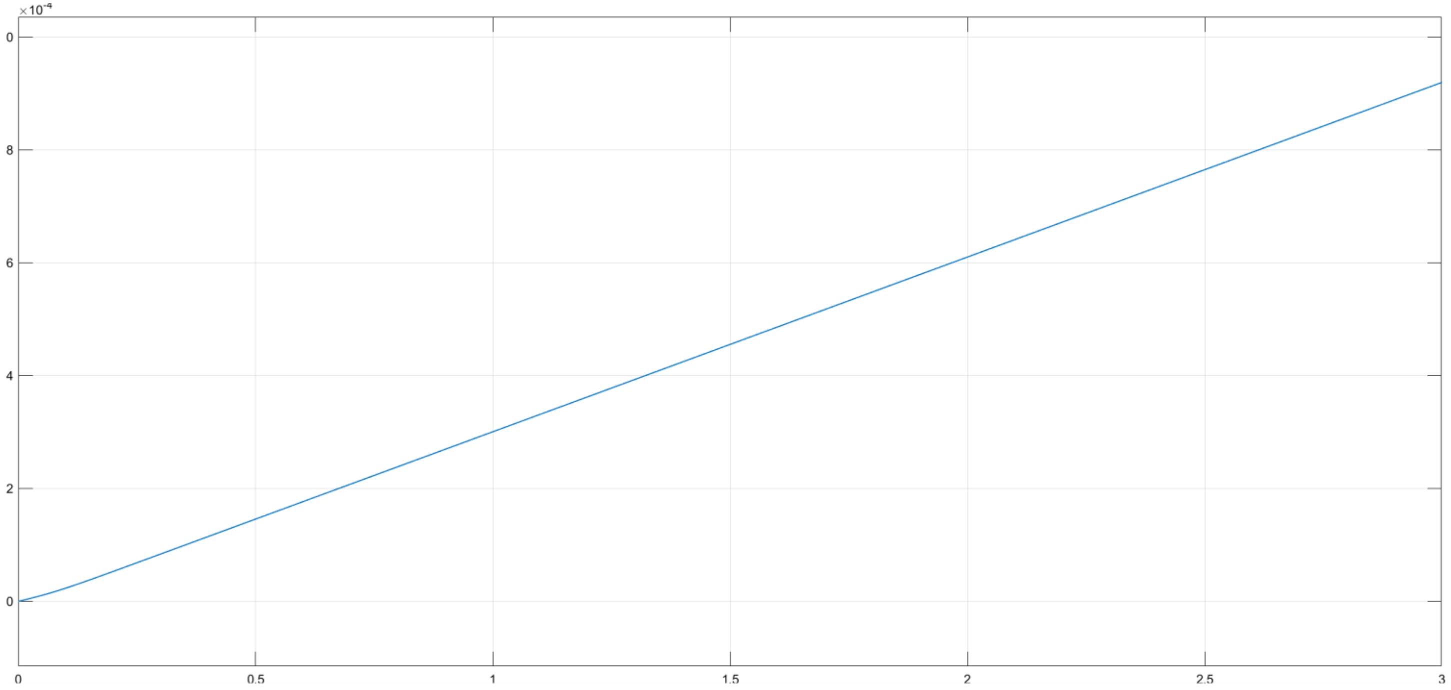


VL-L phase b and c (switch at 1 second)

Dynamic modeling and Simulink:

Temperature analysis

- Site located in warm and dry environment
- Changes temperature step by step
- Temperature doesn't have affect on the system



Water level in the tank during the temperature changes

Conclusion:

- the optimum sizing of a solar water pumping system was proposed using Homer pro for a site in Iran for three configurations.
- a hybrid storage system was proposed, which included both battery and water tank.
- This hybrid storage system not only slightly decreases the capital cost of the system but also increases the reliability and stability of the system.
- The hybrid storage system was optimized using ICA algorithm
- to study the system's outcome and ensure the proposed system's correct performance, dynamic analysis was done in MATLAB/Simulink
- This simulation showed that the proposed solar water pump with a hybrid storage system was functioning perfectly.

Future Work:

- ❖ Select another site and study the same system.
- ❖ Develop and optimum design in building water tanks.
- ❖ Employ other optimization algorithms for storage optimization.
- ❖ Using a hybrid solar-wind energy system where it has a reasonable potential for wind energy.
- ❖ Design data logging and SCADA system
- ❖ Design remote control system

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Publications:

[1] A. Jahanfar and M. T. Iqbal, "Design and Simulation of a Wind Turbine Powered Electric Car Charging System for St. John's, NL," 2021 IEEE 12th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON), 2021, pp. 0765-0771, doi: 10.1109/IEMCON53756.2021.9623257.
[2] Iqbal, Tariq and Jahanfar, Amirhossein (2021) Design and dynamic simulation of a wind turbine powered electric vehicle charging system. In: 30th IEEE NECEC Conference, November 18, 2021, St. John's, Newfoundland and Labrador.
[3] A. Jahanfar and M. Tariq Iqbal, "A Comparative Study of Solar Water Pump Storage Systems," 2022 IEEE 12th Annual Computing and Communication Workshop and Conference (CCWC), 2022, pp. 1070-1075, doi: 10.1109/CCWC54503.2022.9720912.
[4] A. Jahanfar and M. T. Iqbal, "An Optimum Sizing for a Hybrid Storage System in Solar Water Pumping Using ICA," in 2022 IEEE International IOT, Electronics and Mechatronics Conference (IEMTRONICS), 2022, pp. 1–6, doi: 10.1109/IEMTRONICS55184.2022.9795848.
[5] A. Jahanfar and M. T. Iqbal, "Dynamic Modeling and Simulation of Solar Water Pumping With Hybrid Storage System," in 2022 IEEE 13th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON).

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References:

[1] Bangari, Naresh & Madhu, P & Prasad, K & Prof, Asst. (2012). Analysis Of Dc Solar Water Pump and Generalized Photovoltaic Model Using Matlab/Simulink. UACEE International Journal of Advancements in Electronics and Electrical Engineering Volume 1: Issue 1. 1. 6.
[2] Mahmoud M. Elkholy, Ahmed Fathy, Optimization of a PV fed water pumping system without storage based on teaching-learning-based optimization algorithm and artificial neural network, Solar Energy, Volume 139, 2016, Pages 199-212, ISSN 0038-092X, https://doi.org/10.1016/j.solener.2016.09.022.
[3] A. Betka, A. Attali, Optimization of a photovoltaic pumping system based on the optimal control theory, Solar Energy, Volume 84, Issue 7, 2010, Pages 1273-1283, ISSN 0038-092X, https://doi.org/10.1016/j.solener.2010.04.004.
[4] M. Zamanlou and M. T. Iqbal, "Design and Analysis of Solar Water Pumping with Storage for Irrigation in Iran," 2020 IEEE 17th International Conference on Smart Communities: Improving Quality of Life Using ICT, IoT and AI (HONET), 2020, pp. 118-124, doi: 10.1109/HONET50430.2020.9322660.
[5] F. Alkarrami, T. Iqbal and K. Pope, "Optimal sizing of a stand-alone hybrid energy system for water pumping in Sirte, Libya," 2016 IEEE Electrical Power and Energy Conference (EPEC), 2016, pp. 1-5, doi: 10.1109/EPEC.2016.7771679.
[6] Kiprono, A. W., & Llario, A. I. (2020). Solar Pumping for Water Supply: Harnessing solar power in humanitarian and development. pp 68-69
[7] Yahia Bakelli, Amar Hadj Arab, Boubekeur Azoui, Optimal sizing of photovoltaic pumping system with water tank storage using LPSP concept, Solar Energy, Volume 85, Issue 2, 2011, Pages 288-294, ISSN 0038-092X, https://doi.org/10.1016/j.solener.2010.11.023.
[8] Soenen, Camille & Reinbold, Vincent & Meunier, Simon & Cherni, Judith & Darga, Arouna & Dessante, Philippe & Loic, Queval. (2021). Comparison of Tank and Battery Storages for Photovoltaic Water Pumping. Energies. 14. 2483. 10.3390/en14092483.
[9] Wagdy R. Anis, M.A. Nour, Optimum design of a photovoltaic powered pumping system, Energy Conversion and Management, Volume 35, Issue 12, 1994, Pages 1123-1130, ISSN 0196-8904, https://doi.org/10.1016/0196-8904(94)90016-7.

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Thank you

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