Performance Comparison of Solar Photovoltaic Submersible Centrifugal and Reciprocating Water Pumping System

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Abstract- Solar energy is the present trending technology in the world. Solar energy is harnessed and used for real time applications like water heater, dryer, electricity, street lighting, irrigation etc. From Past one decade onwards the technology of solar water pumping system is playing a very important role in the agricultural sector and it meets the farmer needs in supplying water to the farming fields. Centrifugal and reciprocating pumps are mostly commonly used in the agricultural sector.
In this paper, we are analyzing a case study between centrifugal and reciprocating submersible pump set of the capacity 5hp 100m DC by using simulator and Outdoor Condition methods. By evaluating the below mentioned factors like how the motor pump set will operate with solar energy and analyzing the results of the performance of motor pump set with different parameters like power consumption, voltage, current, flow rate, pump output and required solar irradiation to attain the desired head for both the pumps.

Keywords: Solar Energy, Photovoltaic module, Simulator, Irradiation, Submersible pump.

Abbreviations:
AC: Alternating Current
DC: Direct Current
Pmax: Maximum Power
Vmax: Voltage at Maximum Power
Imax: Current at Maximum Power
Voc: Open Circuit Voltage
Isc: Short Circuit Current
F.F: Fill Factor
PV: Photovoltaic
MMS: Module Mounting Structure
PLC: Programmable Logic Control
VFD: Variable Frequency Drive
SWPS: Solar Water Pumping System
SPVM: Solar Photovoltaic Module

1.INTRODUCTION

Solar energy is the abundant amount of light energy released by the sun to the earth. This light energy is converted into the various other forms like (heat and electricity) and used for real time applications by using solar photovoltaic modules. The solar photovoltaic modules made up of silicon material. These silicon materials have a property to generate electricity by converting radiant sun light into heat energy. It generates pure DC power. This is pure and clean renewable energy. Solar energy is pollution free and there is no emission of greenhouse gases. While coming to the real time applications, where electrical grid and transmission lines are not available there solar energy is very helpful.

Solar energy is very helpful to farmers in agriculture cultivation. In most of the agriculture fields both centrifugal and reciprocating pumps are used for water supply. These pumps are used to draw the water from depth of ground to surface. Centrifugal pumps are high pressure pumps. These are used for large scale farming, because of their high flow rate delivery of water. Reciprocating pumps are low pressure pumps. So it is used in oil and gas, automotive industries, medical and small scale irrigation lands.

From Past one decade onwards solar energy is playing a major role in agriculture sector. In 2014 government of India has made an ambitious goal to replace 26 million ground water pumps which run on costly diesel with more efficient and environment friendly options such as Solar Water Pumping System. Government also encouraging farmers to set up solar based water pumps in their farming fields. Under “PM KUSUM” Yojana scheme government giving more subsidy on solar water pumps.

2.TEST SETUP

For testing the solar water pumps, we have a basic test setup with measuring, controlling and testing equipment's like chroma simulator, solar panels mounting structure as per the requirements. Below figure 1 shows test setup of solar water pumping system.

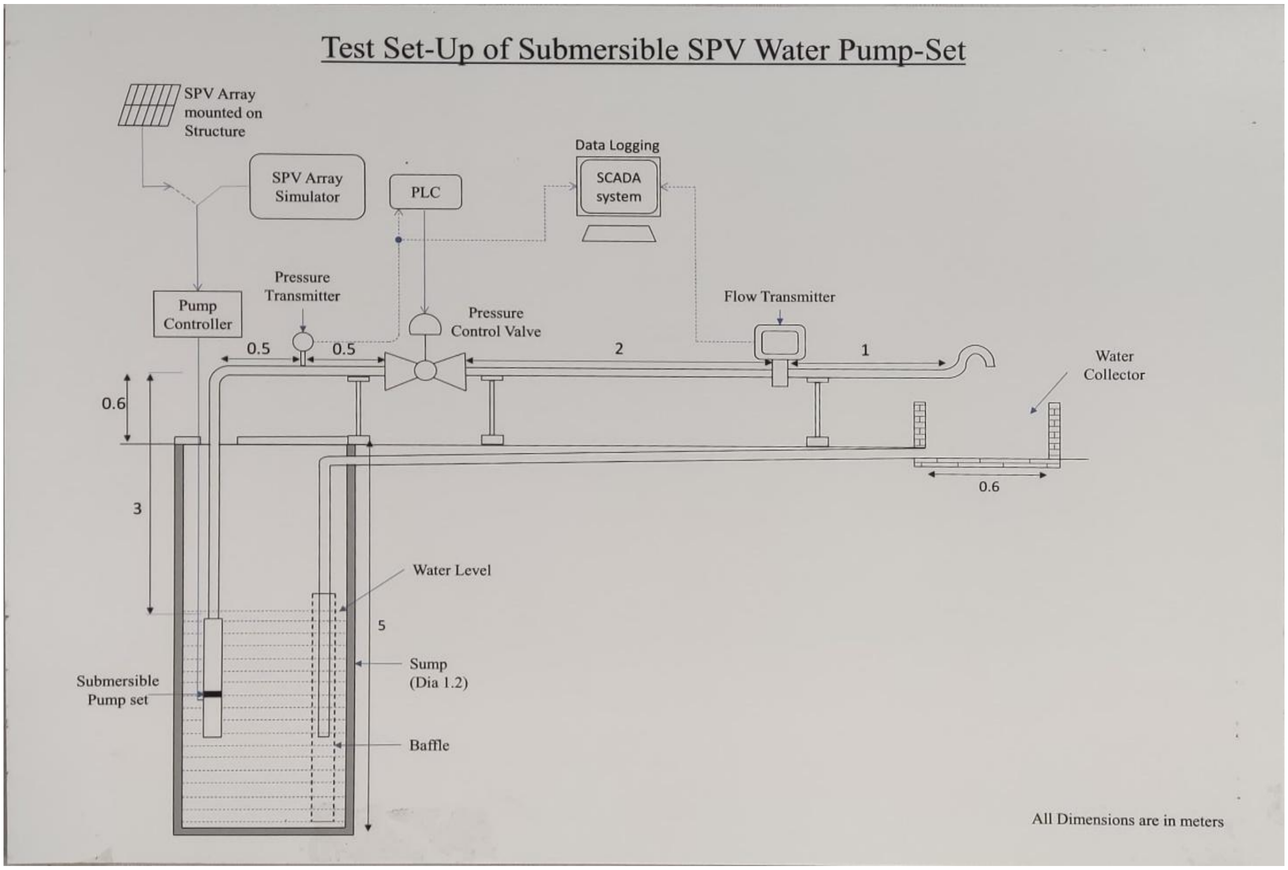


Figure 1:Test set up of submersible SPV water pump set

- Flow transmitter, pressure transmitter and data loggers these are the measuring equipment's need for testing of SWPS.
- Pressure control valve, Programmable Logic Control (PLC) and Pump Controller these are controlling equipment's need for testing of SWPS.

2.1 Test procedure

According to the test setup from figure 1 installed the equipment's and following are the step wise test procedure.

1. The motor Pump set are Submersed in the sump of 5 meter depth. Delivery line is equipped with pressure transmitter, pressure control valve and flow transmitter.
2. Motor is connected to pump controller device and this pump controller is connected to solar array simulator for simulator testing and solar panels for outdoor analysis.
3. Before going to the test methods we Should compulsorily test the protection compliance of the controller for the parameters like open circuit, short circuit, dry run and under voltage by conducting protection test.
4. First we will test the motor pump set by simulator method through a programmable DC power supply called chroma simulator.
5. When the DC simulator gives power supply to pump controller, then pump controller will switch on the motor Pump set. Pressure is created by pump to lift the water.
6. During testing we need to maintain a constant required head, for this purpose a PLC is used

through which we can control the pressure control valve throughout the testing.

7. When pressure control valve is opened water flow will start from the pump. This flow will measured by flow transmitter.
8. In entire simulator testing, each minute data of flow, pressure, power consumption, voltage and current will be recorded.
9. After completion of simulator testing pump controller is connected to solar panels array mounting structure for outdoor analysis.
10. According to the capacity of motor Pump set we need to connect an array of solar panels on mounting structure in series and parallel combination as per requirement.
11. From solar panels power supplied to pump controller. Pump controller will switch on the motor Pump set.
12. Outdoor testing is carried throughout entire solar day morning 6:00 AM to evening 6:00 PM.
13. Outdoor testing data is also recorded by the measuring equipment's and data loggers.
14. Both simulator and outdoor testing results should be compared and analyzed the performance of motor Pump set.

3. TEST METHODS

The performance of solar photovoltaic water pumping system is evaluated by two testing methods:

a) Simulator Method
   - A Hot Summer Day / Cold Winter Day

b) Outdoor Condition using sun radiation

3.1 Simulator Method

Figure 2: Programmable DC supply Chroma simulator

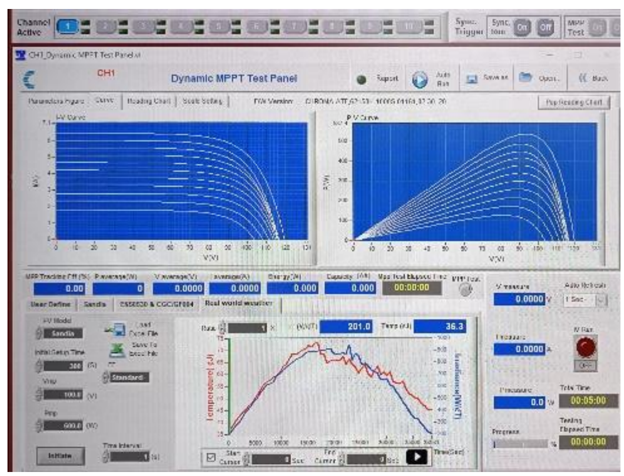


Figure 3: Dynamic Test Panel

The simplest and fastest method for evaluating the performance of solar photovoltaic water pumps is simulator method. Here a programmable solar photovoltaic array simulator which is capable of generating equal power output to the actual solar photovoltaic array under the given irradiation and temperature conditions will be used in this instance. For a given solar photovoltaic array configuration (i.e., number of modules with series/parallel combination). Whereas a combination of irradiation and temperature can be produced in two different situations which is selected for the testing of SPV water pumping system.

3.1.1 Standard Irradiation and Module Temperature during summer and winter Day

The two configurations of irradiation and temperature named as a hot summer day or hot profile and a cold winter day or cold profile.

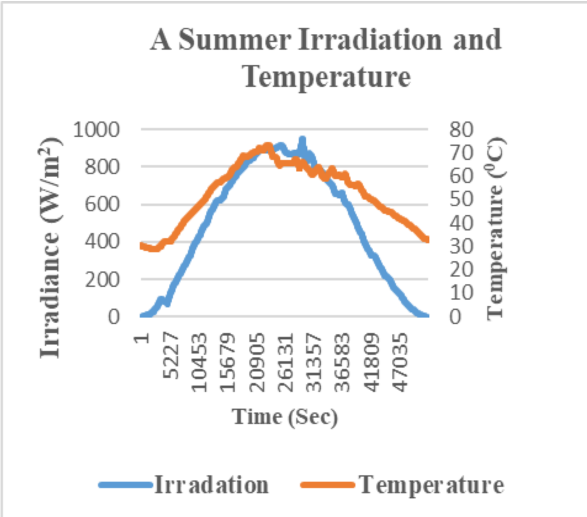


Figure 4: Hot profile

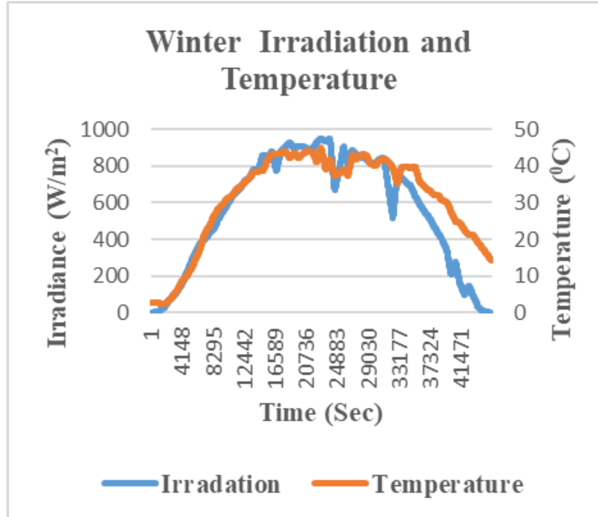


Figure 5: Cold Profile

Above figure 4 & 5 shows the standard hot and cold day profiles. The standard solar temperature and irradiance for the entire day will be loaded into the photovoltaic array simulator one after the other. The pump controller connects the simulator's output to the motor and pump and the profiles are going to execute in real time. For the entire duration of the profiles, a selected constant head or dynamic head can be utilized to calculate the total water output and output in liters/watt STC/day. The standard test report of the modules provided with the pump set where the maximum power and voltage can be obtained.

3.2 Outdoor Condition using sun radiation

Figure 6: PV Module Mounting Structure

During outdoor testing, the photovoltaic modules are mounted on the structures in the form of array and modules are connected in series and parallel combinations. To produce required PV array DC power output to run the solar photovoltaic water pumps. Based on the PV array capacity of the motor pump set, required number of solar photovoltaic modules are connected, the output of the PV array is directly connected to solar PV controller (VFD) and the output is used to run the motor pump set.

The present day water output is measured from sunrise to sunset at the desired constant dynamic head. Measurements of irradiance is done using pyranometer and the output from the pyranometer is recorded in the Data logger at an interval of 1min between each data. Tracking can be done automatically or manually. The entire cycle has to be corrected at the reference. 7.15 kWh/m2 of average daily solar irradiation on the SPV array's surface.

The performance of the motor pump set is evaluated by comparing the results of the outdoor tested data with the results of simulator tested data.

4. RESULTS AND DISCUSSIONS

The below table shows the comparison between the results of simulator and outdoor test methods of the 5hp 100m submersible DC centrifugal and reciprocating motor pump sets.

Sl. no	Parameters	Centrifugal Pump	Reciprocating Pump
1	Markings on Solar	a) Solar Motor Pump set	a) Solar Motor Pump set

	a) Motor pump set b)VFD controller c) Photovoltaic Module	 *Figure 7: 5 hp100m DC Centrifugal submersible motor pump set* Motor Pump set Specifications on sample • Pump Head : 100m • Pump Outlet : 2” • HP / kW : 5 HP / 3.7kW • Material : SS b) Solar VFD Controller  *Figure 9: VFD controller* Controller Specifications on sample • V_{DC} max : 800 V_{DC} • I_{DC} max : 10A • V_{DC} MPPT range : 550V • Power/HP : 5000W/ 5HP c) Solar Photovoltaic Module  *Figure 11: 335Wp Solar Photovoltaic Module*	 *Figure 8: 5 hp100m DC Reciprocating submersible motor pump set* Motor Pump set Specifications on sample • Pump Head : 100m • Pump Outlet : 2” • HP / kW : 5 HP / 3.3kW • Material : SS b) Solar VFD Controller  *Figure 10: VFD controller* Controller Specifications on sample • V_{DC} max : 400 - 800 V_{DC} • I_{DC} max : 10A • V_{DC} MPPT range : 560V • Power/HP : 5000W/ 5HP c) Solar Photovoltaic Module  *Figure 12: 335Wp Solar Photovoltaic Module* Module Specifications on sample

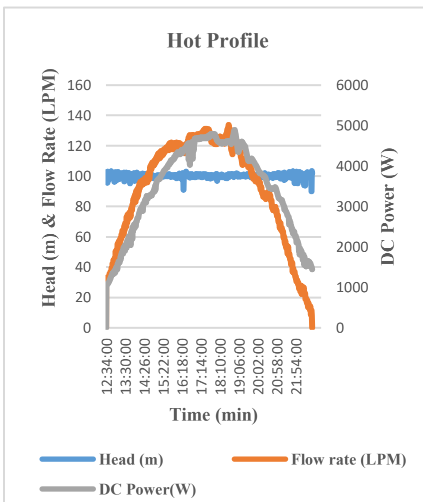
<table>
<tr><td></td><td></td><td>Module Specifications on sample
Pmax of panel : 335Wp
Vmax of panel : 37.02V</td><td>Pmax of panel : 335Wp
Vmax of panel : 37.07V</td></tr>
<tr><td>2</td><td>Results of Protection tests with VFD controllers</td><td>a) Safety Protection Tests
Dry run : Dry Run (Motor stopped within 30 sec)
Open circuit : SPO (Motor stopped within 05 sec)
short Circuit : A-L5 (Motor does not gets on)
Reverse Polarity : No error (Motor gets on)</td><td>a) Safety Protection Tests
Dry run : S-L6 (Motor stopped within 10 sec)
Open circuit : SPO (Motor stopped within 10 sec)
short Circuit : S-L5 (Motor does not gets on)
Reverse Polarity : S-L4 (Motor does not gets on)</td></tr>
<tr><td>3</td><td>Results of
a) Simulator Method
b) Outdoor Method</td><td>a) Simulator Method
A Hot Summer Day
Input data loaded to Chroma Simulator
No of Modules Considered: 16
Total Pmax : 5283.2 Wp
Total Vmax : 589.2V
Loaded Profile : Standard Hot Summer Day
Test Duration: 12hrs
Output data obtained from Chroma Simulator


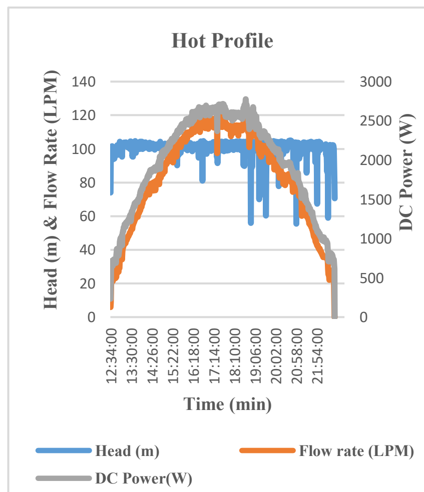
Figure 13: Simulated output of A Hot Summer Day
Total water output per day: 55598.40LPD
Total Liters per watt Peak per day : 10.52L / Wp
Average Total Head : 100.25m
Garbage Flow: 131.30LPD</td><td>a) Simulator Method
A Hot Summer Day
Input data loaded to Chroma Simulator
No of Modules Considered: 12
Total Pmax : 3820.42Wp
Total Vmax : 447.33V
Loaded Profile : Standard Hot Summer Day
Test Duration: 12hrs
Output data obtained from Chroma Simulator


Figure 14: Simulated output of A Hot Summer Day
Total water output per day: 50999.80LPD
Total Liters per watt Peak per day : 9.65L / Wp
Average Total Head : 100.98m
Garbage Flow: 5035.60LPD</td></tr>
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- Average Input Power from Chroma: 3.5327kW
- Average pump output power : 1.4985kW

b) Outdoor Method
A Real Time Profile
Input data considered to outdoor method

- No of Modules Considered: 16
- Pmax of each panel : 335Wp
- Vmax of each panel : 37.02V
- Connected type : Series

Output data obtained from outdoor method

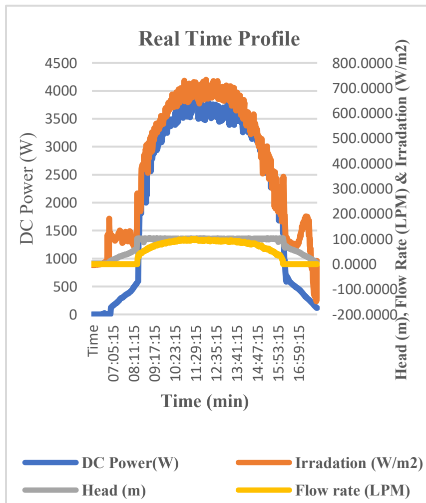

Figure 15: Real time output of centrifugal pump

- Total water output per day: 55662.78LPD
- Total Liters per watt Peak per day : 10.53L / Wp
- Irradiation of tested day : 4.717kWh/m2/day

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- Average Input Power from Chroma: 2.0329kW
- Average pump output power : 1.3832kW

b) Outdoor Method
A Real Time Profile
Input data considered to outdoor method

- No of Modules Considered: 12
- Pmax of each panel : 335Wp
- Vmax of each panel : 37.02V
- Connected type : Series

Output data obtained from outdoor method

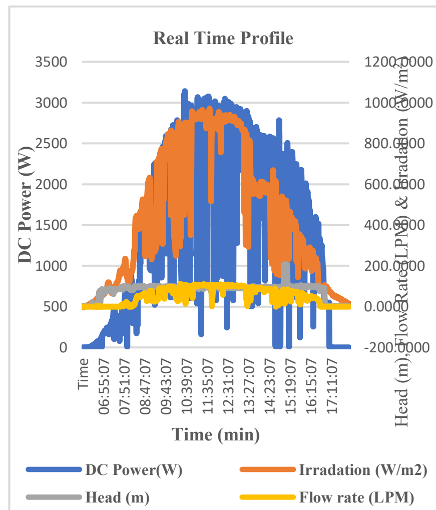

Figure 16: Real time output of centrifugal pump

- Total water output per day: 52293.45LPD
- Total Liters per watt Peak per day : 13.68L / Wp
- Irradiation of tested day : 5.183kWh/m2/day

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<td>4</td>
<td>Threshold Observations</td>
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- Irradiation where pump flow started : 246.4 W/m^2
- Irradiation where pump flow stopped : 236.4 W/m^2

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- Irradiation where pump flow started : 145.6 W/m^2
- Irradiation where pump flow stopped : 138.9 W/m^2

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5. CONCLUSION

Both Centrifugal and reciprocating pumps have their own advantages and disadvantages over the other as per our test results and observations we have come across the below conclusions.

Centrifugal pump runs at higher speeds, which maintain higher head as compared to the reciprocating pump, since operating mechanism of the reciprocating pump is like a positive displacement piston, thus comparatively as per our observation this pump cannot achieve higher head as compared to the centrifugal pump. A reciprocating pump consumes less power input has compared to the Centrifugal pump which results in water discharge with lower irradiation this result we did not find in our observation of the Centrifugal pump .Centrifugal pump results better flow rate has compared to the reciprocating pump. When it comes to maintenance, centrifugal pumps requires less maintenance than reciprocating pumps.

REFERENCE

[1] Saurabh K. Bhosale "Development of a Solar-Powered Submersible Pump System without the Use of Batteries in Agriculture", Indonesian Journal of Educational Research and Technology, ISSN 2775-8419, e- ISSN 2775-8427, November – 2022, pg.no: 57 – 64.

[2] Yigrem Solomon, P.N Rao, Tigist Tadesse "A Review on Solar Photovoltaic Powered Water Pumping System for off-Grid Rural Areas for Domestic use and Irrigation Purpose", International Journal of Engineering Research & Technology (IJERT), ISSN NO : 2278-0181, IJERTV10IS020101, Vol. 10 Issue 02, February-2021, pg.no: 258 – 269.

[3] Anoop J R , Reema N "Evolution of Solar Powered Water Pumping System", International Journal of Innovative Research in Science, Engineering and Technology Vol. 6, Issue 2, ISSN(Online) : 2319-8753 ISSN (Print) : 2347-6710, February 2017 pg. no : 2185 - 2189

[4] Priyanka, V, Raghavendra, Vijaykumar Palled "Performance Evaluation of Solar Water Pumping System" International Journal of Current Microbiology and Applied Sciences, ISSN: 2319-7706 Volume 7, Number – 2018.

[5] Dr. K. Chandramouli, J. Sree Naga Chaitanya P, Yogeshwarao "A Review on Centrifugal and Reciprocating Pumps", International Journal of Research Publication and Reviews, Vol 4, no 3, March – 2023 pg.no: 1626 - 1630.

[6] D.B. Jani1, Chaudhary Chetan, Baria Darshan "Performance investigation on double acting reciprocating pump", IJIRT, Volume 6 Issue 4, ISSN: 2349-6002, September – 2019 Pg.no 14 - 17.

[7] Mustafa Elrefai, Ragi A. Hamdy, Amr ElZawawi "Design and Performance Evaluation of a Solar Water Pumping System: A Case Study", DOI: 10.1109/MEPCON.2016.7837005, December - 2016.

[8] ShraiyaPant, R.P.Saini, "Solar Water Pumping System Modelling and Analysis using MATLAB/Simulink', SCES - 2020 Prayagraj, India.

[9] Akshay Sharma, Richa Parmar, Dr. Sachin Kumar "Solar Water Pumping System Real-Time Testing & MATLAB Simulink Validation".

[10] R P Singh, ERDA Vadodara "Solar Pumping System under PMKUSUM Yojana Evaluation Requirements and Challenges Case Studies".

[11] https://mnre.gov.in/

[12] https://mnre.gov.in/policies-and-regulations/schemes-and-guidelines/schemes/

[13] https://www.india.gov.in/website-ministry-new-and-renewable-energy