

Solar Water Pumping System Design and Analysis-A Numerical Study at Dum Dum, Kolkata



A. Kr. Roy  and S. Dutta 

Abstract Solar water pumping system is one of the engineering marvels, which uses solar energy to pump underground water for irrigation, agricultural and drinking purposes in India and most importantly it does not utilize the traditional fuels which are responsible for polluting the environment. In the following research article, we carry out a technical analysis of pumping water by utilizing solar systems for agricultural irrigation needs and fresh drinking water supply for a project located at Dum Dum, Kolkata (chosen as per the nearest location available in software) by execution of simulations utilizing photovoltaic system software. Accordingly in the research paper, we present the results in terms of water delivered for human uses, the water volume which is absent or missing, the additional (underutilized) solar energy, and the entire calendar yearly generated photovoltaic system efficiency. The results of the simulations display that investment in photovoltaic solar technologies could be highly beneficial for this site location, as the amount of pump operation energy was found to be maximum in the month of June (6454 Kwh), while the monthly performance ratio was found to be 55.3% and the efficiency of the system was found to be 15.22%.

Keywords PV panel · Solar pump · Irrigation · Solar inverter · Photovoltaic system

1 Introduction

The solar irrigation system mostly utilized by society and human needs comprises the photovoltaic system array and pumping components such as motor, positive displacement pump and a control system. The intention for this project work is that some rural areas of West Bengal, India are currently suffering from acute power crises because of recent cyclones. Nonrenewable energy sources are the main energy source of India and the power generation sector is heavily dependent on that. The

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price of fossil fuel and pollution level is increasing rapidly. Due to these problems, the farmers in the rural areas are not able to irrigate the crops properly. In this paper, we aim to design an optimized solar water pumping system in photovoltaic system software for irrigation purposes.

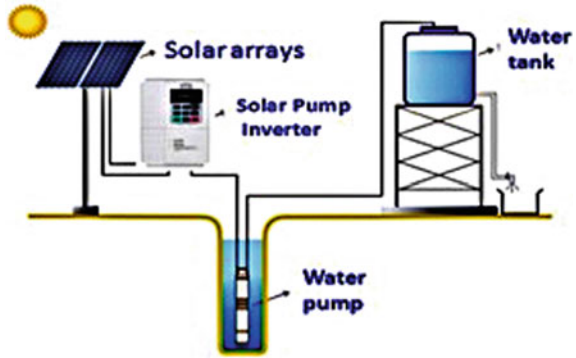
A critical literature survey analysis reveals that Arab et al. [1] has presented a method for doing estimation regarding the probability of loss load (PLL) pertaining to photovoltaic water system centrifugal pumping by choosing regarding constant profile, and utilizing a water tank with an autonomy capacity of maximum 2 (two) days and also considering two pumping heads when applied to a centralized system of centrifugal pumping. Abu-Aligah [2] had carried out research work pointing out the fact that in localized areas where electricity was unavailable, other measures were of necessity to pump water pertaining for human consumption. One option proposed by them was a photovoltaic (PV) pumping system. Sudhakar et al. [3] had investigated the solar water pump for lift irrigation. A “modified pump” was also suggested by them, which could have been beneficial to rural requirements of water. The authors had presented the thermodynamic analysis of the pumps. The authors had also presented the results pertaining to the solar water pump being operational with solar collectors having flat-plate, but it was also analyzed by them whether the same pump could be run more efficiently by utilizing concentrating coupled solar collectors. Barua and Prasath [4] had carried out simulations pertaining to an academic campus utilizing the grid-connected solar photovoltaic top roofing system and accordingly the feasibility and the design study of the solar photovoltaic rooftop system project was presented by them after the authors inspected their project viable area by critical utilization of specific NASA meteorological surface data points in the photovoltaic system. Sharma et al. [5] studied solar photovoltaic system design and the performance depends on geographical location and solar irradiation using a photovoltaic system. Matchanov et al. [6] studied a 2.24 kW grid-connected micro-inverter system output by photovoltaic system software. Another well-known research article presented by Shrivastava et al. [7] used photovoltaic system software evaluation of a grid-connected standalone system consisting of 20.8 kW 10 PV modules was also referred to.

2 Methodology

The solar water pumping system runs on electricity generated by solar panels. (Please refer to Fig. 1). A submersible pump is used in the simulations, which is used to pump water from a well and stored in an overhead tank for irrigation, drinking and other household purposes. Solar panels generate an electric charge and the solar pump inverter controls the charge for the smooth running of the pump. Further, the pump is placed in a well to pump the well water to a tank for future use.

PVsyst is the most sought-after software analysis utilized in the critical investigation and modeling examination of photovoltaic solar structural schemes for several practical applications (be it standalone, or water pumping and grid-connected). A

Fig. 1 Deep well solar water pumping diagram



huge database is inbuilt in the software analysis with the simulation tool closely associated with the photovoltaic solar structural synthesis that is currently in demand for day-to-day analysis and commercial market applications. Photovoltaic system simulation can also lead to a detailed eco-commercial analysis too. The solar water pumping system runs on electricity stemming from the solar panelized cabinets. A submersible pump is used in the simulations, which is used to pump water from a well and stored in an overhead tank. Solar panels generate an electric charge and the solar pump inverter controls the charge for the smooth running of the pump. It should also be mentioned in this context that the photovoltaic system software runs on an hour-to-hour criterion and measure.

In this project, we have utilized, the photovoltaic system 6.88 [8] for utilizing the simulations obtained by the photovoltaic system software for deepwater pumping criterion and measure for two water levels of 40 m and 60 m, but we have presented the results for 60 m only, because of paper length constraints. The inputs of this software are irradiation energy (Avg. monthly and solar), average everyday water requirements, the depth of the water well or reservoir indications, exact selection of the pump and photovoltaic system solar modules. The final relevant results include mainly the delivery of exact water transported for human uses, the loss of water data, the additional (underused) solar power available, and most importantly the exact ratio of performance (PR) measured to calculate the photovoltaic system software efficiency which we can calculate either monthly or yearly.

In this research paper, we chose the geographical location from the software database, the meteo data for the location was provided by the software (Metronome 7.2). The tilt and azimuth angle can be ascertained from the latitude and longitude of the located place. We had also chosen the angle of inclination which yields maximized system output. Also, in this context, it is important to note that the angle of azimuth is defined as that angle that is calculated intervening the south/north and the plane of solar collectors. In this PVsyst software simulated input value, the angle of inclination in summer is assumed 22 and in winter it is 42°, and the azimuth angle was chosen as Zero (0°) degrees. The software also provides a huge number of different kinds of solar panels based on material, output and quality. In this simulation, we used

250-W si-poly photovoltaic system modules accordingly which were chosen to give the best possible results and maximize the output obtained. The inverter used in this simulation is an maximum power point tracker (MPPT)-AC inverter for power conditioning of this system and is also provided by the photovoltaic system software and has a large number of choices.

3 Validation

Extensive research work was carried out by concentrating upon the dataset of NASA surface meteorology utilized via the coordination of geographical viewpoints of several project places before embarking on the simulations on this research paper. The research papers which we had referred to compare the research results are the system efficiency (during the entire year), effectiveness and array global energy.

We had carried out two validations from the previously published research work. The 1st validation was from the research paper of Touahri et al. [9] who analyzed a design of a 3 MW grid which consisted of 245 W, 12,244 photovoltaic panels and 500 kW, 6 inverters, and had a cumulative total output of 5980 MWh during the year using photovoltaic system software. The 2nd validation was carried out by comparing the published results pertaining to the paper of Kumar et al. [10] who presented a work of requirements of power in the department of mechanical engineering office at a Bikaner based reputed engineering college, Rajasthan by designing and installing the standalone solar photovoltaic system. The validation results are now compared in the present manuscript from Touahri et al. [9]

Figure 2a–c are the figures of simulations that was achieved by present photovoltaic system simulation software for normalized productions and performance ratio, loss diagram, and the main simulation results of 3 MW system by PVsyst software (connection achieved by grid) and it is validated and compared from Touahri et al. [9] who presented results for Kabertene in the NE of Adrar state, conforming to latitude $28^{\circ} 27'04.8''$ N, and longitude of $0^{\circ} 02'49.8''$ W. The balances and main results as carried out from the present photovoltaic system of 3 MW grid-connected PVsyst is also presented in Fig. 3.

From the simulations carried out, it is found that the normalized productions (per installed Kwp), performance ratio, loss diagram of the present simulations are closely matching the published results. The balances and main results are presented in Fig. 3, and it should be mentioned in this context that the present authors had simulated the E_array and E_grid results in MWh whereas Touahri et al. [9] had presented those in KWh.

The validation results of Kumar et al. [10] are now presented in Fig. 4a, b and when we compare the published results of Kumar et al. [10] suiting to Engineering College Bikaner it's found that the Normalized productions (per installed Kwp), performance ratio, loss diagram of the present simulations are closely matching the published results.

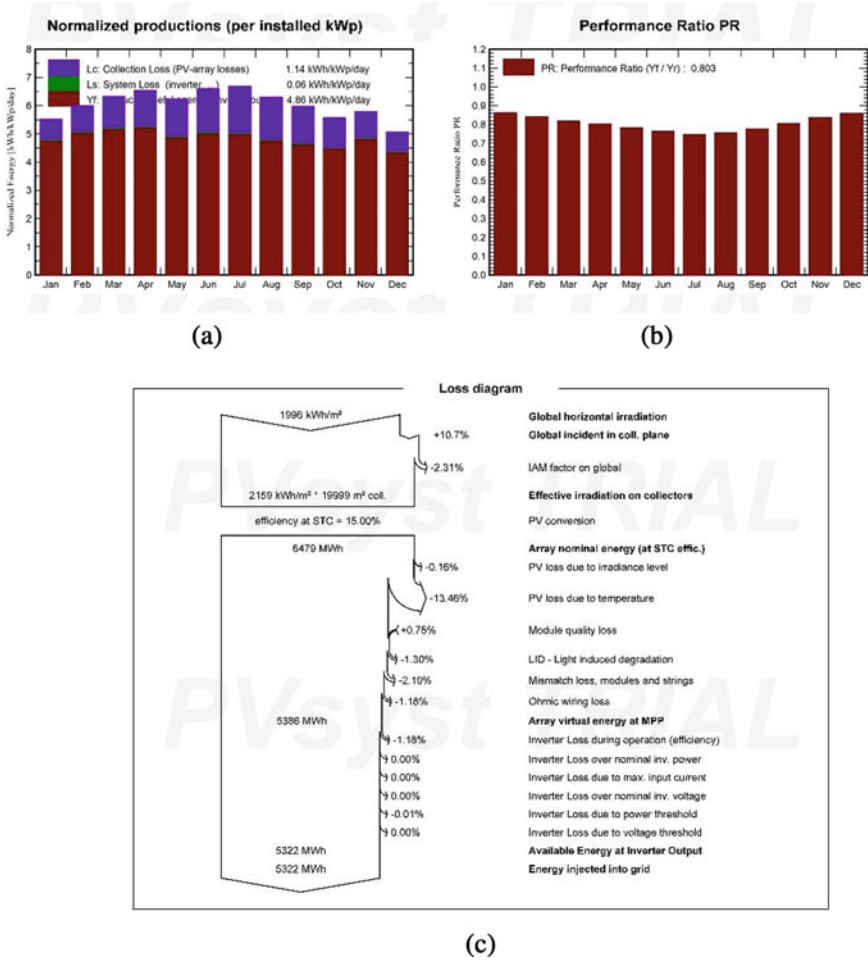


Fig. 2 a, b and c From our present simulation (PVsyst V7.2.8) and validated from Touahri et al. [9]

4 Result and Discussion

4.1 Site Location

To start with this research paper, we have carried out simulations of the solar photovoltaic pumping water systems by selecting one potential site. The region selected by us is Gauripur, Dumdum (Latitude 22.6420° N, Longitude 88.4312° E) located in West Bengal, the eastern part of India and it is the closest site of meteo data available in the photovoltaic system database. We also present here solar energy (radiation) set

Balances and main results								
	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	PR
	kWh/m ²	kWh/m ²	°C	kWh/m ²	kWh/m ²	MWh	MWh	ratio
January	116.8	37.27	12.32	171.7	168.2	449.4	444.3	0.863
February	128.9	45.41	15.62	168.0	164.9	430.3	425.3	0.844
March	171.5	68.74	20.93	196.6	192.5	488.8	483.0	0.819
April	192.0	82.78	25.32	196.0	191.2	477.7	472.2	0.803
May	207.2	97.02	30.82	193.7	188.3	461.0	455.3	0.784
June	219.3	99.35	34.76	197.7	192.0	459.0	453.2	0.764
July	226.6	99.72	38.39	207.7	201.9	471.8	465.9	0.748
August	198.7	99.46	37.53	195.6	191.0	450.0	444.7	0.758
September	165.4	76.16	33.15	179.7	175.6	423.3	418.4	0.776
October	143.1	69.05	27.30	172.7	169.3	422.8	417.8	0.806
November	122.1	39.83	18.50	173.6	170.3	440.9	435.8	0.837
December	104.8	35.97	13.55	157.3	154.1	410.5	405.7	0.860
Year	1996.5	650.75	25.74	2210.3	2159.3	5385.7	5321.6	0.803

Legends			
GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	PR	Performance Ratio
GlobInc	Global incident in coll. plane		
GlobEff	Effective Global, corr. for IAM and shadings		

Fig. 3 From our present simulation (PVSyst V7.2.8) and validated from Touahri et al. [9]

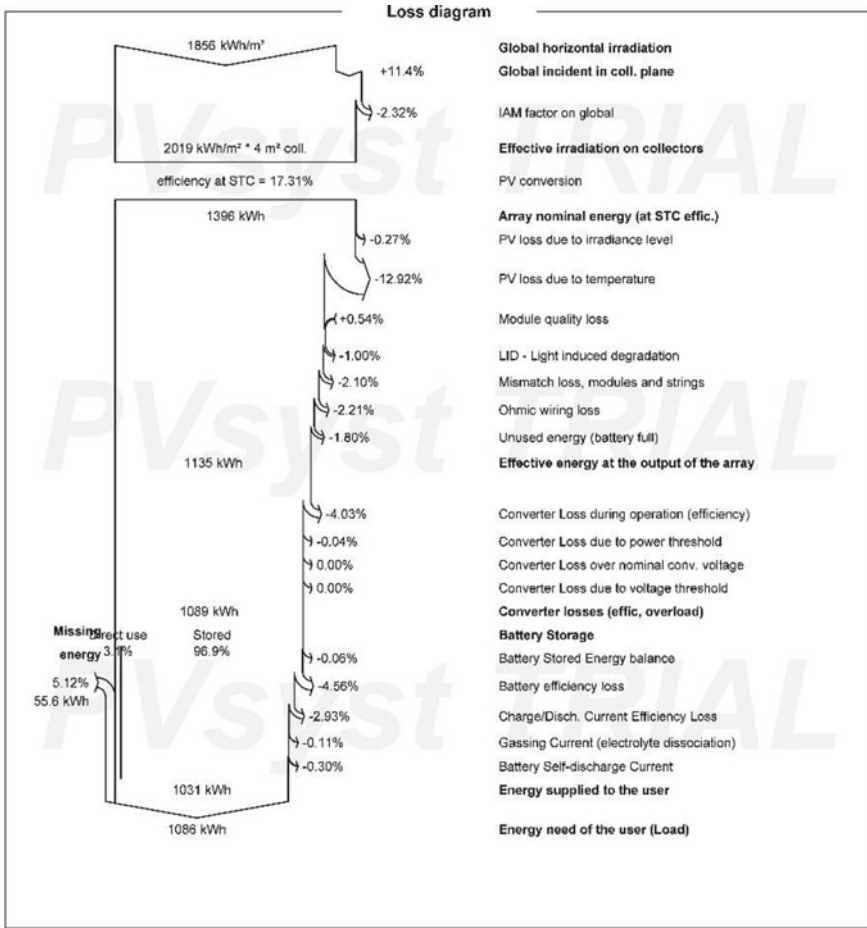
of data according to geographical location which is collected from the photovoltaic system software database (Metronome 7.2, 1981–1990) as shown in Fig. 5.

4.2 Simulation Input Parameter

While critical analysis of the present design and the simulation results of the system, some assumptions were done accordingly and results presented. The primary among those was that the panels of solar cells were considered un-shaded and with the pump working at the fullest consideration of water extraction to meet the annual summer months demand. We have tried to present the important design main input values and the chosen simulation parameter in Table 1 which was selected as per our choice of parameters. This table represents the details of 60 m well simulation parameters and components, also their manufacturer power rating and model name. It is important to mention that changing these parameters will change the simulation results too. Simulations corresponding to 60 m deep well are presented in Table 2. It can be seen from the simulation values that it selected photovoltaic size and pump power too. Pump efficiency is pegged at 67.7% which is a healthy ratio.

For the following paper and in this section, we now present the results of the simulations for the proposed photovoltaic system.

Here we can see how much water is pumped than needed, energy at the pump, pump efficiency, unused PV energy are presented for 60 m deep well PV pumping systems as done by design simulation result. The ratio of water pumped vs. water needs is found to be 46.9%.



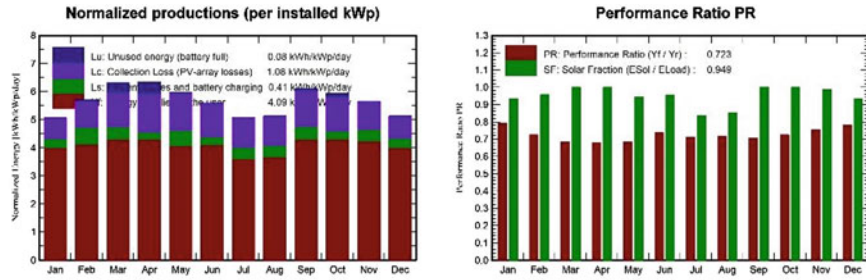
(a)

Fig. 4 a, b Simulations carried through PVsyst by a present photovoltaic system and suiting to Kumar et al. [10] for Engineering College Bikaner at 28.060 N latitude and 73.300 E longitude

And it can be seen that the results enumerated are energy production, production specified energy along with the performance ratio and loss diagrams. Accordingly, we now present the entire simulation main and balance data results of the photovoltaic systems in Table 3.

Here we can see that the system balances consist of the global effect, array virtual energy, pump operation energy, unused energy, average total head of the pump, water pumped, water drawn by the user, missing water.

Legends and abbreviation used: G_{eff} = Effective global energy, E_{ArrMPP} = Array virtual energy at MPP, $E_{\text{Pmp Op.}}$ = Pump operation energy, ETK_{Full} =



Balances and main results

	GlobHor	GlobEff	E_Avail	EUnused	E_Miss	E_User	E_Load	SolFrac
	kWh/m ²	kWh/m ²	kWh	kWh	kWh	kWh	kWh	ratio
January	111.5	153.7	89.3	0.000	6.34	85.92	92.26	0.931
February	125.4	156.3	88.9	0.609	3.56	79.77	83.33	0.957
March	171.7	191.6	105.2	7.249	0.00	92.26	92.26	1.000
April	185.5	186.0	100.0	8.762	0.00	89.28	89.28	1.000
May	197.0	179.9	95.1	0.146	5.18	87.08	92.26	0.944
June	183.3	162.9	87.3	0.000	4.11	85.17	89.28	0.954
July	169.4	152.6	82.3	0.000	15.17	77.08	92.26	0.836
August	162.1	154.7	84.1	0.002	13.60	78.66	92.26	0.853
September	168.4	178.9	96.5	1.208	0.00	89.28	89.28	1.000
October	150.8	180.6	97.9	2.770	0.00	92.26	92.26	1.000
November	122.3	166.2	92.9	0.000	1.30	87.98	89.28	0.985
December	108.3	155.7	89.9	0.013	6.36	85.89	92.26	0.931
Year	1855.7	2019.3	1109.4	20.760	55.62	1030.62	1086.24	0.949

Legends

- GlobHor Global horizontal irradiation
- GlobEff Effective Global, corr. for IAM and shadings
- E_Avail Available Solar Energy
- EUnused Unused energy (battery full)
- E_Miss Missing energy
- E_User Energy supplied to the user
- E_Load Energy need of the user (Load)
- SolFrac Solar fraction (EUsed / ELoad)

(b)

Fig. 4 (continued)

Unused energy (full Tank), H_{Pump} = Avg. total head of the pump, W_{Pumped} = Water pumped, W_{used} = Water drawn by the user, W_{miss} = Missing water.

It can be observed that January records the highest effective global energy and the Array virtual energy at Multiple Maximum PowerPoints (MPP). The yearly effective global energy was found to be 1829.1 Kwh/m². The pump operation energy was found to be maximum in June (6454 Kwh). We now analyze Fig. 6 which shows the simulations of produced normalized energy and measured in terms of unused energy ($L_u = 1.27$ kWh), collective energy loss obtained ($L_c = 0.58$ kWh), photovoltaic system's loss obtained ($L_s = 0.45$ kWh), and effective energy at the pump ($Y_f = 2.85$ kWh) installed and measured in kWp/day per pump for the entire year. Figure 7 represents the monthly performance ratio and it is found to be 55.3%.

It can also be seen from the simulation results that the system's unused energy is not low while the collective losses in the system are on the higher side. This can be attributed to the fact that we had designed the system in such a manner so that the

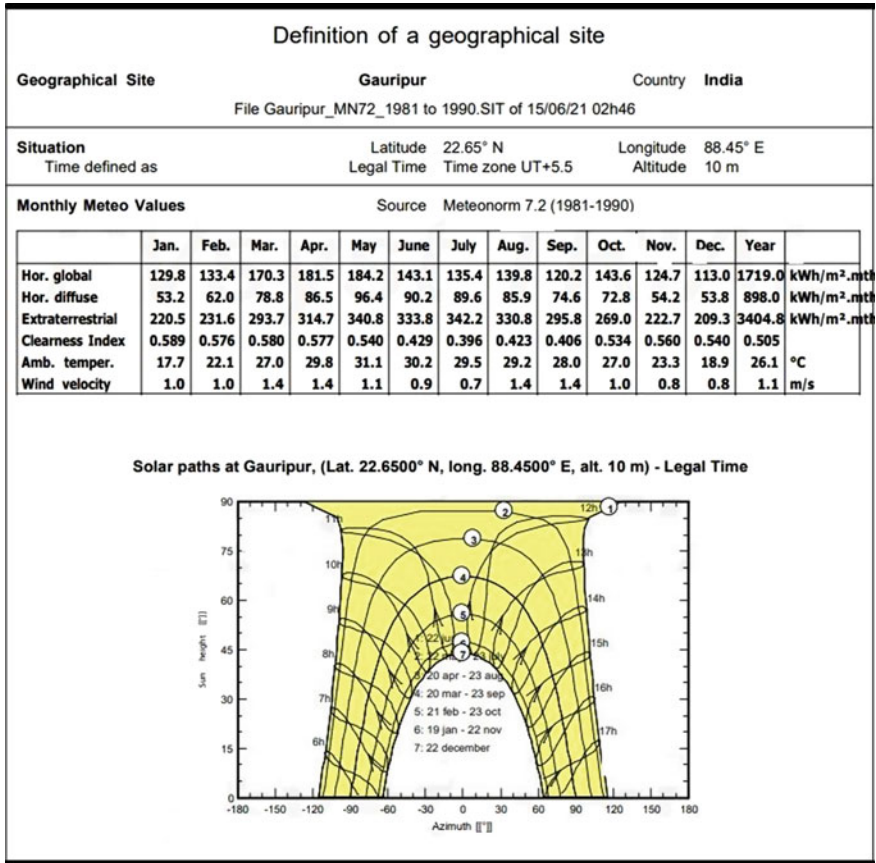


Fig. 5 Solar radiation data of the site

motor and pump unit pumps out the maximum water possible and the production accordingly maximizes and happens by reducing this is what leads to the collective losses. Minimization of losses and unused systems will be catapulted and this has to happen if we reduce water pump capacity. In Fig. 8 we can refer to the loss diagram for the entire year for the present preposition of the chosen grid. It has been found that the global irradiance (horizontal parameter) is pegged at 1719 KW/m² while the irradiance (as effective on collector) is 1829 KWh/m². The maximum loss that is encountered here is the loss in the array which has a value of 11.8% and the converter loss reached 3.21%. The efficiency of the system is thus obtained as 15.22%. The efficiency can be increased by reducing the array losses which will be our target for a better system design.

Table 1 Design simulation input parameters

Input parameters	Specifications
Total requirement of water	1200 m ³ /day
Water head (Total)	67 m
The tank storage volume of water	240 m ³
Well depth	60 m
Borehole diameter	40 cm
Length of the pipes	70 m
Summer sun angle (tilt)	22°
Winter sun angle (tilt)	42°
Consideration of Azimuth angle	0°
Types of solar panel	Model: TSM-310PD14, 250w, si-poly, manuf. Trina solar
Pump manufacturing type	Model: SP 95-7, 37 kW, ac motor, Manufacturer Grundfos
Control device	Model: ACSM1, 45 kw 440 vac, MTTP AC inverter, manuf. ABB

Table 2 Simulation result of 60 m deep well

Simulation result	
Pumped water	205,493 m ³
Water needed	438,000 m ³
Pump energy	56,217 kWh
PV energy underutilized (for full tank conditions)	20,154 kWh
System efficiency//pump efficiency	65.6 and 67.7%
Missing water//unused fraction	53.1 and 23.5%

5 Conclusion

For the present research paper, solar photovoltaic-based water pumping has been designed and presented for a rural **project located at Dum Dum, Kolkata**. In this research paper, we have accordingly presented the results such as the effective global energy and the Array virtual energy at MPP, pump operation energy and the system efficiency during the year. The lifespan of solar pumping systems is more than 20 years and is also reliable too. It is more cost-effective than conventional diesel-powered systems. Efforts should be made to reduce the array losses which will make this system more feasible in the long run. In today's world, pollution is a very big problem to mankind, and by replacing diesel or fossil fuel systems with solar pumping systems, pollution can be controlled at a great point.

The main summary of this research paper was:

Table 3 Entire simulation main and balance data results of the photovoltaic systems

	Globe kWh/m ²	EArr _{MPP} kWh	E_Pmp Op K	ETK _{Full} kWh	H_Pump Meter (W)	W_Pumped m ³	W_used m ³	W_miss m ³
January	175.9	8461	4057	4112	47.84	21,458	21,578	15,622
February	157.7	7453	3674	3505	47.80	19,663	19,663	13,937
March	175.6	8132	4052	3695	47.78	21,795	21,795	15,405
April	177.2	8090	4044	3688	47.73	21,462	21,462	14,538
May	168.0	7697	4056	3261	47.63	21,234	21,234	15,966
June	127.8	5971	6454	2017	47.52	17,794	17,794	18,206
July	121.7	5752	3268	1734	47.48	17,961	17,961	19,239
August	132.0	6173	3443	2217	47.59	18,153	18,153	19,047
September	120.0	5640	3261	1882	47.51	16,772	16,772	19,228
October	159.7	7459	3868	3173	47.72	20,733	20,733	16,467
November	161.0	7548	3765	3472	47.82	20,167	20,167	15,833
December	152.4	7332	3732	3318	47.83	20,231	20,231	16,969
Year	1829.1	85,709	44,875	36,075	47.68	237,423	237,523	200,457

Normalized productions (per installed kWp): Nominal power 54.0 kWp

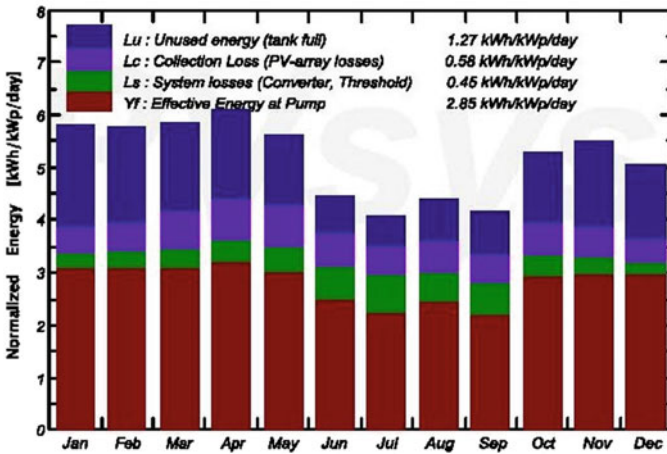


Fig. 6 Normalized energy production of the system

- The month of January records the highest effective global energy and the Array virtual energy at Multiple Maximum PowerPoints (MPP).
- The pump operation energy was found to be maximum for June (6454 Kwh) while the monthly performance ratio was found to be 55.3%.

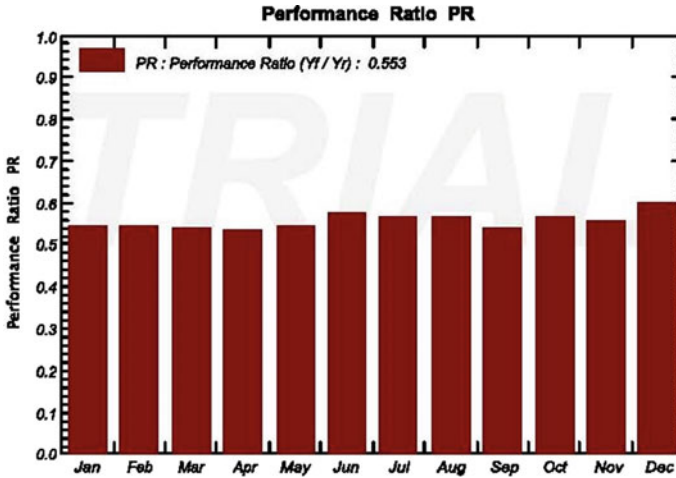


Fig. 7 Monthly performance ratio

- The unused energy was found to be ($L_u = 1.27$ kWh), the collective loss was pegged to be: ($L_c = 0.58$ kWh), the loss of the system performance was ($L_s = 0.45$ kWh) and effective energy at the pump was found to be ($Y_f = 2.85$ kWh).
- The horizontal global irradiance found from simulations was found to be 1719 KW/m² while it was found that the irradiance (effective collector value) to be 1829 kWh/m².
- The efficiency of the system is thus obtained as 15.22% . The lifespan of solar pumping systems is more than 20 years and is also reliable.
- From the analysis it can be concluded that if we can install a similar machine in the present location then it will be more cost-effective than conventional diesel-powered systems. However, care should be taken to take care about the efforts to be made to reduce the array losses which will make this system more feasible in the long run.

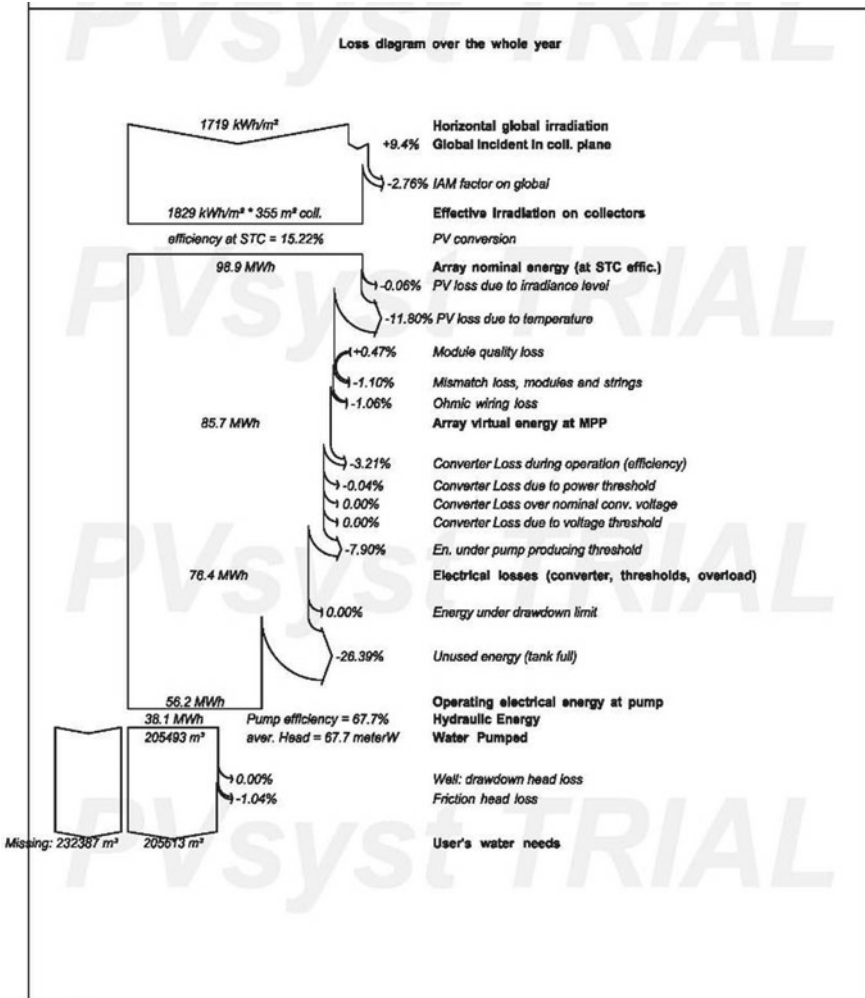


Fig. 8 Loss diagram of the present PV system

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