

# Techno-economical study of solar water pumping system: optimum design, evaluation, and comparison

Hussein A. Kazem , Anas Quteishat\* , and Mahmoud A. Younis

Electrical & Computer Engineering Stream, Sohar University, PO Box 44, Sohar, PCI 311, Oman

Received: 18 September 2021 / Received in final form: 4 October 2021 / Accepted: 4 October 2021

**Abstract.** Solar water pumping systems are fundamental entities for water transmission and storage purposes whether it is has been used in irrigation or residential applications. The use of photovoltaic (PV) panels to support the electrical requirements of these pumping systems has been executed globally for a long time. However, introducing optimization sizing techniques to such systems can benefit the end-user by saving money, energy, and time. This paper proposed solar water pumping systems optimum design for Oman. The design, and evaluation have been carried out through intuitive, and numerical methods. Based on hourly meteorological data, the simulation used both HOMER software and numerical method using MATLAB code to find the optimum design. The selected location ambient temperature variance from 12.8°C to 44.5°C over the year and maximum insolation is 7.45 kWh/m<sup>2</sup>/day, respectively. The simulation results found the average energy generated, annual yield factor, and a capacity factor of the proposed system is 2.9 kWh, 2016.66 kWh/kWp, and 22.97%, respectively, for a 0.81 kW water pump, which is encouraging compared with similar studied systems. The capital cost of the system is worth it, and the cost of energy has compared with other systems in the literature. The comparison shows the cost of energy to be in favor of the MATLAB simulation results with around 0.24 USD/kWh. The results show successful operation and performance parameters, along with cost evaluation, which proves that PV water pumping systems are promising in Oman.

## 1 Introduction

The enormous population growth and corresponding industrialized world growth have brought up many challenges and issues such as lack of drinking water, food, and inability to access electricity, etc. One of the main issues associated with growth in human activity is its effect on the environment. Human behavior leading to the emission of CO<sub>2</sub> and other pollutants led to the rise of global warming and climate change [1]. The fossil fuel industry has been a massive emitter of carbon dioxide and the primary source of energy in the world. These international treaties have provided a boost to finding alternative clean sources of energy, like renewable energy, which are considered the perfect candidates to replace/have a share of fossil fuels in the future as they are clean and sustainable [2]. Solar energy technologies have received a great deal of research and development to enhance their efficiency and reduce its costs. The two leading technologies in solar energy are photovoltaics and solar thermal

collectors [3]. Photovoltaic (PV) or solar cells is a device use to converts solar energy into electricity, while solar thermal collectors harvest the thermal energy of the solar irradiation, either for use in a thermal application or it is converted into electricity. A more innovative method of capitalizing on solar energy is to establish a hybrid “Photovoltaic/Thermal (PV/T)” collector, which produces both electrical and thermal energy at once [4].

The applications of PV have expanded to cover a broad spectrum of electrical appliances from spacecraft, airplanes, traffic lights, weather stations, and even small calculators [5]. One of the essential applications of PV is water pumping systems. This application due to the importance of water transmitting and storage for irrigation or drinking purposes. Research in optimizing solar water pumping systems (SWPS) has accelerated over the past decade, mainly due to its crucial need in developing countries that suffer from lack of water.

Benghanem et al. [6], determined the optimum design of solar water pumping system in Madinah-Kingdom of Saudi Arabia (Longitude = 39.62°E and Latitude = 24.46°N). The main variables in the optimum designed system were the water head (five different heads used) and solar

\* e-mail: [aquteishat@su.edu.om](mailto:aquteishat@su.edu.om)

irradiance. Intuitive methods have been used to design the proposed systems and the results validated by outdoor experiments. However, for more accurate design a more sophisticated methods and more variables must be used.

In Nagpur-India (Longitude 79.0900 °E and Latitude 21.1500 °N), Tiwari and Kalamkar, investigated the optimum design of solar water pumping system in term of water head pressure (four different values used) and solar irradiance. Also, intuitive method has been used for optimization and experimental validation is presented. The study is a technical optimization and evaluation. However, economic assessment has not been included in this study.

Setiawan et al. [7] experimentally investigated solar water pumping system in Purwodadi-Indonesia (Longitude 110.9134 °E and Latitude 7.0872 °S). The study was experimental technical evaluation of SWPS. However, the system is installed by contractor and usually they use intuitive methods in their calculations.

Based on the literature it is found that some studies used optimization to design SWPS and others directly installed the system. Also, some references used intuitive methods, which is simple and less accurate method, for optimization with limited parameters. Furthermore, economic evaluation has not been conducted in many studies, which minimize the full picture. It is essential to conduct optimization study considering the technical and economic aspects.

Ghoneim [8] designed and investigated SWPS in Kuwait (Longitude 47.4818 °E and Latitude 29.3117 °N) using computer simulation program based on intuitive method. The proposed SWPS components has been selected and different performance parameters was investigated such as water flow, head, efficiency, and water volume. The author claimed that the proposed system is viable to be used in Kuwait. However, more sophisticated simulation program is recommended to find optimum design in term of technical and economic parameters.

Kala et al. [9] intuitively designed and installed SWPS in Laramie, United State (Longitude 105.5911 °W and Latitude 41.3114 °N). The study discussed the intuitive design steps, experimental installation, and performance assessment. Three scenarios proposed such as one, five- and fifteen-years assessments. However, evaluation of many essential performance parameters was missed in this study such as water head and volume, impact of solar radiation, etc. Furthermore, the economic impact and feasibility was not investigated in this paper.

Rakhi et al. [10] simulated and evaluated an optimum design of SWPS using PVsyst 5.52 software. The study conducted for Karansar, Jaipur-India (Longitude 75.4403 °E and Latitude 27.1064 °N). Intuitive method used to find the system component rating. After that, numerical method by PVsyst software used to evaluate the proposed system performance. It is found that the overall system efficiency is 82.50%. Also, the authors claimed that using numerical methods for optimum design help to increase the accuracy, find the optimum system components, evaluate more performance parameters, and save time.

Caton [11] designed and evaluated SWPS in Ying village, Africa (Longitude 0.8403 °W and Latitude 0.8064 °N). Intuitive method was used for the proposed

designed system and different configuration adopted for comparison purpose. Single and dual tracking was considered in the design and NASA data used for solar irradiance. The study focusses more on the effect of tracking, seasonal and yearly evaluation of the system. However, economic was missed in this study.

Solar photovoltaic used for water pumping systems in Oman. Some theoretical design [12] and experimental evaluation [13] has been conducted to explore the possibility of using such systems. However, the high relatively temperature in Oman reduce the photovoltaic efficiency so that using photovoltaic/thermal system to cool the PV and irrigation application is suitable choice for SWPS [14]. Furthermore, the water could be used to clean the PV to improve the energy production, and increase the efficiency [15].

This paper aims to provide a techno-economic evaluation of SWPS to conclude its technical and cost-effectiveness to highlight the criteria for creating optimum designs. The study was conducted northern Oman. The contribution of this study is to find the optimum design using two numerical methods (HOMER software and proposed NATLAB code). The resulted optimum design is compared in term of technical and economic aspects. Also, the system results compared with similar systems in literature.

The coordinates of the selected location are 24.1539° N, and 56.8648° E for latitude and longitude, respectively. The average ambient temperature, humidity, and wind speed of the studied location are 31 °C, 66%, and 10 km/h, respectively. The measured solar irradiation data is shown in Figure 1. The solar irradiation in Saham is various throughout the day average 4.062 kWh/m<sup>2</sup>/day and in average ambient temperature is 38.89 °C, with high clearing index.

## 2 Materials and methodology

### 2.1 Sizing of water pumping system

PV systems are categorized into two categories: grid-connected and standalone. Grid-connected systems inject electricity directly to the utility grid while standalone PV systems serve for free uses. Standalone configurations are more suitable for rural and remote communities, which suffer from a lack of electricity due to dependence on diesel generators instead of the electricity grid. Standalone designs are also very useful in urban areas. PV systems are commonly comprised of a PV panel or array that generates DC electricity, which is then inverted into AC electricity and fed to an AC load. PV systems could be linked with other renewable or non-renewable energy sources like wind and diesel, respectively. The previous combination is known as hybrid PV systems. The addition of storage units (batteries) allows for later use of the PV panel. This should be accompanied by a charger controller. The implementation of battery units remains an option whether to directly supply electricity to the water pump, to avoid the battery's capital and maintenance costs, or to implement batteries if it is necessary to use the pumping system at night [6,16].

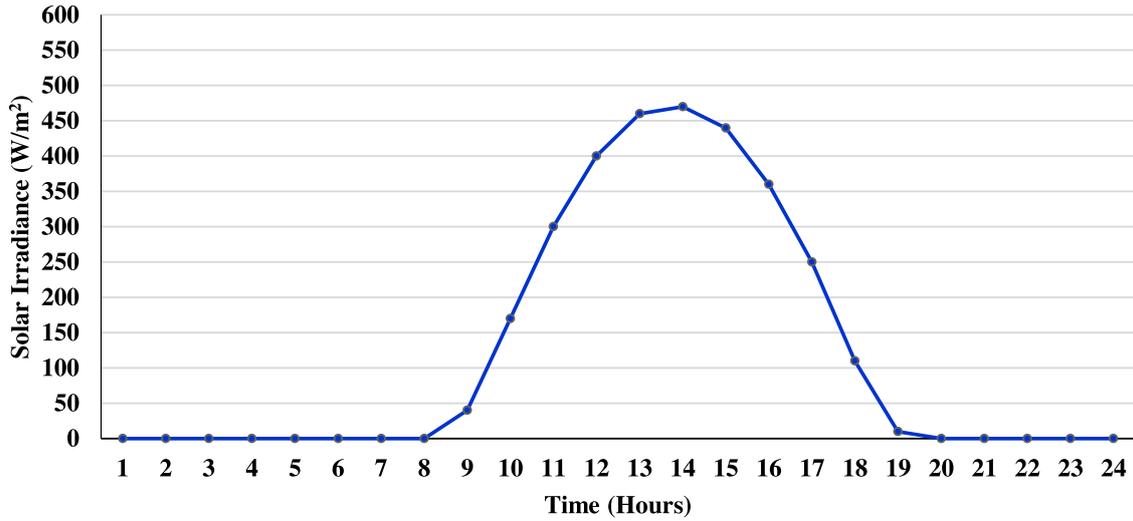


Fig. 1. Daily solar energy profile in Saham-Oman.

SWPS is considered to be cost-effective, in general, in rural, isolated, and desert areas. In addition to having PV panel/array provide energy to the water pumping system, it also reduces the carbon footprint of the system as appose to the diesel generator powered water pumping system. Most common applications of SWPS are irrigation, livestock watering, and village water supply.

The intuitive method is presented, in this section, for hydraulic and PV sizing of SWPS. The input data required for the hydraulic sizing are pumping head, daily water volume, pipe material and length, and pump pressure and efficiency. Equation (1) is used to calculate the pumping power [17], while equation (2) calculates the required hydraulic energy in kWh/day.

$$P_{pump} = \frac{\rho g (h + \Delta H) Q}{\eta_b \cdot \eta_e} \quad (1)$$

$$E_h = \eta_s \cdot E_{PV} = \rho g h V \eta_s \quad (2)$$

As for the PV system sizing the needed values for the calculation are daily solar irradiance, PV area and efficiency, inverter efficiency and wire efficiency. The energy produced by PV array in kWh is calculated using equation (3) [18], with area of PV power calculated using equation (4).

$$E_{PV} = A_{PV} \times G_T \times \eta_{module} \times \eta_{inv} \times \eta_{wire} \quad (3)$$

$$A_{PV} = \frac{\rho g h V}{G_T \eta_{PV} \eta_S} \quad (4)$$

Based on equations (3) and (4), the needed power of the PV array is:

$$P_{PV} = \frac{E_h}{G_T \cdot F \cdot E} \quad (5)$$

Finally, the overall proposed system efficiency is,

$$\eta_{system} = \frac{P_h}{P_{PV}} = \frac{\rho g h V}{G_T A_{PV}} \quad (6)$$

## 2.2 Proposed system components

The SWPS design to contain number of PV modules and how they are connected, wires and protection devices, DC charger controller, AC inverter, storage battery banks, and accessories such as sensors etc. Also, the electrical load (centrifugal pump), which selected based on many parameters such as the well height, needed water, etc. The proposed system schematic diagram is shown in Figure 2. The selected well depth is 15 m, dynamic water level is 6.96 m, static water level 5.9 m, design criteria is 4.4 m<sup>3</sup>/day, well productivity is 7.87 m<sup>3</sup>/h, and pump head is 17 m.

The required PV system components were estimated based on equations in Section 2. The energy and power needed to supply the proposed pump was calculated using equations (2) and (5) and found to be 2.286 kWh/day, and 0.81 kW, respectively. However, the voltage, power and frequency of the electrical load was 230 V, 810 W and 50 Hz, respectively. It is important to mention that the pump works on peak hours. A 120 Wp PV modules with maximum voltage 18.5 V, were proposed for the system simulation are 120 W with an estimated capital and replacement costs of USD 1.50/W and USD 1.02/W, respectively. These costs are relatively high due to services included such as installation and commissioning, protection, and control system. These PV panels have a lifetime expectancy of 25 year and a derating factor of 90%. The tilt angle of the PV array should be similar to the latitude of the location of its setup, 27° as claimed by [19]. The charger controller and inverter are extremely important parts of the system, providing protection, regulation, and inversion of DC current to AC current. Converter lifetime as available commercially is up to

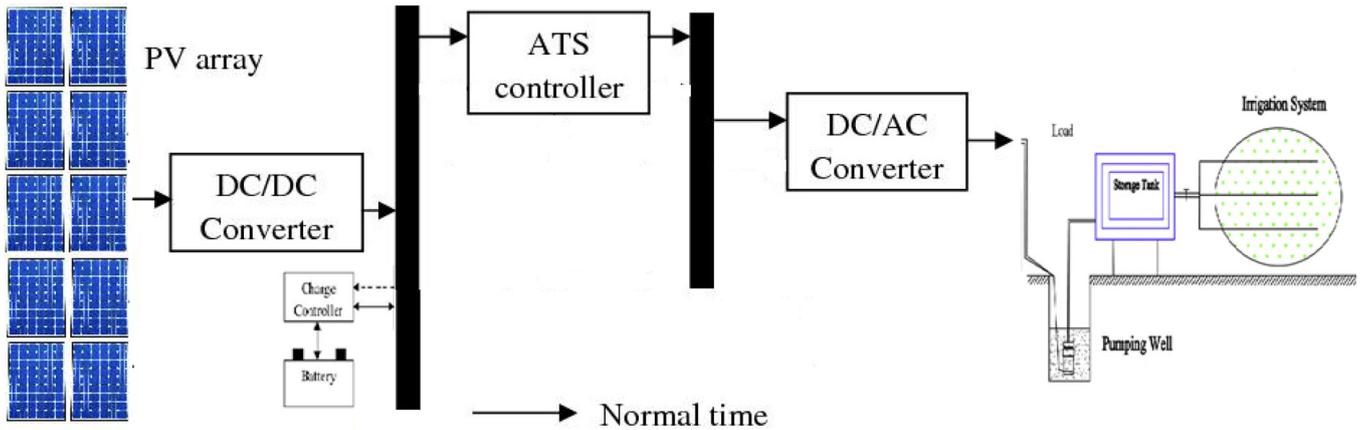


Fig. 2. SWPS schematic diagram.

fifteen years with efficiency around 90.5–94.5% and estimated price of an inverter is USD 0.5/W. Finally, the batteries should be selected depending on their state of charge and discharge. In this study, the batteries proposed have 12 V, 200-Ah capacity, each. The lifetime of each battery is 12 years.

### 2.3 Optimum design and assessment of PVWPS

Four criteria have been used to assess the system feasibility in term of technically and economic aspects. There are two technical criteria “Capacity Factor (CF)” and “Yield Factor (YF)”, and two economic criteria “Payback Period (PBP)” and “Cost of Energy (CoE)”. CF and YF used to evaluate the SWPS productivity and PBP and CoE evaluate economic feasibility. Firstly, the capacity factor, which represents “a ratio of a PV’s actual energy output to its potential energy output if it ran 24 hours per day for a year at full rated power ( $P_r$ )”, is calculated using equation (7). Secondly, the “annual net AC energy output of the system divided by peak power of installed PV at standard testing conditions” or else known as yield factor, is calculated using equation (8) [20].

$$CF = YF/8760 = E_{PV\text{annual}}/(P_R \times 8760) \quad (7)$$

$$YF = E_{PV}(kWh/year)/PV_{WP}(kW_p) \quad (8)$$

The economic criteria use equations (9)–(12) which provides the life cycle cost (LCC), present net worth (RPW), cost of energy (COE) and payback period (PBP), respectively [21].

$$LCC = C_{\text{capital}} + \sum_1^n C_{O\&M} \cdot R_{PW} + \sum_1^n C_{\text{replacement}} \cdot R_{PW} - C_{\text{salvage}} \cdot R_{PW} \quad (9)$$

$$R_{PW} = F_m/(1 + I)^N \quad (10)$$

$$CoE = LCC / \sum_1^n E_{PV\text{annual}} \quad (11)$$

Finally

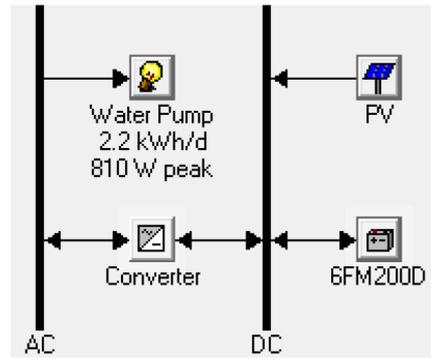
$$PBP = C_{\text{capital}}(USD) / \times [E_{PV\text{annual}}(kWh/year) \times CoE(USD/kWh) \times R_{PW}] \quad (12)$$

The SWPS is intended to be use for irrigation purposes in Saham, Oman with a 0.81 kW water pump. Hence no mention of water purification system. The feasibility of the design is examined using HOMER software and a MATLAB code written to find the optimum system component. Both programs allow modeling the different elements in the system in terms of physical behaviour and life-cycle cost. Based on techno-economic merits, the optimum system components have been selected. Figure 3a displays the schematic diagram window of HOMER software for the proposed system. The strategy for the system is to utilize the sunshine and peak hours of solar radiation to generate electricity to supply water pump to transfer water to the tank. Table 1 and Figure 3b provide the specification of PV module, and economic assumptions.

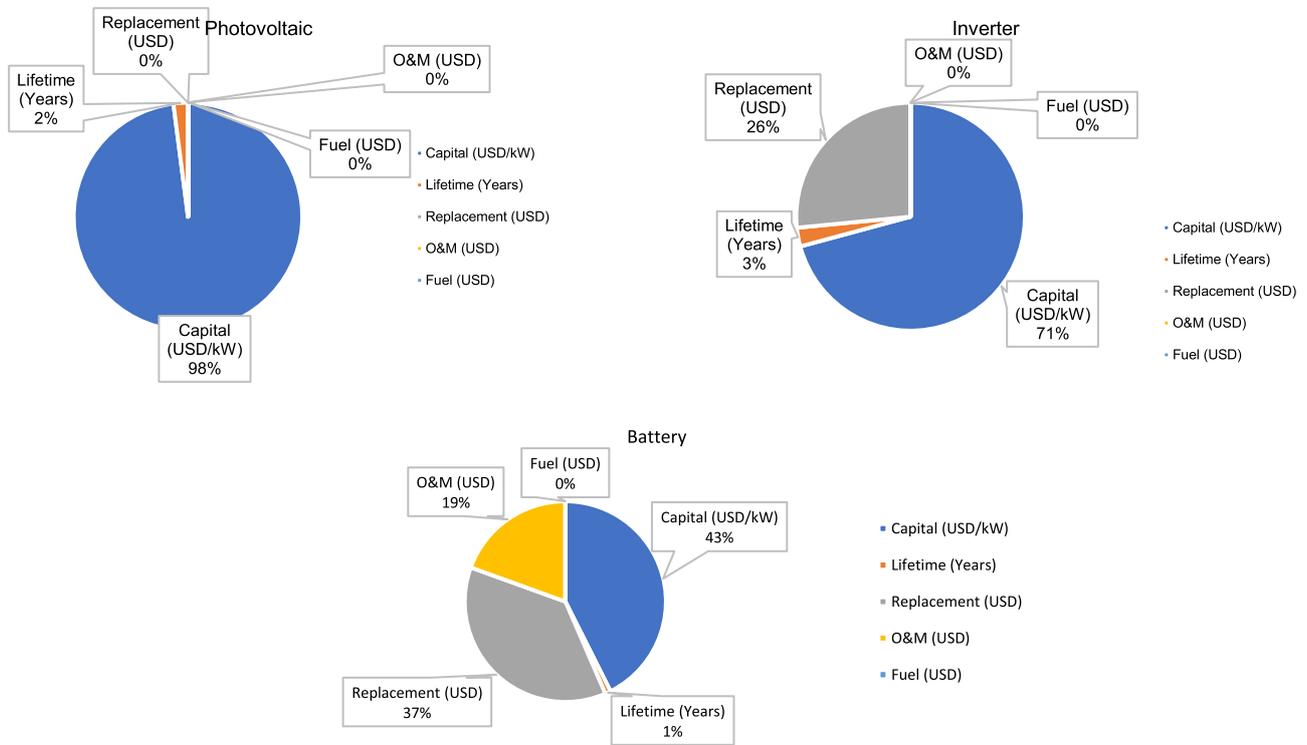
An 18.5  $V_{\text{max}}$ , 120 Wp PV module was suggested for the simulation of the optimum system. These capacities ranged use for the simulation ranged between 1 and 10 modules. The battery suggested for the system was a 12 V, 200 Ah with estimated cost of 130 USD. Sensitivity analysis was also introduced with a range of 1–5 battery banks. Moreover, 94.5% inverter efficiency was assumed for all considered sizes with an estimated cost of 0.5 USD/W, and lifetime 15 years. For analysis consideration, the inverter range selected was 0.8–1.2 kW.

### 3 Results and discussion

HOMER simulation run and 688 feasible solutions found in term of technical and economic aspects. The best yielded feasible solutions for the entered parameters and sensitivity



(a)



(b)

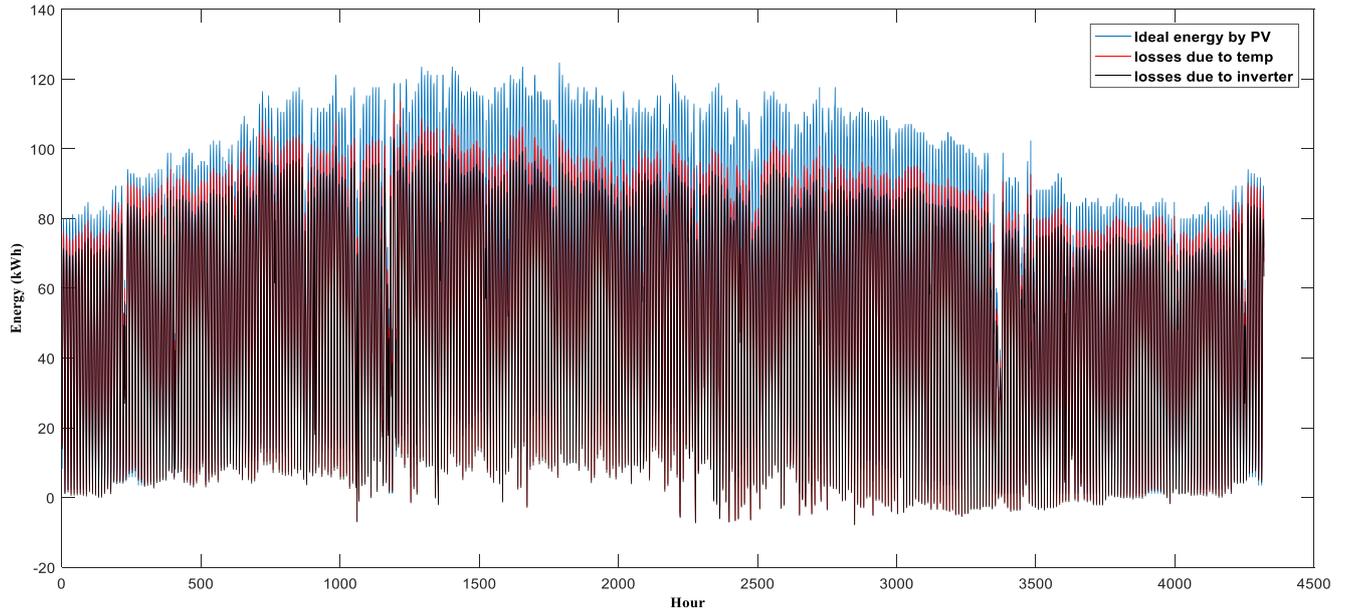
Fig. 3. (a) SWPS HOMER schematic diagram, (b) SWPS economic assumption.

Table 1. Photovoltaic module specification.

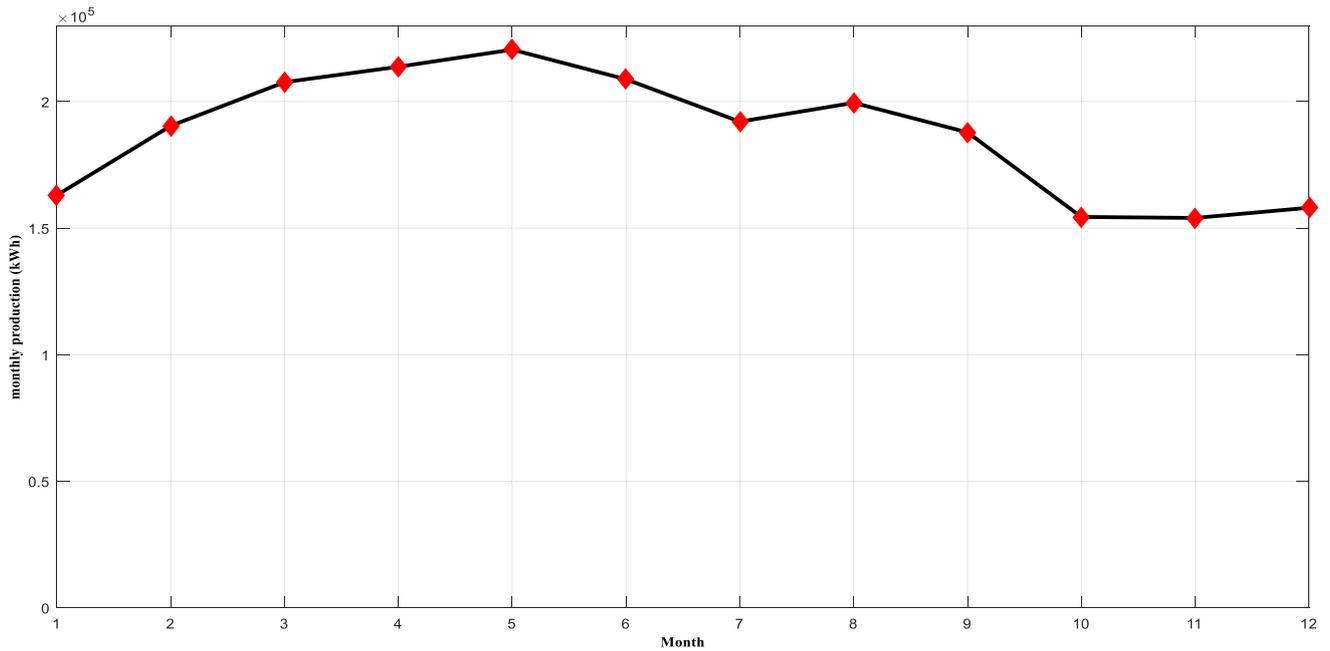
Rated power	120 Watt
Maximum voltage	18.5 Volts
Maximum current	5.98 Amperes
Open circuit voltage	22.5 Volts
Short circuit current	6.49 Amperes
Efficiency	14%
Temperature coefficient of $V_{o.c}$	-0.36 %/k
Temperature coefficient of $I_{s.c}$	0.06 %/k
Size	1020 × 670 × 35 mm

analysis found that six PV modules and four batteries are needed. The top three best solution which are judged based on their net present cost (NPC), cost of energy (COE) and ability to supply the demand, are presented in Table 2.

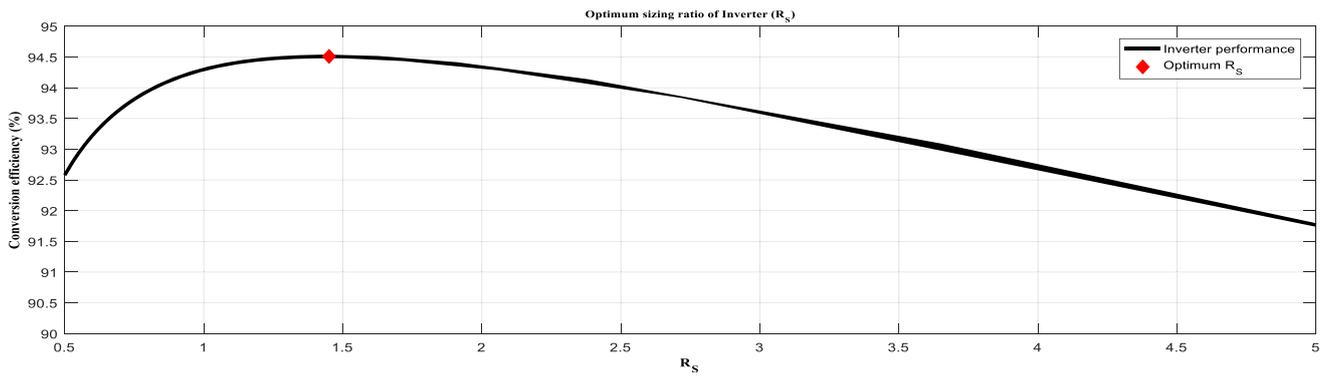
From Table 2, the optimal system configuration is composed of 0.84kW, and 0.8kW PV and inverter, respectively. The optimum solution was found to have 3190 USD, 62 USD/year, and 0.309 USD/kWh for total NPC, operating cost, and CoE, respectively. As for the results obtained from the MATLAB code, it is found that the optimum system configuration is composed of 0.81 kW PV array, three batteries, and 0.81 kW inverter. Furthermore, MATLAB optimum solution found, the total NPC is



(a)



(b)

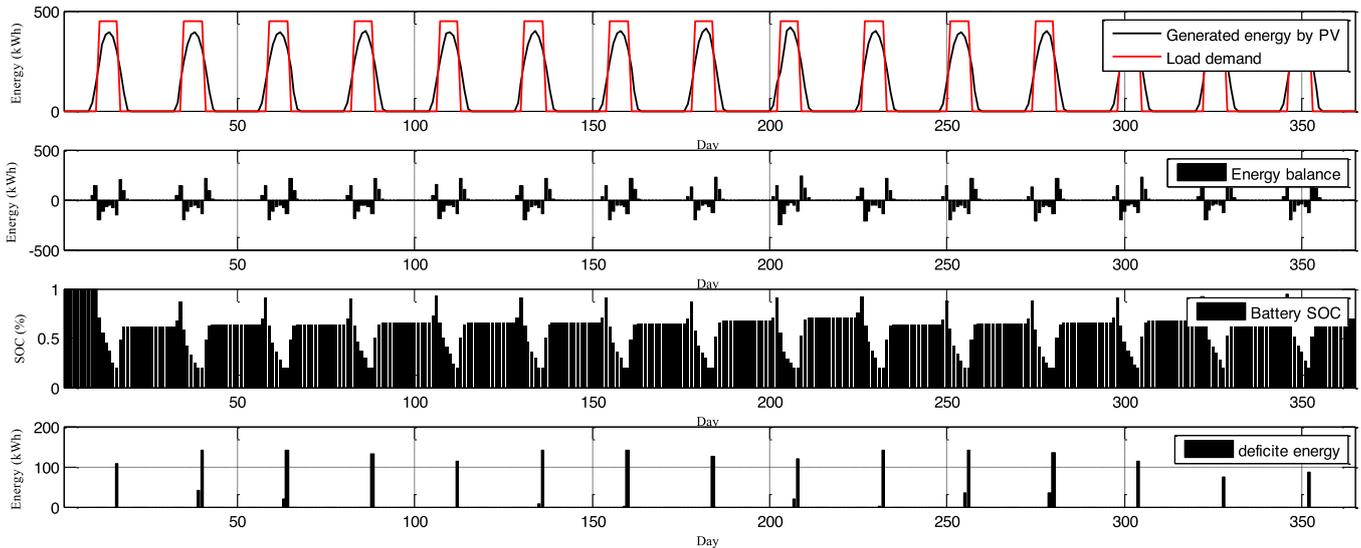


(c)

**Fig. 4.** SWPS performance and optimization results. (a) PV hourly energy production for one year (12 hours/day). (b) Monthly energy production. (c) Optimum inverter.

**Table 2.** SWPS optimum solutions – HOMER.

PV (kW)	6FM200D	Conv. (kW)	Initial capital	Operating cost (\$/yr)	Total NPC	COE (\$/kWh)	Ren. frac.	Capacity shortage
0.84	4	0.8	\$2400	62	\$3190	0.309	1.00	0.00
0.83	4	0.8	\$2460	65	\$3275	0.316	1.00	0.00
0.71	5	0.9	\$2350	74	\$3279	0.317	1.00	0.00

**Fig. 5.** System performance for complete year.

1880 USD with an operating cost of 32 USD/year and the cost of energy equals to 0.18 USD/kWh. The energy generation of the proposed system in MATLAB are shown in Figure 4. The availability of the proposed PV system is the percentage of time the PV meets the load demand, which is found to be 98%. The optimum system availability achieved by the MATLAB code is superior to the systems proposed by HOMER and the intuitive method. The proposed system yearly performance is shown in Figure 5. It is observed from the performance that solar energy covered most of the needed electrical load. Also, the battery is used intensively throughout the year, as Oman is known sometime to have dusty weather. Finally, the system annual yield factor and capacity factor are 2016.66 kWh/kWp and 22.97%, which is promising since the typical, is 21%. Also, it is worth mentioning that the polluted emission saved because of using PV system is illustrated in Figure 6 is equivalent diesel generator used.

A comparison in terms of cost of energy between the proposed systems in this study and other systems in the literature is shown in Figure 7 [22–29]. The cost of the proposed system seems to be acceptable, relative to the comparison. However, it is difficult to determine which is more suitable as various parameters affect the selection of optimum configuration such as type of PV, location of

pumping system, pumping head, weather parameters, and system configurations. Different circumstances for each study make it difficult to compare the systems.

## 4 Conclusions

The solar water pumping system was designed and optimized in terms of technical and economic aspects in this study. Two methods have been used to optimally design the system using HOMER software and numerical method using MATLAB. The optimum system equipment was found to be 0.81 kW and consume 2.22 kWh/day. However, it is found that the CoE found to be 0.309 USD/kWh, and 0.180 USD/kWh using HOMER and MATLAB, respectively. Also, the system annual yield factor and capacity factor are 2016.66 kWh/kWp and 22.97%, which is promising. CoE compared with similar studies for Oman, and it was found that MATLAB proposed system shows the lowest cost. Moreover, using SWPS to replace diesel generator will protect the environment from emitted polluted gas such as 897 kg/year of Carbon dioxide, 2.17 kg/year of Carbon monoxide, 0.236 kg/year of Unburned hydrocarbons, 0.169 kg/year of Particulate matter, 1.79 kg/year of Sulfur dioxide, and 21.3 kg/year of Nitrogen oxides.

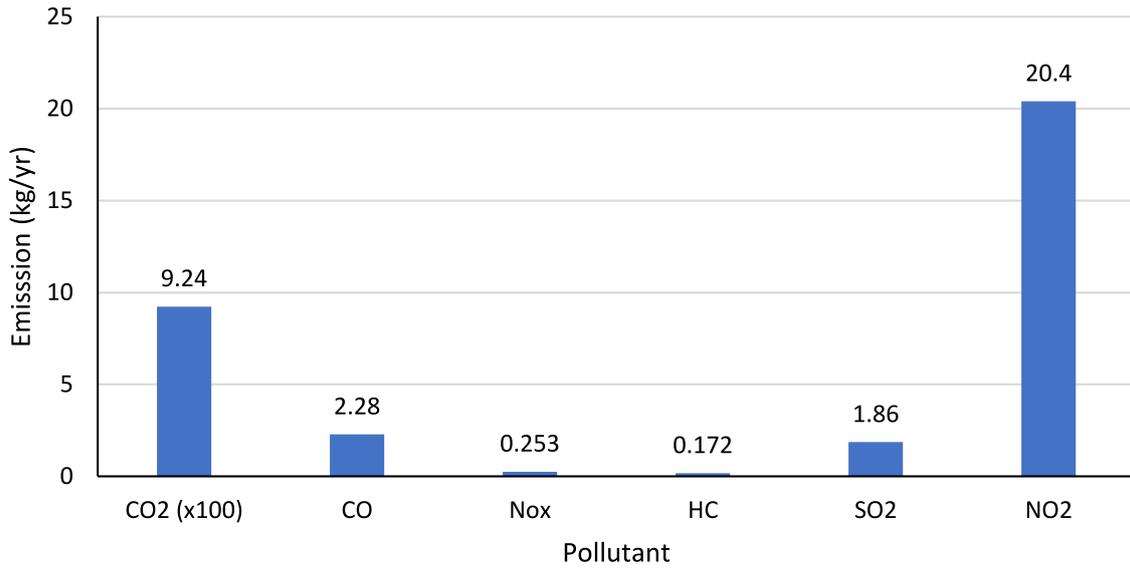
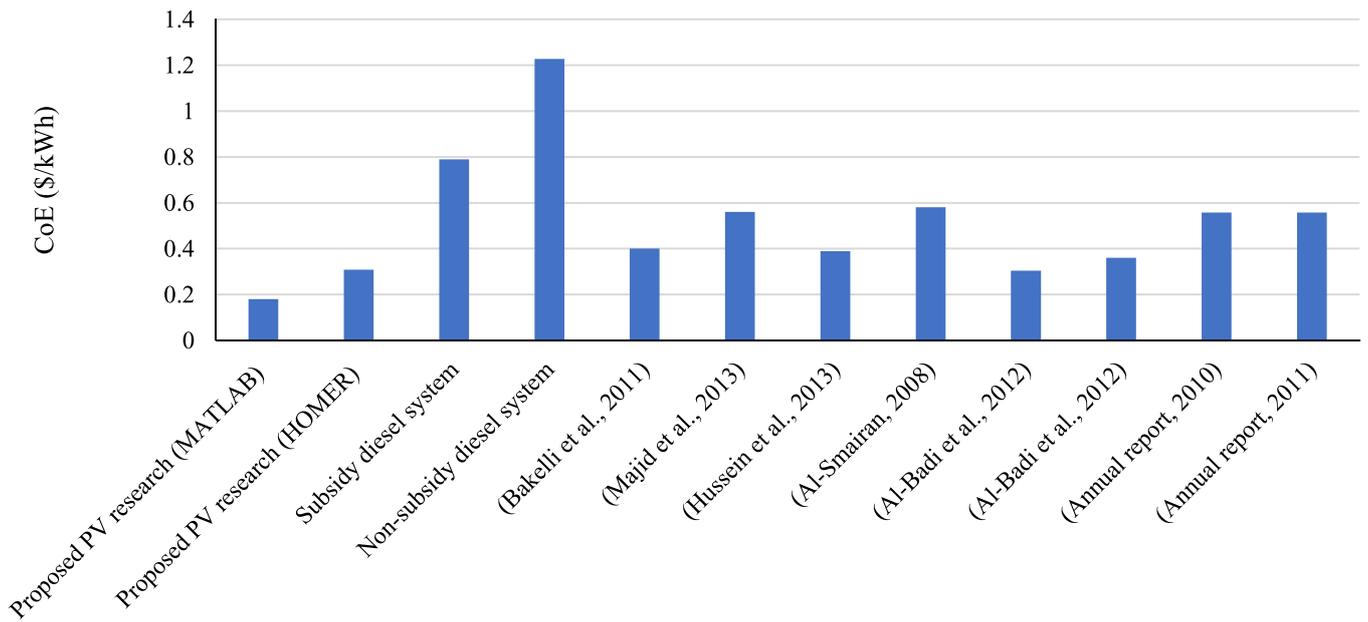


Fig. 6. Polluted emissions produced by equivalent diesel generator.



References

Fig. 7. Cost of energy of different systems.

Nomenclature

$A_c$	The collector area (m <sup>2</sup> )
$A_{PV}$	Area of the PV array in m <sup>2</sup>
$C_{capital}$	The capital cost of a project
$C_{O\&M}$	The yearly operation and maintenance costs
$C_{replacement}$	The cost of all equipment replacement and repair
$C_{salvage}$	The net worth of the system at the final year of project lifetime
$CF$	Capacity Factor
$CoE$	Cost of Energy

$E$	Daily subsystem efficiency 0.2–0.6 typically
$E_{AC}$	Alternating current energy
$E_{PV}$	PV energy (Wh)
$E_{PVannual}$	Annual energy production of the PV system
$F$	Mismatch factor which is in the range 0.85–0.90
$Fm$	Future sum of money
$g$	Acceleration due to gravity m/s <sup>2</sup>
$G_T$	Daily solar radiation in kWh/m <sup>2</sup>
$h$	Total pumping head in m
$I_{SC}$	Short Circuit Current
$LCCA$	Life Cycle Cost Analysis

$MC$	The system total maintenance cost
$MC_{or}$	The maintenance cost of the $r$ th component in the first year (USD)
$MC_r$	The maintenance cost (USD)
$PV$	Photovoltaic
$PBP$	Payback period
$P_{in}(t)$	The instantaneous input power
$P_{Inv}$	The inverter power
$P_{loss}(t)$	The instantaneous power losses
$P_{PV}$	The PV module power
$P_{peak}$	The PV peak power
$P_R$	Rated power
$RC_k$	The replacement cost of the $k^{th}$ component (USD)
$STC$	Standard test conditions
$V$	Volume required in $m^3/day$
$V_{OC}$	Open Circuit Voltage
$YF$	The yield factor
$\Delta H$	Hydraulic losses in m
$\rho$	Water density $kg/m^3$
$\eta_b$	Pump efficiency
$\eta_e$	Electric motor efficiency
$\eta_s$	Subsystem efficiency
$\eta_{PV}$	PV module efficiency
$\eta_{inv}$	Inverter efficiency
$\eta_{wire}$	Wires efficiency

## Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

*Acknowledgments.* The research leading to these results has received Research Project Grant Funding from the Research Council of the Sultanate of Oman, Research Grant Agreement No. ORG SU EI 11 010.

## References

- H.M.S. Al-Maamary, H.A. Kazem, M.T. Chaichan, Climate change: the game changer in the Gulf Cooperation Council Region, *Renew. Sustain. Energy Rev.* **76**, 555–576 (2017)
- R. Gurusthal, A. Kumar Singh, T. Tyagi, A critical review on efficiency enhancement of solar panels using advanced technologies, *Think India J* **22**, 116–151 (2019)
- H.A. Ali Alwaeli, H.A. Kazem, M.T. Chaichan, K. Sopian, *Photovoltaic/Thermal (PV/T) Systems: Principles, Design, and Applications*. 1st edn., Springer Nature, Switzerland (2019)
- A.H.A. Al-Waeli, K. Sopian, H.A. Kazem, M.T. Chaichan, Photovoltaic/Thermal (PV/T) systems: status and future prospects, *Renew. Sustain. Energy Rev.* **77**, 109–130 (2017)
- M. Vasiliev, M. Nur-E-Alam, K. Alameh, Recent developments in solar energy-harvesting technologies for building integration and distributed energy generation, *Energies* **12**, 1080 (2019)
- M. Benganem, K.O. Daffallah, S.N. Alamri, A.A. Joraid, Effect of pumping head on solar water pumping system, *Energy Convers. Manag.* **77**, 334–339 (2014)
- A. Agus, D. Hari, D. Setyo, N. Huda, Development of a solar water pumping system in Karsts rural area Tepus, Gunungkidul through student community services, *Energy Proc.* **47**, 7–14 (2014)
- A.A. Ghoneim, Design optimization of photovoltaic powered water pumping systems, *Energy Convers. Manag.* **47**, 1449–1463 (2006)
- Å. Kala Meah, S. Fletcher, S. Ula, Solar photovoltaic water pumping for remote locations, *Renew. Sustain. Energy Rev.* **12**, 472–487 (2008)
- R. Sharma, S. Sharma, S. Tiwari, Design optimization of solar PV water pumping system, *Mater. Today: Proc.* **21**, 1673–1679 (2020)
- P. Caton, Design of rural photovoltaic water pumping systems and the potential of manual array tracking for a West-African village, *Solar Energy* **103**, 288–302 (2014)
- H.A. Kazem et al., Design, measurement and evaluation of photovoltaic pumping system for rural areas in Oman, *Environ. Dev. Sustain.* **19**, 1041–1053 (2017)
- H.A. Kazem et al., Design, measurement and evaluation of photovoltaic pumping system for rural areas in Oman, *Environ. Dev. Sustain.* **19**, 1041–1053 (2016)
- A.H. Al-Waeli, K. Sopian, H.A. Kazem, M.T. Chaichan, Photovoltaic Solar Thermal (PV/T) collectors past, present and future: a review, *Int. J. Appl. Eng. Res.* **11**, 10757–10765 (2016)
- H.A. Kazem, M.T. Chaichan, The effect of dust accumulation and cleaning methods on PV panels' outcomes based on an experimental study of six locations in Northern Oman, *Solar Energy* **187**, 30–38 (2019)
- I. Odeh, Y.G. Yohanis, B. Norton, Influence of pumping head, insolation and PV array size on PV water pumping system performance, *Solar Energy* **80**, 51–64 (2006)
- D.H. Muhsen, T. Khatib, F. Nagi, A review of photovoltaic water pumping system designing methods, control strategies and field performance, *Renew. Sustain. Energy Rev.* **68**, 70–86 (2017)
- H.A. Kazem, T. Khatib, K. Sopian, Sizing of a standalone photovoltaic/battery system at minimum cost for remote housing electrification in Sohar, Oman, *Energy Build.* **61**, 108–115 (2013)
- H.A. Kazem, T. Khatib, K. Sopian, W. Elmenreich, Performance and feasibility assessment of a 1.4 KW roof top grid-connected photovoltaic power system under desertic weather conditions, *Energy Build.* **82**, 123–129 (2014)
- N. Kittner, S.H. Gheewala, D.M. Kammen, Energy Return on Investment (EROI) of Mini-Hydro and Solar PV systems designed for a mini-grid, *Renew. Energy* **99**, 410–419 (2016)
- N.A. Mohammed, M.H. Albadi, Demand response in electricity generation planning, *Electr. J.* **33**, 106799 (2020)
- Y. Bakelli, A. Hadj, B. Azoui, Optimal sizing of photovoltaic pumping system with water tank storage using LPSP concept, *Solar Energy* **85**, 288–294 (2011)
- M.A. Salam, A. Aziz, A.H.A. Alwaeli, H.A. Kazem, Optimal sizing of photovoltaic systems using HOMER for Sohar, Oman, *Int. J. Renew. Energy Res.* **3**, 470–475 (2013)
- H.A. Kazem, A.A. Alkurwi, M.M. Alabdul Salam, A.H.A. Alwaeli, Levelized electricity cost for photovoltaic system in Sohar-Oman, in *2013 8th International Conference and Exhibition on Ecological Vehicles and Renewable Energies, EVER 2013* (2013)

25. M. Al-smairan, Application of photovoltaic array for pumping water as an alternative to diesel engines in Jordan Badia, Tall Hassan Station: case study, *Renew. Sustain. Energy Reviews* **16**, 4500–4507 (2012)
26. A.H. Al-Badi, M.H. Albadi, A.M. Al-Lawati, A.S. Malik, Economic perspective of PV electricity in Oman, *Energy* **36**, 226–232 (2011)
27. A.H. Al-Badi et al., Hybrid systems for decentralized power generation in Oman, *Int. J. Sustain. Energy* **31**, 411–421 (2012)
28. Authority for Electricity Regulation, Oman. 2010. *2010 Annual Report from Rural Areas Electricity Company, Oman.*
29. Authority for Electricity Regulation, Oman. 2011. *2011 Annual Report from Rural Areas Electricity Company, Oman.*

**Cite this article as:** Hussein A. Kazem, Anas Quteishat, Mahmoud A. Younis, Techno-economical study of solar water pumping system: optimum design, evaluation, and comparison, *Renew. Energy Environ. Sustain.* **6**, 41 (2021)