Journal of Advanced Engineering Trends
ISSN : 2682 - 2091
Vol.43, No.1. January 2024
http://jaet.journals.ekb.eg

Considering Dust Accumulation on PV for Sizing PV/Wind/Battery Energy System Based on Weather Data

Mahmoud Aref(1), Safaa Saleh(2), Mohammed Nayel(3)
Assistant Professor Department of Electrical Engineering, faculty of engineering, Assiut University, Egypt(1)
Department of Electrical Engineering, faculty of engineering, Assiut University, Egypt(2)
Professor Department of Electrical Engineering, Faculty of Engineering, Assiut University(3)

ARTICLE INFO
Article history:
Received:
Accepted:
Online:

Keywords:
Hybrid energy system
Regression model
HOMER software

ABSTRACT
Photovoltaic systems are the most effective alternative renewable energy source for isolated areas. But PV output power is affected by environmental factors such as temperature and dust accumulation. Periodically cleaning of PV panels increase converted solar energy. Isolated areas in Egypt do not have a connection to the electricity grid due to the high cost of transmission lines extension. Using conventional sources is not practical, as they cause emission gases. Moreover, they are limited sources. Renewable sources become essential power suppliers for isolated areas, as they are clean and unlimited sources. This paper introduces an optimal sizing for a stand-alone hybrid energy system PV/Wind/Battery (PV+WT+BAT) considering the dust effect on PV with different cleaning scenarios at tilt angle 30, supplying electrical energy needs for an isolated area in Egypt (Shalateen city). The optimal sizing is obtained using HOMER software. Then getting the optimal cleaning frequency based on minimizing the cost due to cleaning and dust accumulation power reduction. The results show that the optimal solution is the (PV+WT+BAT) system with a weekly cleaning scenario with a net present cost (NPC) of 103M$ and a cost of energy (COE) 0.319$/kWh. When using only a PV source for supplying the system, the optimal system is also with a weekly cleaning scenario with 117M$ NPC and 0.363$/kWh COE.

1. Introduction

In Egypt, there are several isolated areas from the electricity grid. These areas suffer from electricity shortages due to the large distance from the electrical network and the high cost of transmission lines, so conventional resources represent the main source of power for these areas [1]. But the generated electricity from these resources causes greenhouse gas emissions which increase environmental pollution and have a great impact on global warming. Increasing energy demand, the high cost of fuels, and their limitation have led the world to use renewable energies as alternative resources for electricity generation [2].

Renewable energy resources are considered a viable solution to decrease the impact of global warming. Renewable energies such as solar, wind, hydro, tidal, geothermal, and wave are a clean and limitless energy resources. Moreover, 50% of energy demand for Egypt was foreseen to be met by renewable resources in 2030 [3].

Solar power is a main renewable energy resource, it is generation continues to increase globally according to the International Energy Agency's Photovoltaic Power System Project. Due to increasing the solar energy around the world, more attention has been paid to studying the performance of PV systems. Many environmental factors affect the performance of PV, dust accumulation on PV is one of the most important factors which degrade the output power from PV [4, 5]. It is necessary to study the impacts of dust accumulation on the performance of PV modules, which can help PV systems designers to predict the PV power outputs more precisely and schedule the cleaning and maintenance more carefully [6].

A lot of researches can be found in the literature which study the impact of accumulated dust on photovoltaic systems, and estimate the effect of dust on PV power output and performance, considering many parameters which affect the dust accumulation such as tilt angle, temperature, rains, wind speed and geographical location [7]. In Ref. [8], an experimental study for the impact of accumulated dust and cooling by water for different two types of PV panels at a fixed tilt angle of 30° and directed to the South direction at El-Sherouk City, Egypt was presented. Moreover, the impact of tilt angles from 0 to 60 on dust accumulation and efficiency is studied. The results reported that the accumulation of dust on the PV surface degrades it is output power. Moreover, the optimal tilt angle for Egypt conditions is 30° to reduce the loss due to the dust accumulation effect. Ref. [9] investigated the impact of air-born suspended matters accumulated on the PV system in Alexandria, Egypt near the sea experimentally to determine the reduction of the PV performance and the scheduled time for cleaning. From the results, the average reduction of output power and efficiency due to dust is 10.33% after 30 days. Ref. [10] Studied the effect of tilt angle, the accumulated dust on the power output, and the transmittance of the PV panel at the Faculty of Engineering of Helwan University, Helwan City in Egypt. The results indicate that by the 25th day of dust accumulation, the PV module efficiency

Revised:14 May , 2022, Accepted:17 July , 2022

has been reduced by 30 %, and by day number 75 of dust accumulation the efficiency reduced to be around 53 % for an angle of 30°. Ref. [11] Presented a study in Beni-Suef, Egypt that examines the impact of dust accumulation on the performance of PV panels for three months adjusting at an angle of 0°. From the results, the output power of the PV is degraded by 65% after three months. Ref. [12] introduced an experimental study for the impact of dust on the performance of PV modules by comparing the measured data from five PV modules under the same operating conditions with different cleaning scenarios in the summer season. The modules are installed at a tilt angle of 30° in Cairo, Egypt. The obtained results indicate that the output power of the dusty modules is decreased by 2.4%, 11%, 30%, and 42%, when cleaned one time per week, per month, per two months, and every three months, respectively. In addition to that, washing the PV panel with saltwater decreases its output by about 2% over that washed with freshwater after one month. While a test methodology is proposed to study and analyze the factors that affect the Photovoltaic system's performance including dust accumulation and tilt angle in Upper Egypt in Aswan [13]. In Ref. [14–17], the computational fluid dynamic (CFD) simulation numerical method is used to investigate the influence of dust deposition on PV efficiency, as well as study the effect of tilt angle, orientation, and height of PV on dust deposition on the PV system. In China, an experimental investigation is done to study the dust accumulation on three different types of PV modules and the influence of dust on their efficiency. From the obtained results the materials of the surface have a potential effect on the PV efficiency [18]. Where in Oman an experimental study investigated the influences of relative humidity, and wind speed on dust accumulation on PV, and the effect of nine different cleaning methods applied to it for six cities after one month of dust accumulation [19]. Ref. [20] presented computational models to determine the influences of dust and climate temperature on the performance of a grid-connected photovoltaic system in Jordan based on experimental data. Ref. [21] studied the factors which influence the dust accumulation on PV such as tilt angle, azimuth angle, wind direction, and where the samples are placed in the environment, moreover, the effect of dust on the transmittance of the PV glass.

This paper focuses on estimation the loss due to dust accumulation effect on the efficiency of PV modules, then considering this effect on sizing the system. In this study, the optimal sizing for a hybrid PV/Wind/Battery system including the loss due to dust accumulation effect on PV system, for supplying Shalateen city in Egypt using HOMER software based on minimizing the NPC and COE of the system is presented. The optimization including different cleaning scenarios for the system to get the optimal cleaning period.

The rest of the paper is organized as follows: In section 2, the methodology which includes the specification of the studied city, dust effect estimation unit based on weather data, Power reduction extraction in Shalateen city, load profile of the studied city, solar, wind, resource data, and system component technical data. Section 3, is the problem formulation which includes HOMER software and objective function and constraints. Section 4, is the optimal cleaning frequency Section 5, describes the results and discussion of the study. Finally, Section 6 is the conclusion for the system.

2. Methodology

Dust accumulation effect prediction on the photovoltaic systems is an important concern to be considered in system sizing and to determine the optimal cleaning scenario for it. The procedure of this paper includes three different stages which are shown in the flowchart in Figure 1 and by the following analysis structures.

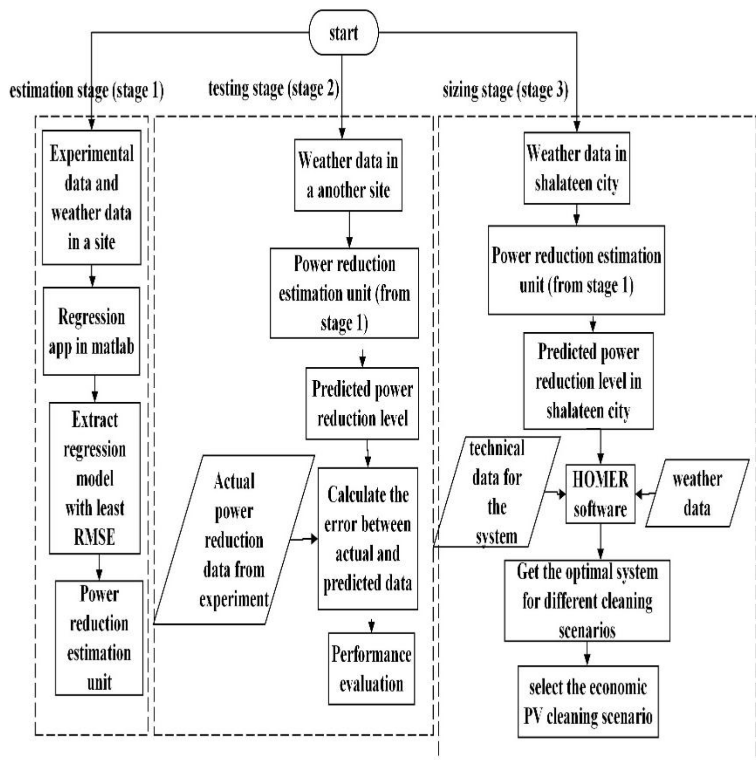

Figure 1: The proposed procedure flowchart

2.1. Specification of the studied city

Shalateen is a small city in Egypt. It locates on the Red Sea coastline in the southeastern part of the Eastern Desert at latitude (N: 23° 09') and longitude (E: 35° 36'), to the north of

Halayeb Triangle. Shalateen is an isolated area from the Egyptian electricity network. Its loads are supplied from a diesel station consisting of six diesel generators and one renewable energy source, a PV system.

2.2. Dust effect estimation unit based on weather data

Data collection is the first and essential step in the model which is obtained from a previous literature measured data in Egypt. These data are entered into the regression app on MATLAB software. Regression is a machine learning type that is used in problems of estimation [22]. Furthermore, it is an analytical procedure that is used to predict a relation between a single output variable called the response and one or more input variables called Predictors [23]. In this study, six variables were used as predictors which are air quality index (AQI), temperature, relative humidity, irradiation, wind speed, and wind direction, one variable used as a response is the power loss due to dust accumulation on PV. After entering the data for the regression app, train the model using this data to make it learn how to predict the power loss. After training data, many regression models have been used that estimate the power loss due to dust based on the root mean square error (RMSE). The model which has minimum RMSE is selected, then extracted and fed by (AQI), temperature, relative humidity, irradiation, wind speed, and wind direction in shalateen city to predict power reduction after testing the model in another site in Egypt, and good agreements are obtained from it. Testing the model including entering (AQI), temperature, relative humidity, irradiation, wind speed, and wind direction for another site in Egypt and getting the power reduction for this site then compare the predicted power reduction with the actual power reduction which is obtained from experimental data from previous literature to ensure that the model is accurate which is represented by the testing stage in Figure 1.

2.3. Power reduction extraction for shalateen city

After extracting the best regression model, (AQI), temperature, relative humidity, irradiation, wind speed, and wind direction for Shalateen city are fed to the model to get the power reduction due to dust accumulation. Power reduction every day, week, month, two months, and six months is obtained to get the optimal system for five cleaning scenarios. The effect of dust accumulation is applied to the solar irradiation for entering it into HOMER software and which is shown in Figure 2.

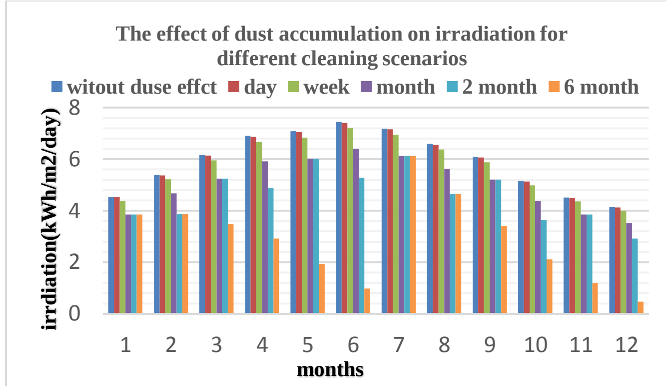

Figure 2: The monthly average solar irradiation without dust effect, and with dust effect when cleaning the PV every day, every week, every month, every two months, and every six months

2.4. Load profile of shalateen city

Load data for the studied city are obtained for one year from the station which supplies Shalateen city with it is electrical demand loads. The daily load profile in Shalateen is shown in Figure 3. The electrical load demand changes seasonally due to the variation in energy consumption in summer and winter, summer months (Jul, Aug, Sep) have more load demand than other months. The hourly load profile in one year for the studied city is shown in Figure 4 with a peak value of 6900 kilowatts and an average value of 68458.13 kilowatt-hours per day.

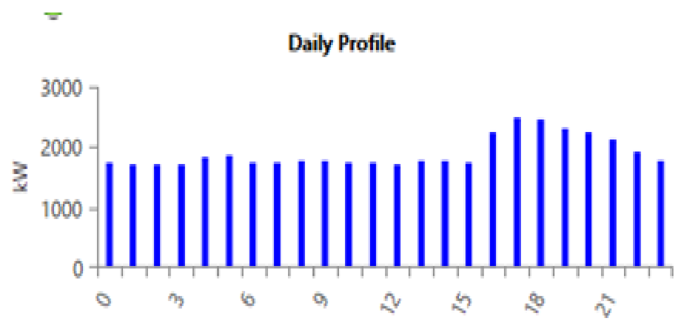

Figure 3: The daily load profile for 24 hours

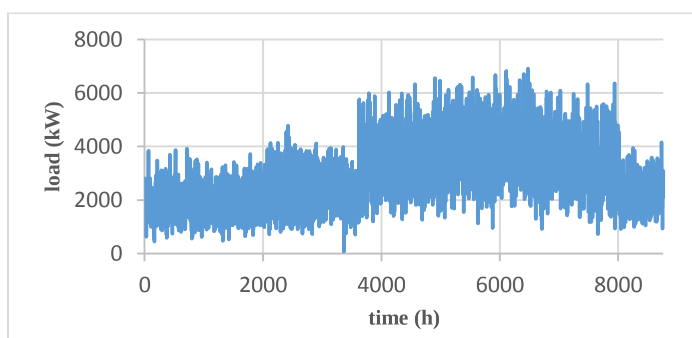

Figure 4: The hourly load profile for one year

2.5. Solar resource and temperature of Shalateen city

The amount of solar power generation is mainly affected by solar irradiance and ambient temperature. The data for temperature and global horizontal radiation are used as input parameters in HOMER software, which were obtained from (NASA website). Monthly average solar irradiance and ambient temperature are shown in Figure 5 and Figure 6 for the studied city with a scaled annual average of 5.94-kilowatt hours per square meter per day and 26.88 Celsius respectively.

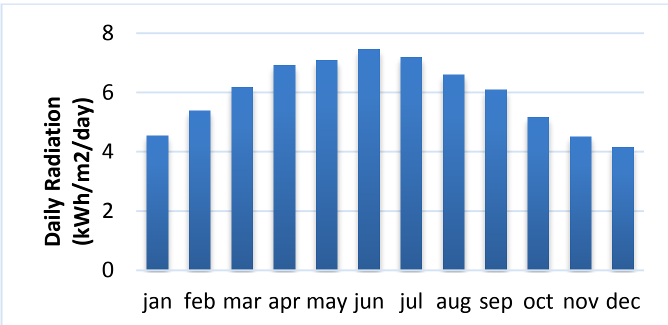

Figure 5: The monthly average solar irradiance data for Shalateen

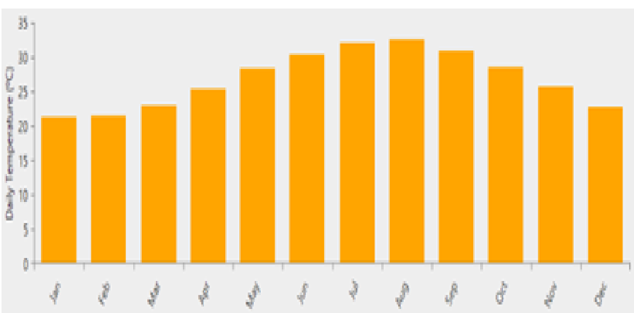

Figure 6: The monthly average temperature data for Shalateen

2.6. Wind resource of Shalateen city

Calculating the quantity of generated power from wind depends on wind speed in the studied city, as it is an input parameter for HOMER software. Wind speed data was taken from (NASA website). The monthly average wind speed for the studied city is shown in Figure 7 with a scaled annual average of 4.09 meters per second at the 10-meter height of the anemometer.

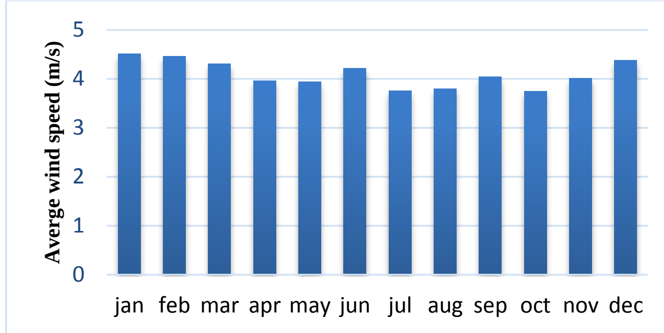

Figure 7: The monthly average wind speed for Shalateen

2.7. System components technical data

Technical data such as costs, rates, and lifetimes for all system components are necessary for HOMER software simulation, so these data are presented as input parameters for HOMER. Technical data for system components are shown in Table 1.

Table 1: Technical data for system components

component	*parameter*	*Value*	*unit*
Solar PV	**Rated power (P_{PVr})** **Derating factor (df)** **Temperature coefficient (k_t)** **Capital cost.** **Replacement cost** **M&O cost** **Lifetime** **Cleaning cost**	**5** **80** **-0.37** **14000** **0** **100** **25** **1$**	**kW** **%** %/°C **$** **$** **$/year** **Year**
Wind turbine	**Rated power(P_{wtr})** **Cut-in wind speed(V_{ci})** **Cut out wind speed(V_{co})** **Rated wind speed(V_r)** **Hub Height(H_{wt})** **Capital cost.** **Replacement cost** **M&O cost** **Lifetime**	**6.25** **2** **14** **6** **30** **26000** **26000** **200** **18**	**kW** **m/s** **m/s** **m/s** **m** **$** **$** **$/year** **Year**
Battery	**Nominal capacity (kWh)** **Nominal capacity (Ah)** **Minimum state of charge** **Maximum state of charge** **Roundtrip efficiency** **Capital cost.** **Replacement cost** **O & M cost** **Lifetime**	**100** **167** **20** **100** **90** **13700** **13700** **200** **15**	**kWh** **Ah** **%** **%** **%** **$** **$** **$/year** **Year**
Converter	**Capital cost** **Replacement cost** **O & M cost** **Lifetime** **efficiency**	**300** **300** **0** **15** **95%**	**$/kW** **$/kW** **$/kW** **Year** **%**
Others	**Project lifetime** **Real discount rate**	**25** **6**	**Year** **%**

3. Problem formulation

3.1. HOMER software

HOMER is an optimization tool used for sizing micro grid systems developed by National Renewable Energy Laboratory. This software is a powerful tool for the optimal sizing of hybrid renewable energy systems by carrying out techno-economic analysis for off-grid and grid connected power systems. It takes inputs such as electric loads and the hybrid combinations of components to perform simulations. Moreover, the range of components with different constraints, sensitivities and costs which includes capital, replacement, maintenance and operational costs are fed into the HOMER. Then HOMER performs the required simulation to meet the required load demand. Optimization of system is executed by minimizing the objective function to the constraints [24].

3.2. Objective function and constraints

The optimal solution using HOMER is obtained based on minimizing the net present cost and the cost of energy for the system which represent the objective function for the optimization**.** Calculating NPC depends on capital costs, replacement costs, and maintenance and operation (O&M) costs.

The objective function is mathematically expressed by (1) and constrained by (2) [25].

$$\text{Minimize}\begin{cases} COE = \frac{C_{ann,tot}}{E_{served}} \\ NPC = \frac{C_{ann,tot}}{CRF(i,n)} \end{cases} \quad (1)$$

$$\text{Subjected to}\begin{cases} N_{pv}min \le N_{pv} \le N_{pv}max \\ N_{wt}min \le N_{wt} \le N_{wt}max \\ N_{bat}min \le N_{bat} \le N_{bat}max \\ SOC\_max \le SOC \le SOC\_max \end{cases} \quad (2)$$

$C_{ann,tot}$ is the total annualized cost in ($/year), E_{served} is the annual production energy in (kilowatt per year), n is the project lifetime in (year), i is the annual real interest rate (%), $N_{pv}, N_{wt}, and\ N_{bat}$ are the decision variables which represent the number of PV, wind turbines, and batteries, SOC is the state of charge of battery, i can be estimated using (3), CRF is the capital recovery factor and can be calculated using (4).

$$i = \frac{i' - f}{1 + f} \quad (3)$$

$$CRF(i,n) = \frac{i * (1+i)^n}{(1+i)^n - 1} \quad (4)$$

Where i' is the nominal interest rate, f is the annual inflation rate.

4. Optimal cleaning frequency

The optimum cleaning frequency is the cleaning period carried out for the PV system under which the two effects of cleaning are minimized, the cleaning cost of the PV system panels and the dust accumulation loss for a given cleaning period calculated for the study period using the prediction model [26].

In this section we consider the cleaning cost (1$/module) and with many electricity tariffs (0.135, 0.37, 0.5, 0.6 $//kWh). Firstly, for one year the cleaning cost is computed for different cleaning periods for the interval from 1–120 days based on the sizing of the system for each cleaning period which is represented by (cleaning cost/ module*N_{pv} *number of cleaning times in year). Secondly, the cost of power reduction due to dust accumulation on PV is calculated based on the average reduction on PV efficiency for different cleaning periods, the electricity tariffs, and the sizing of the system which is represented by (power reduction* N_{pv} in kW* electricity tariffs * number of cleaning times in year). Figure 8 shows the cleaning cost and power reduction cost for four electricity tariffs for one year respect the different cleaning periods from 1 to 120 day.

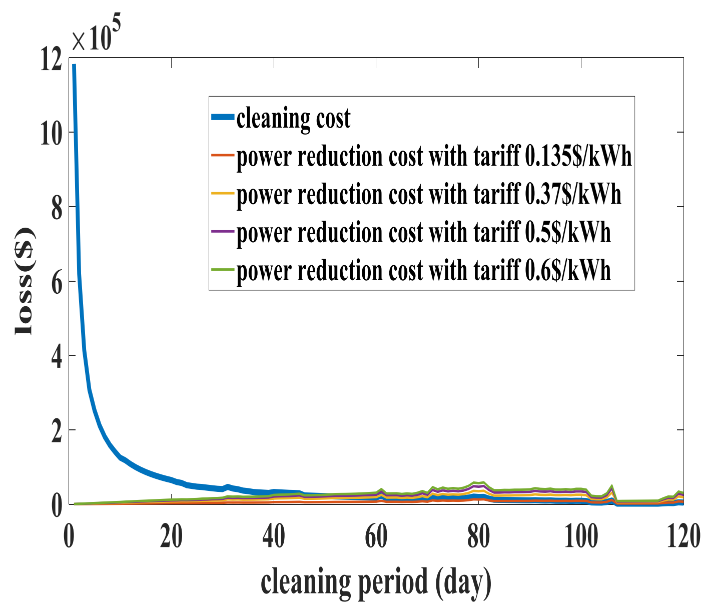

Figure 8: Average daily losses due to cleaning cost (inversely proportional curve) and losses due to dust accumulation (almost linear curves) obtained for four electricity tariffs.

To identify the optimum cleaning frequency from Figure 8, the average daily losses due to cleaning cost and losses due to dust accumulation obtained are combined as in Figure 8. The optimum cleaning frequencies are the intersections of the cleaning cost curve with the reduction power cost curves.

5. Results and discussion

Many environmental factors influence the accumulated dust on PV panels such as air quality index, wind speed, wind direction, and relative humidity. In this study dust accumulation on a PV system is estimated using a dust estimation unit that receives the weather data to obtain the power reduction. The estimated monthly power reduction for one year when using different cleaning scenarios is shown in Figure 9. From the figure, the accumulated dust on PV is increase with increasing the cleaning period.

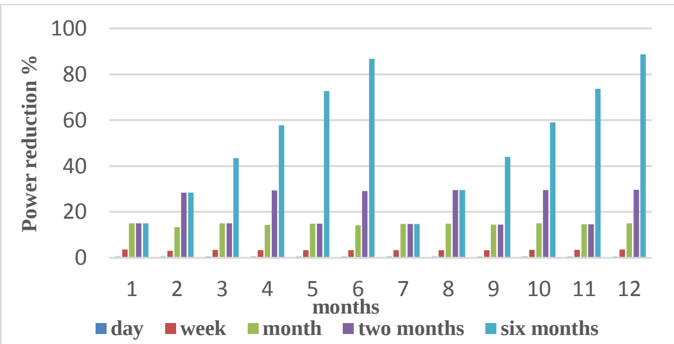

Figure 9: The monthly power reduction for one year when cleaning the PV every day, every week, every month, every two months, and every six months

After that HOMER software is used to get the optimal hybrid energy system to supply load demand for the studied area in Egypt based on the NPC and COE of the system. Simulation for (PV+WT+BAT) and (PV+BAT) systems is carried out with five cleaning scenarios. Table 2 presents the optimization results of the optimal cleaning scenarios. From Table 2, N_{PV} is the size of PV arrays in kW, N_{WT} is the number of wind turbines, N_{BAT} is the number of battery storages, NPC is the net present cost of the system in M$, COE is the cost of energy for the system in ($/kWh), EEF is the excess energy fraction. From the results, for daily cleaning scenario, the cleaning times is 365 time per year so the cleaning cost is high so the wind turbine number increases and PV system decreases. For weekly cleaning scenario, the cleaning times become 52 time per year so the cleaning cost decreases by a high value but the PV power output decreases by a low value so the wind turbine number is decreases and PV system increases. For monthly cleaning scenario, the cleaning times become 12 time per year so the cleaning cost and the PV power output decreases by a high value so the wind turbine number is increases and PV system decreases and so on for two and six month cleaning scenarios. The optimal solution is the proposed system with weekly cleaning scenario. The optimal system consists of a 15053 kW PV array, 797 wind turbines, 1187 batteries, and a 6895 kW converter, as it has the least NPC and COE compared to other cleaning scenarios. The net present cost and the cost of energy for the optimal solution were 103 M$ and 0.319 $/kWh respectively. Results show that this optimized system reduces the COE and NPC by about 8.7%, 3%, 6.9%, and 15.5% compared with daily, monthly, two months, and six months cleaning scenarios respectively.

For a single resource system (PV+BAT), the weekly cleaning scenario gives the minimum COE and NPC which are 0.363$/kWh and 117M$ respectively. The system consists of a 26967 kW PV array, 1315 batteries, and 8807 kW converter.

By comparing (PV+WT+BAT) with (PV+BAT), it is obtained that the cost of a single resource system is larger than the cost of the hybrid system. The saved cost when using a hybrid energy system is 12% less than the cost when using (PV+BAT) system according to the optimal system for the two cases. The comparison between the (PV+WT+BAT) and (PV+BAT) and between the different cleaning scenarios for the two systems is shown in Figure 10 and Figure 11 based on COE and NPC respectively.

For getting the optimal cleaning frequency which based on the minimization of cleaning cost and power reduction cost, from figure 8 by increasing the electricity tariffs the power reduction loss increase and the cleaning frequency period decrease, so we need to clean the system after small period. With electricity tariff 0.135$/kWh the optimal cleaning frequency is 99 day, 59 day with electricity tariff 0.37$/kWh, 50 day with electricity tariff 0.5$/kWh, and 44 day with electricity tariff 0.6$/kWh.

According to the results shown in Table 2, it is concluded that with a short cleaning period the output power from the PV system is increasing so PV size decreases, but the cost of cleaning is increasing so the total cost of the system is high. With a long cleaning period, the cost of cleaning is increasing so the size of the PV system increases by a high value so the total cost of the system is high such as in a month, two months, or six months cleaning scenarios. Consequently, the weekly cleaning scenario is the optimal scenario. The hybrid renewable energy system is more economic and feasible for isolated areas in Egypt compared to the single-source system.

Table 2: The results received from HOMER with dust effect for PV+WT+BAT and PV+BAT systems with different cleaning scenarios

Cleaning Scenarios	Daily cleaning		weekly cleaning		monthly cleaning		Two-month cleaning		Six-months cleaning	
system	PV+ WT+ BAT	PV+ BAT	PV+ WT+ BAT	PV+ BAT	PV+ WT+ BAT	PV+ BAT	PV+ WT+ BAT	PV+ BAT	PV+ WT+ BAT	PV+ BAT
N_{PV}(kW)	9388	26410	15053	26967	11397	29421	10447	32358	2222	51264
N_{WT}	1245	0	797	0	1194	0	1347	0	2038	0
converter(kW)	8136	9724	6895	8807	7213	6937	6752	7609	7069	7271
N_{BAT}	1356	1280	1187	1315	1318	1429	1402	1345	1743	1312
NPC (M$)	112	137	103	117	106	124	110	131	119	188
COE ($/kWh)	0.346	0.423	0.319	0.363	0.33	0.383	0.341	0.405	0.368	0.581
EEF	44.2%	28.5%	38.5%	28.3%	43.9%	28.1%	46%	28.9%	53%	30.1%

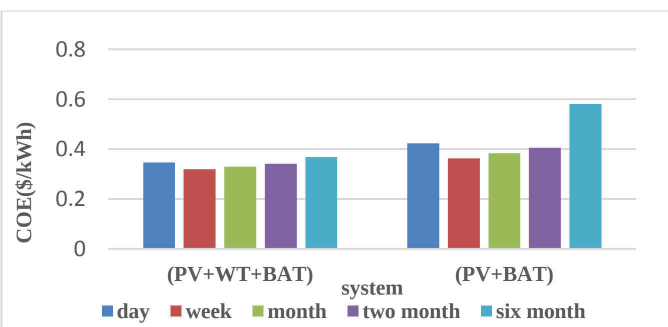

Figure 10: comparison of the cleaning scenarios for the two systems based on COE

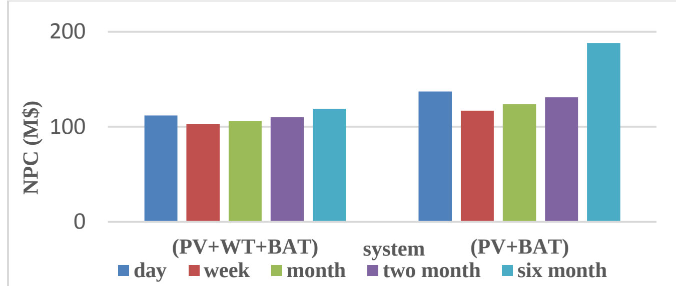

Figure 11: comparison of the cleaning scenarios for the two systems based on NPC

6. Conclusions

Dust accumulation on the surface of PV modules is a challenge for the use of PV systems, as it reduces the power output from it. Dust accumulation influences the amount of transmitted solar radiation for the system due to scattering or absorbing the radiation. This paper acts as an optimal sizing for a hybrid PV/Wind/Battery system to supply the electrical energy needs for an isolated area in Egypt (Shalateen city) considering the dust accumulation effect on the system with different cleaning scenarios and getting the optimal cleaning frequency for more electricity tariffs. Optimal sizing for the system is obtained by using HOMER software with daily, weekly, monthly, two month, and six months cleaning scenarios. The simulation results show that the optimal solution of hybrid renewable energy system was with 103 million dollars NPC and 0.319 dollars per kilowatt hours COE when using the weekly cleaning scenario. For single source system (PV/Battery), the optimal solution was with NPC of 117M$ and COE of 0.363$/kWh also with weekly cleaning scenario. The optimal cleaning frequency depends on minimizing the cleaning cost and the power reduction cost due to dust accumulation. It is concluded from the above results, that the PV modules should be cleaned one time every week to maximize the output power from it and to minimize the cost of the system. A renewable hybrid energy system is more reliable for isolated areas in Egypt, as it is considered a solution for electricity shortage in these areas and an environmentally friendly system.

References

[1] I. Elsayed, I. Nassar, and F. Mostafa, “Optimization and economic evaluation of small scale hybrid solar/wind power for remote areas in Egypt,” in *2017 Nineteenth International Middle East Power Systems Conference (MEPCON)*, 2017, pp. 25–30. doi: 10.1109/MEPCON.2017.8301158.

[2] H. Z. Al Garni, A. Awasthi, and M. A. M. Ramli, “Optimal design and analysis of grid-connected photovoltaic under different tracking systems using HOMER,” *Energy Convers. Manag.*, vol. 155, pp. 42–57, Jan. 2018, doi: 10.1016/J.ENCONMAN.2017.10.090.

[3] M. R. A. Rezk, A. Radwan, N. M. Salem, M. M. Sakr, and M. Tvaronavičienė, “Foresight for sustainable energy policy in Egypt: results from a Delphi survey,” *Insights into Reg. Dev.*, vol. 1, no. 4, pp. 357–369, 2019, doi: 10.9770/ird.2019.1.4(6).

[4] A. Al-Dousari *et al.*, “Solar and wind energy: Challenges and solutions in desert regions,” *Energy*, vol. 176, pp. 184–194, Jun. 2019, doi: 10.1016/J.ENERGY.2019.03.180.

[5] J. Chen, G. Pan, J. Ouyang, J. Ma, L. Fu, and L. Zhang, “Study on impacts of dust accumulation and rainfall on PV power reduction in

East China," *Energy*, vol. 194, pp. 1–10, 2020, doi: 10.1016/j.energy.2020.116915.

[6] T. Zarei and M. Abdolzadeh, "Optical and thermal modeling of a tilted photovoltaic module with sand particles settled on its front surface," *Energy*, vol. 95, pp. 51–66, Jan. 2016, doi: 10.1016/J.ENERGY.2015.11.045.

[7] Y. Jiang, L. Lu, and H. Lu, "A novel model to estimate the cleaning frequency for dirty solar photovoltaic (PV) modules in desert environment," *Sol. Energy*, vol. 140, pp. 236–240, Dec. 2016, doi: 10.1016/J.SOLENER.2016.11.016.

[8] E. Elshazly, A. A. Abd El-Rehim, A. A. Kader, and I. El-Mahallawi, "Effect of dust and high temperature on photovoltaics performance in the new capital area," *WSEAS Trans. Environ. Dev.*, vol. 17, pp. 360–370, 2021, doi: 10.37394/232015.2021.17.36.

[9] A. M. A. M. S. Eldin, A. K. Abel-Rahman, A. H. H. Ali, and S. Ookawara, "Effect of dust deposition on performance of thin film photovoltaic module in harsh humid climate," in *Proceedings of 2013 International Conference on Renewable Energy Research and Applications, ICRERA*, 2013, pp. 674–679. doi: 10.1109/ICRERA.2013.6749839.

[10] R. H. A. Hamid, Y. Elidrissi, A. Elsamahy, M. Regragui, and K. Menoufi, "Examining the Impact of Different Technical and Environmental Parameters on the Performance of Photovoltaic Modules," *Environ. Clim. Technol.*, vol. 25, no. 1, pp. 1–11, 2020, doi: 10.2478/rtuect-2021-0001.

[11] K. Menoufi, H. F. M. Mohamed, A. A. Farghali, and M. H. Khedr, "Dust accumulation on photovoltaic panels: A case study at the East Bank of the Nile (Beni-Suef, Egypt)," *Energy Procedia*, vol. 128, pp. 24–31, 2017, doi: 10.1016/j.egypro.2017.09.010.

[12] E. T. El Shenawy, H. H. El Ghetany, A. Qasem, and S. Anan, "Effect of Dust Accumulation on the Performance of PV Modules Under Cairo Climate Conditions," *Int. J. Renew. Energy Res.*, vol. 11, no. 3, pp. 1313–1321, 2021, doi: 10.20508/ijrer.v11i3.12266.g8266.

[13] E. Abdeen, E. S. Hasaneen, and M. Orabi, "Real study for Photovoltaic system performance in desert environment - Upper Egypt - case study," in *2016 18th International Middle-East Power Systems Conference, MEPCON 2016 - Proceedings*, 2017, pp. 843–847. doi: 10.1109/MEPCON.2016.7836993.

[14] H. Lu and W. Zhao, "CFD prediction of dust pollution and impact on an isolated ground-mounted solar photovoltaic system," *Renew. Energy*, vol. 131, pp. 829–840, 2019, doi: 10.1016/j.renene.2018.07.112.

[15] K. Chiteka, R. Arora, and V. Jain, "CFD Prediction of dust deposition and installation parametric optimisation for soiling mitigation in non-tracking solar PV modules," *Int. J. Ambient Energy*, vol. 42, no. 11, pp. 1307–1320, 2021, doi: 10.1080/01430750.2019.1594373.

[16] H. Lu and L. Z. Zhang, "Influences of dust deposition on ground-mounted solar photovoltaic arrays: A CFD simulation study," *Renew. Energy*, vol. 135, pp. 21–31, 2019, doi: 10.1016/j.renene.2018.11.096.

[17] H. Lu, L. Lu, and Y. Wang, "Numerical investigation of dust pollution on a solar photovoltaic (PV) system mounted on an isolated building," *Appl. Energy*, vol. 180, pp. 27–36, 2016, doi: 10.1016/j.apenergy.2016.07.030.

[18] H. Jiang, L. Lu, and K. Sun, "Experimental investigation of the impact of airborne dust deposition on the performance of solar photovoltaic (PV) modules," *Atmos. Environ.*, vol. 45, no. 25, pp. 4299–4304, 2011, doi: 10.1016/j.atmosenv.2011.04.084.

[19] H. A. Kazem and 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," *Sol. Energy*, vol. 187, pp. 30–38, 2019, doi: 10.1016/j.solener.2019.05.036.

[20] W. Al-Kouz, S. Al-Dahidi, B. Hammad, and M. Al-Abed, "Modeling and analysis framework for investigating the impact of dust and temperature on PV systems' performance and optimum cleaning frequency," *Appl. Sci.*, vol. 9, no. 7, 2019, doi: 10.3390/app9071397.

[21] A. Gholami, A. Saboonchi, and A. A. Alemrajabi, "Experimental study of factors affecting dust accumulation and their effects on the transmission coefficient of glass for solar applications," *Renew. Energy*, vol. 112, pp. 466–473, 2017, doi: 10.1016/j.renene.2017.05.050.

[22] Bishop and C., *Pattern recognition and machine learning*, vol. 9, no. 4. 2006. doi: 10.1109/TIT.1963.1057854.

[23] M. F. Shaaban, A. Alarif, M. Mokhtar, U. Tariq, A. H. Osman, and A. R. Al-Ali, *A new data-based dust estimation unit for pv panels*, vol. 13, no. 14. 2020. doi: 10.3390/en13143601.

[24] M. K. Shahzad, A. Zahid, T. Rashid, M. A. Rehan, M. Ali, and M. Ahmad, "Techno-economic feasibility analysis of a solar-biomass off grid system for the electrification of remote rural areas in Pakistan using HOMER software," *Renew. Energy*, vol. 106, pp. 264–273, 2017, doi: 10.1016/j.renene.2017.01.033.

[25] H. Rezk, M. Alghassab, and H. A. Ziedan, "An optimal sizing of stand-alone hybrid PV-fuel cell-battery to desalinate seawater at Saudi NEOM city," *Processes*, vol. 8, no. 4,382, 2020, doi: 10.3390/PR8040382.

[26] W. Al-Kouz, S. Al-Dahidi, B. Hammad, and M. Al-Abed, "Modeling and analysis framework for investigating the impact of dust and temperature on PV systems' performance and optimum cleaning frequency," *Appl. Sci.*, vol. 9, no. 7, 2019, doi: 10.3390/app9071397.

Abbreviation and symbols

NPC	**Net present cost**
COE	**Cost of energy**
AQI	**Air quality index**
$C_{ann,tot}$	**Total annualized cost**
E_{served}	**Annual production energy**
i	**Annual real interest rate**
f	**Annual inflation rate**
i'	**Nominal interest rate**
CRF	**Capital recovery factor**
$\mathrm{N_{PV}}$	**Size of PV arrays**
$\mathrm{N_{WT}}$	**Number of wind turbines**
$\mathrm{N_{BAT}}$	**Number of battery storages**