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Optimal Design of a Standalone Hybrid Energy System for a COVID-19 Quarantine Center Energization

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Abstract:

This work is motivated by the need to overcome the electricity crises in Gaza that is initiated in Gaza due to political reasons. In addition, it is related to current situation in the world in particular the spread of COVID-19. Building quarantine centers is one of the most important means used in combating the Corona epidemic, but connecting these centers to the electricity distribution network at the appropriate time is not always possible and increases the burden on the local utility company. This paper proposed a Hybrid off-grid Energy System (HES) to effectively energies the quarantine centers economically and environmentally. To achieve this aim, the load profile of the quarantine center is estimated, the system components are modeled and the system design is optimized. In addition, the developed approach was tested using a real case study considering realistic input data. HOMER-pro program is used to simulate and optimize the system design. The results revealed the potential of the HES to provide environment-friendly, cost-effective, and affordable electricity for the studied quarantine center, as compared to only diesel generators system. For the considered case study, it is found that the PV-Wind-Diesel hybrid power system is able to cover the connected load with the lowest cost in comparison to other possible HES structures. It also environmentally friendly as it has the least harmful emissions. Finally, it is proved that the developed approach gives a reasonable solution to the decision-makers to find a fast, economic and reliable solution to energies the quarantine centers.

KEYWORDS: HOMER, Hybrid Energy System, quarantine center, photo voltaic system, generator, wind turbine, COVID-19.

1. Introduction

Environmentally friendly sources of energy become a necessity to replace traditional fossil fuel in various applications [1, 2]. Researches in renewable energy has been dramatically increased compared to nonrenewable energy sources. The most useable sources of renewable energy are

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solar radiation, wind, hydropower, biomass, and geothermal energies[3].The drawback of using renewable energy specifically solar and wind energy that it is vary from season to season and even during the day[4]. Thus, hybrid energy system (HES) which is an integration of more than one energy source is recommended. HES decreases the effect of greenhouse gas emissions by increasing the renewable energy fraction to cover the electrical load demands[5].

Several studies have been conducted to study different types of hybrid energy systems[6]. Example of HES is an energy system that produces energy from solar system, storage battery and electrical generator[7]. The storage battery is a must to produce stable output of HES that consists of solar energy or wind energy due to the fact that these sources are intermittence sources of energy. A review is given by Sawle et al. [8] for HES based on PV and wind sources of energy. A feasibility study has been conducted by Fazelpour et al. [9] for using various hybrid energy systems in order to assess power requirements of a 125 rooms hotel in Kish Island. Babatunde et al. gave an analysis of an off-grid PV-wind-battery-gasoline generator-HES for a single residential apartment owned by a low-income earner in particular technical, economic and environmental considerations [7]. The results assured that HES is promising technology with high efficiency, environmentally friendly and affordable for low-income household, as compared to using only gasoline generators[7]. In a different study performed in Qeshm Island in Iran[10], authors performed a feasibility study of electrical energy needs using wind-PV-battery HED for a household in Qeshm Island Iran. Using HOMER, results suggested that the optimal configuration based on the lowest net present cost (NPC) cost of energy (COE) is PV-wind hybrid system with battery storage. Different HES models consists of combined sources of energy such as wind, photovoltaic (PV), and diesel generator are proposed for a village in the north-eastern part of Saudi Arabia [11].

HES is cost effective compared to diesel fueled generators which makes them very attractive to low-income countries to adopt them [7]. HES may be stand- alone or in grid system or off grid system. These selection depends on parameters such as grid availability, cost of grid supplied electricity, and meteorological conditions in the application site [12]. A detailed analysis of PV-wind converter HES connected to grid is studied in [13]. Table 1 presents studies that have been carried in different areas in the world. By this review table, we seek to show the importance of using HES in our area as compared to other places in the world.

Table 1. Summary of the literature review on hybrid solar-wind-diesel system, in different countries.

year	Publication	Country	Components	Load kWh/day- kWpeak	Grid	\$/kWh
2015	Gan et al. [14]	Scotland	wind–photovoltaic–diesel	15 kWh/day	Off-grid	0.78
2015	Diab et al.[15]	Egypt	photovoltaic/wind/diesel/ battery	1100 kwh/day	Off-grid	0.19
2020	Alzaid et al.[16]	Saudi Arabia	Wind-solar photovoltaic	5 kW/h	Off-grid	0.33
2019	Major & Oshiemele [17]	Nigeria	wind–diesel	50 MWpeak	Off-grid	0.077
2016	Ani [18]	Nigeria	photovoltaic–diesel	69 kWh/day.	Off-grid	0.745
2019	Nurunnabi et al. [19]	Bangladesh	wind–photovoltaic	2687.54 kwh/day	On-grid	0.097
2019	Nurunnabi et al. [19]	Bangladesh	wind–photovoltaic	1521.37 kwh/day	Off-grid	0.288
2020	Rehman [20]	Saudi Arabia	solar-pv/diesel	11160 kwh/day	Off-grid	0.349
2015	El Khashab & Al Ghamedi [21]	Saudi Arabia	PV - Wind- Fuel cell	16 kwh/day	On-grid	0.36
2015	Jasim et al.[22]	Iraq	Solar PV- Diesel	76 KWpeak	Off-grid	3.43
2019	El Attafi [23]	Morocco	PV - Wind	3626 KWpeak	Off-grid	0.130
2019	Ali and Jang [24]	South Korea	PV-Wind	7.296 MWh/year	Off-grid	0.123
2015	Diab et al. [25]	Egypt	photovoltaic/wind/diesel/ battery	10000 kwh/day	Off-grid	0.17
2020	Silva & Villalva [26]	Brazil	PV-Diesel	6.16 kWh/day 4.08 kWpeak	Off-grid	0.126
2021	Falama et al. [27]	Cameroon	PV/Battery	12,231 Whpeak	On-grid	0.15
2018	Richa & Karaki [28]	Lebanon	Solar PV - Diesel	23 MWpeak/year	Off-grid	0.0081
2021	Canziani et al. [29]	Peru	Photovoltaic/ /diesel/battery	23 kWh	Off-grid	0.267
2013	Bahta [30]	Ethiopia	photovoltaic/wind/diesel/ battery	1,505 kWh/day	Off-grid	0.348
2016	Alayan [31]	Lebanon	PV-diesel	1,775 kWh/day	On-grid	0.12
2021	Maoulida et al. [32]	Comoros	PV-Wind-Diesel	63 kWh/day	Off-grid	0.198
2016	Hassan et al. [33]	Iraq	PV/WIND/DIESEL	93 kWh/day	Off-grid	0.321
2014	Nour & Rohani [34]	UAE	PV-diesel	24MWh/day	Off-grid	0.313
2016	Sawle et al. [35]	China	photovoltaic/wind/diesel/ battery	110.6 kWh/day	Off-grid	0.099
2021	Chauhan et al. [36]	India	photovoltaic/ diesel/battery	89.80 kWpeak	Off-grid	0.261

Considering the cost of the electricity transmission for remote area, stand-alone HES is cost effective for low-income countries. Palestine suffers from lack of traditional energy sources and its energy sector depends on imported power. In 2013, Palestine attained 95% of its power from Israel, 4% from Egypt and 1% from Jordan. Israel provides about 4,485 MW/hour of electrical power to Palestine. Egypt feeds merely 208 MW/hour of electrical power to the Gaza Strip. Jordan supplies 41MW/hour to Jericho[37]. Gaza Strip which has only one local power

station that does not cover the local energy need, forced to purchase its energy needs from Israel. In addition, the power station operates on diesel which imported from Egypt or Israel. In best scenarios, the station produces about 403 GW/hours, 8% of Palestine's electricity purchases and 23% Only from the Gaza Strip's purchases of electrical energy, as in 2013[37]. Moreover, population growth in Palestine added an extra burden on the Palestinian power sector where demand on energy increases dramatically. Thus, an alternative energy sources are required to achieve energy security. The major renewable energy resources in Palestine are solar, wind energy, geothermal and biomass[38].

Solar energy is promising source of energy to supply energy to the Palestinian local inhabitants. Palestine lies on the hot belt where it is shiny most of the year (~ 3,000 hours per year) and received 5.4 kWh/m of an average solar radiation. In Palestine, almost 57% of houses and apartments are using domestic solar water heating (SWH) [37]. SWH is made locally in Palestine where about 24,000 units is produced annually which satisfy the Palestinian market needs[39].

The renewable wind power type offers a feasible and cheap solution to distribute power generators over wide areas world- wide. Electricity generation by using wind energy depends on the wind speed. Gaza Strip is characterized by a very low wind speed throughout the year, with an annual average of about 2.5–3.5 m/s[40]. Therefore, wind energy is suitable if jointly operated with solar cells and diesel generators. Though, studies emphasizes the importance of wind energy in the future, only few studies related to wind energy potential in Palestine were performed in the past, and these studies mainly depended on historical data and data from automated meteorological stations[41]. In Palestine, there is a wind turbine which is used to power generation in the Al-Ahli Hospital (AAH) in the city of Hebron (Al-Khalil), south of the West Bank where wind speed in the region varies between 7 and 10 m/s, with an average value of 6.2 m/s[42]. In the Gaza Strip, the uses of wind energy to generate electricity are limited to educational applications only. Some individuals have made initiatives on their own by taking the responsibility of installing small-wind turbines on the roofs of their houses to generate electricity for household's consumption. A group of Al-Azhar University students and another group of Islamic University students are succeeded in completing their university graduation from the Faculty of Engineering by completing a project to generate electrical energy through wind[43].

Recently, several studies in Palestine, considered adopting HES. In 2019, researchers investigated the techno-economic possibilities of the integration of photovoltaic solar with the

existing diesel generators at Nasser Hospital in Gaza[44]. The simulation results showed that the new system will not only cause operating cost reduction but also rapidly curb toxic emissions and environmental pollutions[44]. In a different study, researchers proposed PV-battery-diesel generator off-grid HES at local university (Islamic University of Gaza) as alternative for utility power system which feed the power to the university[45]. They present comparison between the two systems showing that HES contribute to reducing emissions caused by non-renewable energy sources[45].

In 2013, Alaydi presented a parametric study of solar and wind energy in Gaza Strip. The wind power was compared with the monthly mean solar radiation energy. [46]. It has been noticed, that a large stand-alone PV or wind energy converter will be required to meet the peak load in the months June to September. A study performed to compare between different PV systems installed in different location in Gaza strip in particular in The Islamic University of Gaza (IUG), Al Azhar University (AAU) and Deir Elatin School (DES) [47].The simulation results of IUG system showed mainly that the rated power of the system inverters was oversized. In the case of DES system, The simulation results showed that the system has a valid economic feasibility during permanent availability of the utility grid and has no benefit during utility grid outage periods[47]. Regarding AAU system, there was no practical method to obtain an accurate load data so, the simulation could not performed and it was suggested as a future work[47].

Economic and Environmental Feasibility of the Renewable Energy in the Gaza Strip and an overview of renewable energy potential in Palestine are investigated in[39, 40, 48, 49].A Review of Solar Energy Prospects in Palestine was presented by[38]. An Overview of Wind Energy Potentials in Palestine was introduced in [41, 42, 50, 51]. A review of challenges and opportunities of solar and wind energy HES is given by Al Badwawi et al. [52]. Major power quality issues are voltage and frequency fluctuation, and harmonics for both grid-connected and stand-alone systems [53].These can be mostly overcome by choosing the suitable design, advanced control systems and optimization of HES[52].

This present work is motivated by the current situation in the world in particular the spread of COVID-19. World Health Organization (WHO) first learned of this new virus from cases in Wuhan, People's Republic of China on 31 December 2019[54]. Since the outbreak of the Corona virus in the world (in March 2020), specifically in the neighboring countries, the Ministry of Health(MOH) in Gaza Strip has worked from the first moment to take all necessary precautionary

and preventive measures to combat the Corona pandemic[53]. MOH has been prepared a policy to regulate the relationship between quarantine centers and hospitals, mechanisms for transporting patients to and from the quarantine center and hospitals, and dealing with cases coming from the border crossings, especially the Rafah crossing, by isolating suspected cases in the crossing's isolation rooms[53]. Infected people are distributed to different places in Gaza Strip for example in local hospitals and hotels. In august 2020, MOH in Gaza strip built Dier El Balah quarantine center which is located on Dier El Balah town in the Mediterranean coasting central Gaza. It consists of 165 caravans (room), each room can be occupied by three persons. Thus total occupancy is about 495 persons [55]. In case COVID-19 pandemic is finished, these places will be used for summer camps or creation centers. Dier El Balah quarantine center is powered by diesel generators and from utility grid which exhaust the budget of the MOH.

The novelty of the current work is by introducing off grid new HES for quarantine center which might be used later as creation center. Thus, we presented different HES for Dier El Balah quarantine center in mid in Gaza Strip to find the most effective system to power the center. The proposed systems are different combination of diesel generator, wind, PV HES systems. The proposed systems are constructed, analyzed and compared to find the optimal alternative system according to minimum cost of energy and least environmental impact. In order to optimize the HES, several local inputs in hourly base are feed to HOMER Pro software including average wind speed, total solar radiation, and load data. HOMER Pro software is used to solve size and cost problems. Proposed system has reasonable environmental benefits, attractive payback period and less emission.

It is worth mentioning that this problem was initially investigated in [56]. Due to the valuable results that were published in [56], the work is heavily extended in this paper to include further interstation of the proposed system. the theoretical back ground of the work. In comparison to the above studies, the major contributions of this study can be summarized as follows – theoretical back ground of the work—details investigation of different proposed scheme- and Co₂ emission.

2. Modelling of the HES System

The proposed system to be studied, as shown in Fig. 1, consists of a PV-system, wind turbines, and multiple diesel generators (DGs) as well as the connected loads. The mathematical model of the major components of the system are modeled below in detail.

Figure 1. The schematic of the studied HES

2.1 PV-system:

The PV panel is the responsible party of the solar system to convert the solar power to an electrical one. The produced power by a PV panel is calculated as follows [57];

$$P_{PV} = Y_{PV} * f_{PV} * \frac{G_{PV}}{G_{ref}} * \left(1 + K_T(T_C - T_{ref})\right) \quad (1)$$

where P_{PV} represents output power, Y_{PV} (kW) is the yield at standard conditions, f_{PV} is the rated capacity (%), G_{PV} and G_{ref} are the incident solar energy on PV at current time and standard conditions (1 kW/m²), respectively. K_T is the temperature coefficient of the maximum power (%/°C) and T_C and T_{ref} are temperatures of the PV surface at standard conditions, respectively. The derating factor considered is around 80%. In this study, the ground reflectance is equal to 20%.

2.2 Wind Turbines

The generated power by a wind turbine varies with wind speed and wind turbine structure. Based on [33] the generated power by a wind turbine can be formulated as follows

$$P_{wind} = \frac{1}{2} \rho A V C_p(\lambda, \beta) \eta_t \eta_g \quad (2)$$

where ρ is air density, A is the rotor area in m², V is wind velocity in m/s, C_p is performance density of air coefficient of the turbine and η_t and η_g are the efficiencies of wind turbine and the generator, respectively.

2.3 Load profile

Based on the current recommendations from Palestinian Ministry of Health, the quarantine period is at least 14 days and maybe reach 21 days. Therefore, the proposed appliances for each tenant in the quarantine center should provide an adequate comfort level during his stay. In this study, air conditioners, heaters, refrigerators, washing machines, and light are selected as the specified appliances for a tenant in the quarantine center. The estimated power consumption of the nominated applicants as stated in Table 2.

Table 2. Typical appliance rating power in a quarantine center

Electrical device	Power (W)
Air Conditioner12000BTU	1060
Heater(40L)	2500
Heater (2 L)	2200
Refrigerator(6 cu.ft)	150
Washing Machine	1500
Inner light	40
Outer light	100

3. Optimal Design Approach

As discussed before the HES system should be designed to cover the connected loads economically and environmentally simultaneously. In the proposed approach the PV system size PV_{size} , the diesel generator size DG_{size} , the number of the diesel generators N_{DG} , the number of the wind turbines N_w should be optimized to minimize the capital cost of energy and the harmful gas emissions. Therefore, the optimal design problem can be formulated as follows

$$\min_{PV_{size}, DG_{size}, N_{DG}, N_w} COE + Gas_{em} \quad (3)$$

Subject to

$$PV_{size.min} < PV_{size} < PV_{size.max}$$

$$N_{w.min} < N_w < N_{w.max}$$

$$DG_{size} \in DG_{set.given}$$

Where $DG_{set.given}$ is the given set for the possible diesel generators to be installed by the user. Moreover, the COE equals the total-annualized cost of the consumed energy $C_{ann.tot}$ divided by the total served energy by the system E_{served} as follows

$$COE = \frac{C_{ann.tot}}{E_{served}}. \quad (4)$$

Form another side the studied harmful gas emissions includes the Carbon dioxide (CO_2), Carbon Monoxide (CO), Unburned Hydrocarbons, Particulate Matter, Sulfur Dioxide, and Nitrogen Oxides.

2 Case study

The proposed HES is to power the quarantine center locate in Dier El Balah city at the middle of Gaza strip, Palestine at $31^{\circ}24'35.03''N$ and $34^{\circ}21'6.25''E$ as shown in figure 2. Presently, the quarantine center is powered by diesel generator and by power line from Gaza electricity distribution company (GEDCo). Gaza imports diesel causing high price for electricity production by diesel generator and urging the exploration of alternative sources of energy in particular renewable energy to meet load demands. The input data that are used to simulate and analysis the HES as well as the designs results of different HES configurations are discussed in the following sections.

Figure 2. Dier El Balah location

The load inputs are given to Homer-Pro system to do the simulation and obtain the optimal solution. Figure 3 a) shows the interaction between simulation and optimization, and b) presents key information for the modeling.

Figure 3: a) Interactions between Simulation and Optimization b) Key information for modelling

4.1 Input Data

4.1.1 Load profile

The Dier El Balah quarantine center consists of 165 rooms. Dier El Balah quarantine center Load demand is calculated based on the appliances given in Table 2. The usage time for each appliance is assumed according to weather conditions and client demand. It is also considered that each room has an air conditioning, heaters (40L and 2L), inner light and a Refrigerator. Moreover, there is 16 washing machines and 20 outer lights. HOMER-Pro program is used to obtain the daily load profile as given in figure 4. The total daily energy consumption kW/day is found to be 3952 kW/day.

Figure 4. Daily electrical load profile for the study site (HOMER-Pro calculations).

4.1.2 Renewable Energy in Gaza

In Dier El Balah, Gaza strip, the wind velocity profile found in[41, 50]. Figure 5 exhibits the average wind speed per month for the study site. It can be seen from Figure 5, that the site experiences the minimum and maximum speed values of 3.99 m/s and 5.41 m/s in August and February respectively. The average yearly wind speed equals 4.68 m/s.

Figure 5. Average wind speed per month at the study location

The solar irradiance at the location of the study is found in [38]. Solar radiation and temperature data are taken from HOMER-Pro website. The global horizontal irradiation (GHI) at the site is used to calculate the output of the flat panel PV array and is shown in Figure 6. The solar radiation maximum occurs in June and July with a yearly average of 7.985 kWh/m²/day. The annual average solar GHI of Dier El Balah location is equal to 5.57 kWh/m²/day as in figure 6. The clearness index, fraction of radiation on earth to space radiation, is shown in brown curve with black dots in figure 6 as calculated by HOMER-Pro. Its value, between 0 and 1, depends on the atmospheric conditions such as water vapor content and clouds distribution. the clearer the sky is the higher clearness index.

Figure 6. Solar GHI data the study site

4.2 System DESIGN and RESULTS

4.2.1 Power system consists of two Diesel generators:

The techno-economics analysis for two AC-diesel generators with 500 kW and 250 kW ratings (current situation on site) are conducted using HOMER-Pro. The input parameters are summarized in Table 3. The two generators have 20000 h lifetimes, 25% minimum load ratio, and 1.47 US\$/l fuel cost. Figure 7 presents the schematic diagram of the proposed design where the two generators are connected to the load via AC bus line.

Table 3. Input parameters for the two diesel generators.

Item AC generators	CAT-500 kW	CAT-250 kW
Generator capacity (kW)	500	250
Capital cost (US\$/kW)	120	60
Replacement cost (US\$/kW)	90	45
Operation and Maintenance cost, (US\$/h)	1	0.5

Table 4 displays HOMER-Pro simulation results where the first row shows the results for using two generators compared to using one generator second row (base system). Table 4 indicates that the optimal cost of electric energy occurs when operating the two generators and equals 0.43 US\$/kWh. In this case CAT-500 kW and CAT-250 kW operated for 1248 hours and 7512 hours per year respectively and 413,184 liters of fuel were used which is lower than the base system. The

net present cost (US\$) of the optimal system as calculated by HOMER-Pro is 8.06 M, which is lower than the net present cost (US\$) of the optimal system which is 9.3 M. The optimal system has lower CO₂ (kg/yr) emission compared to base system where it is found the optimal system emit 1091.681 kg/yr and base system emit 467781 kg/yr.

Figure 7. diesel-only system

Table 4 presents that the value of total energy generated in one year (1,444,039 kWh/yr) is jointly produced by the two generators where 22.5 % and 77.5% of energy production was generated by CAT-500 kW and CAT-250 kW generators respectively. Accordingly, there are 1486 KWh/year excess energy.

Table 4. Simulation results of diesel only case.

Architecture/CAT-500 (KW)	Architecture/CAT-250 (KW)	Cost/COE (\$)	System/Total Fuel (L/yr)	CAT-500/Hours	CAT-500/Production (kWh)	CAT-500/Fuel (L)	CAT-500/Fuel Cost (\$/yr)	CAT-250/Hours	CAT-250/Production (kWh)	CAT-250/Fuel (L)	CAT-250/Fuel Cost (\$/yr)
500	250	0.432299	413184	1248	325533.9	93372.09	137257	7512	1118505	319812	470123.5
500	-	0.498558	467780.6	8760	1508740	467780.6	687637.4	-	-	-	-

4.2.2 Wind-diesel generatorHES:

To reduce diesel dependency and reduce air pollution in Gaza, the system that analyzed in 4.2.1. is integrated with 8 wind turbines (symbolled by ES25IIA in Figure 8) each has 3 blades

and produce 25 kW. Thus, total power by 8 wind turbines is 200 kW. The wind turbine considered in this study has 30 m rotor diameter and 30 m hub height. The cut-in wind speed is 3.5 m/s and rated wind speed is 12 m/s with 20 years' service-life. Each wind turbine has capital cost equals 40,000 US\$ with 2000 US\$/year for operation and maintenance cost.

Figure 8. Wind-diesel hybrid power system

Table 5 displays HOMER-Pro simulation results of the wind-diesel generators HES. The optimal HES consists of two diesel generators and 8 wind turbines with minimum cost of energy (COE) equals 0.377 US\$/kWh (first line). This is lower than the COE of the diesel generators only (COE=0.43 US\$/kWh). It can also be noticed that by using wind-diesel generators HES there is a reduction in consuming diesel by 332164 liters compared to using the diesel generators only which consume 413,184 liters saving of 81020 liters/yr. Moreover, the total diesel generators operating time in the optimal system is lower than the operating time of diesel generator only system by 30 hours in the year where this system operates 8730 hours while diesel only system operates 8760 hours.

The HES produced 1,538,335 kWh electricity/yr where 28.2% of energy produced by wind turbines, 11.8% and 60% of energy produced by 500 kW and 250 kW generators, respectively. An excess energy equals 95782 kWh/yr is produced by wind-diesel HES as compared with base system. The total capital cost of the wind-diesel HES equals 402,500 US\$/yr and the total replacement and operation and maintenance costs are 52,952 US\$/yr and 268,065 US\$/yr, respectively. Where the replacement cost for wind turbines and diesel generators are considered

zero and 52,952 US\$/yr, respectively. And the operation and maintenance cost for wind turbines and diesel generators are 206,840 US\$/yr and 61,225 US\$/yr, respectively.

Table 5. Simulation results of wind-diesel hybrid power syst

Architecture/EO25IIA	Architecture/CAT-500 (kW)	Architecture/CAT-250 (kW)	Cost/COE (\$)	System/Total Fuel (L/yr)	CAT-500/Hours	CAT-500/Production (kWh)	CAT-500/Fuel (L)	CAT-500/Fuel Cost (\$/yr)	CAT-250/Hours	CAT-250/Production (kWh)	CAT-250/Fuel (L)	CAT-250/Fuel Cost (\$/yr)	EO25IIA/Production (kWh/yr)
8	500	250	0.377237	332164	742	181904.5	52700.63	77469.92	7988	922960	279463.4	410811	433470.7
	500	250	0.432299	413184	1248	325533.9	93372.09	137257	7512	1118505	319811.9	470124	
8	500		0.476996	418963.3	8730	1308225	418963.3	615876.1					433470.7
	500		0.498558	467780.6	8760	1508740	467780.6	687637.4					

4.2.3 PV-diesel generatorHES:

In this section, a solar PV-diesel generator HES is proposed (Figure 9) and analyzed using HOMER-Pro. In Figure 9, CS6X represents PV panels. The load data and diesel generators inputs are kept the same as section 4.2.1. Solar radiation data, discussed in section 4.1.2, and PV panel related technical specifications (table 6) have been considered as input. A 30 years lifetime 325 W PV panel cost is taken as 180 US\$. PV efficiency is 16.17 %, and its derating factor is 80%. The replacement cost and the capital cost are chosen to be equal and 1 US\$/yr per PV panel is assigned for operation and maintenance cost. The PV panels tilt angle (angle with ground) was taken to be equal 30.9° and the ground reflectance was chosen to be 20%. The total capacity of the PV panel is considered 150 kW. The inverter capacity is also equal 150 kW. The inverter cost equals 5000 US\$/30 kW and its maintenance cost is 0 US\$/year per 30 kW. The technical specifications of the inverter are listed in Table 6. The life time and efficiency of the inverter was considered as 20 years and 93%, respectively.

Table 6. PV module specifications.

PV array	
Item description	Value
Brand Name	Canadian
Maximum Power at STC (Pmax)	325Wp
Optimum Operating Voltage (Vmp)	39.1V
Optimum Operating Current (Imp)	10.42
Open Circuit Voltage (Voc)	45.8 V
Short Circuit Current (Isc)	9.28 A
Module Efficiency	16.17%
Operating Module Temperature	40 °C to +85 °C
Maximum System Voltage	1000 V DC
Maximum Series Fuse Rating	20 A
Price	180 \$
Inverter	
Brand Name	STP
Max. DC power / DC rated power	25550 W / 25550 W
Max. input voltage 1000 V	Max. input voltage 1000 V
Output Wave	Pure Sine Wave
Output Voltage	230VAC
Output Frequency	50Hz/60Hz
System Voltage	48VDC
Solar Charger	60A, MPPT
AC Charger	60A @ 48VDC
Max. Efficiency	93%

Figure 9: PV-diesel hybrid power system

Table 7 shows that the optimal solution (from HOMER-Pro analysis) has minimum COE equals 0.38 US\$/KWh which consists of 150 kW PV modules, two generators and 150 kW inverter. The COE for this system is lower than diesel generator system but higher than that of the wind-diesel hybrid system. In the PV-diesel generator HES, 18.6% of total energy is produced by PV systems. Diesel consumption was increased to 357088.26 liters compared to 332164 liters in case of wind-diesel HES but lower than 413,184 liters in case of diesel generator only system. Thus, the PV-diesel generator HES saved 56096 liters compared with diesel generator only system.

Table 7. HOMER-pro results for PV-diesel HES.

CS6X-325P (kW)	CAT-500 (kW)	CAT-250 (kW)	Inverter (kW)	Cost/NPC(\$)	Cost/COE (\$)	Cost/Operating cost (\$/yr)	Cost/Initial capital (\$)	System/Ren Frac (%)	System/Total Fuel (L/yr)
150	500	250	150	7103314	0.380903	534730.5	190576.9	16.59099	357088.3
-	500	250	-	8061773	0.432299	617231.7	82500	-	413184
150	500	-	100	8741314	0.468738	663822	159743.6	5.355938	433109.2
-	500	-	-	9297429	0.498558	714555.6	60000	-	467780.6

The solar PV panels produced a total of 274500kWh while a diesel generators produces a 1203219kWh of electricity of the total of 1477719kWh during one year operation. This means that solar energy and diesel generators contributed by 18.6% and 81.4% of the total energy, respectively. Of this total energy, 28857kWh (1.95%) is surplus. The total capital cost of the HES is 190,577 US\$ as follows; 83077 US\$ PV system cost, 25000 US\$ inverter cost, and 82,500 US\$ diesel generators cost. The replacement cost of HES is 67,382 US\$ due to diesel generator and

PVsystem while a replacement cost for inverter is zero. The total operation and maintenance cost of the HES for one year is 67,501 US\$ (1293 US\$ for PV, 63623 US\$ for diesel generators, and 2586 US\$ for the inverter).

4.2.4 Wind-PV-diesel generator HES:

Figure 10 displays a wind-PV-diesel generator HES. In the HES, the wind turbine capacities are taken to be 25, 50, 75, 100, 125, 150, 175, and 200 kW; PV system capacities are taken to be 50, 100 and 150 kW; inverter capacities are considered to be 50, 100 and 150 kW; and the two generators are 250 kW and 500 kW. The system was simulated using HOMER-Pro software to reveal the optimal HES with minimum COE. Table 8 presents the simulation results that showed the minimum COE of 0.348 US\$/kWh is obtained for a HES consists of 8 wind turbine (200 kW), 150 kW PV panels, 150 kW inverter, and two diesel generating of 750 kW rated power. The initial capital cost of this HES is 510,576 US\$ where the contributions of wind energy, solar PV, inverter, and diesel generators are 320,000 US\$, 83,076 US\$, 25,000 US\$, and 82,500 US\$, respectively. The total replacement cost of 55,918 US\$ is due to diesel generator. The total operation and maintenance cost is 268,737 US\$, i.e., 25.6% for wind turbines, 1.2% for inverters, and 70.7% for diesel generators.

The wind-PV-diesel generator HES generates 1659038 kWh of electricity. The total energy requirement of 1442553 kWh which means a surplus of 212553 kWh of energy/yr. The total amount of energy are an integration of wind, solar and diesel generators outputs which are 427276 (25.8%), 274500 (16.5%), and 857263 kWh (57.7%), respectively. The cost of the fuel consumed during the year is 437,828.769 US\$.

Figure 10. wind - PV-diesel hybrid power system

Table 8: HOMER-Pro simulation output for wind-PV-diesel generator HES.

PV (kW)	Wind converter (kW)	Diesel generator 500 (kW)	Diesel generator 250 (kW)	Inverter 30 (kW)	Cost/COE (\$)	System/Total Fuel (L/yr)
150	8	500	250	150	0.3480626	297842.7
150	-	500	250	150	0.3807641	357088.3
150	4	500	-	100	0.462685	413403
150	-	500	-	100	0.4686452	433109.2

5 Environmental factor

Utility company in Gaza Strip, Palestine (GEDCo) that distribute energy to local costumers in Gaza strip receive energy manly form Israel and Egypt and locally from the only local power station. The local station relies on diesel to generate electricity, the emission factor for producing electricity is more than 0.81 kg CO₂ / kWh due to the old technologies and equipment used at the station[58]. The emission factor includes carbon monoxide, unburned hydrocarbons, particulate matter, proportion of fuel sulfur converted to PM (%), and nitrogen oxide. According to HOMER-Pro simulation results the types and values of greenhouse gases (GHG) (kg/yr) for the proposes systems are listed in table 9.

Table 9: Output Emission for each system

Pollutant	Diesel generators	Wind- Diesel generators	PV- Diesel generators	Wind - PV- Diesel generators
Carbon dioxide (CO ₂) (Kg/yr)	1,091,618	877,475	943,404	786,803
Carbon Monoxide (CO) (Kg/yr)	947	816	826	735
Unburned Hydrocarbons(Kg/yr)	38	32.3	33.1	29.1
Particulate Matter(Kg/yr)	40.8	33.9	35.4	30.5
Sulfur Dioxide(Kg/yr)	2,710	2,179	2,342	1,954
Nitrogen Oxides(Kg/yr)	7,837	6,304	6,773	5,653

We can see that the emissions are reduced significantly when using renewable energy in addition to diesel generator. The best case with the lowest harmful emission is when using wind-pv-diesel generator hybrid system.

6 Conclusions

A new Hybrid energy system for Dier El Balah quarantine center in Gaza Strip is proposed. HOMER-Pro software is used to analyze, simulate and evaluate the proposed systems. The choice of quarantine center in Deir al-Balah as a case study of our study because Gaza Strip has shortages in electric power and at the same time it faces the COVID-19. Thus, to provide quarantine center with electricity is a challenging task. In this work, we present four HES which are diesel generators only, wind-diesel generators HED, PV-diesel generator HES, and wind-PV-diesel HES. In the analysis, the fuel cost is considered equal to 1.47 US\$/L while looking for the optimal HES with minimum COE. The results for different HES are given in Table 10. The result shows that the lowest COE is 0.348 US\$/kWh in case of PV-Wind- Diesel generator HES. Fuel consumed and fuel cost of PV-Wind-Diesel hybrid power system is the lowest value. In addition, this system has the least harmful emission. Therefore, PV-Wind- Diesel generator HES is the most economical and environmentally friendly system.

Table 10. Comparison between different HES at a fuel cost of 1.47 US\$/L.

Item description	Diesel only	Wind-Diesel	PV-Diesel	Wind-PV-Diesel
Renewable penetration,	0	28.2	18.6	42.3
COE, (US\$/kWh)	0.43	0.377	0.38	0.348
Fuel consumed, (L/Yr)	413184	332164	357088.3	297842.7
Fuel cost, (US\$/Yr)	607380.48	488281.08	524919.801	437828.769
Capital cost, (US\$)	82,500	402,500	190,577	510,576

Declarations

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Authors' contributions: H. Kh. formulated the idea of the work, presented the theoretical background, wrote and edited the paper. F. B. shared in collecting data, made the simulation, shared in writing the paper. R. Kh. Shared in collecting data, helped in writing and editing the paper. M. R. shared in presenting the theoretical background, shared in editing the work.

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Code availability: HOMER-Pro software

References

1. Inayat, A., Nassef, A. M., Rezk, H., Sayed, E. T., Abdelkareem, M. A., Olabi, A. G., *Fuzzy modeling and parameters optimization for the enhancement of biodiesel production from waste frying oil over montmorillonite clay K-30*. Sci Total Environ, 2019. **666**: p. 821-827.
2. Jaisin, C., Intaniwet, A., Nilkhoa, T., Maneechukate, T., Mongkon, S., Kongkraphan, P., Polvongsri, S., *A prototype of a low-cost solar-grid utility hybrid load sharing system for agricultural DC loads*. International Journal of Energy and Environmental Engineering, 2019. **10**: p. 137-145.
3. Salameh, T., Abdelkareem, M. A., Olabi, A. G., Sayed, E. T., *Monadhil Al-Chaderchi, Hegazy Rezk, "Integrated standalone hybrid solar PV, fuel cell and diesel generator power system for battery or supercapacitor storage systems in Khorfakkan, United Arab Emirates*. International Journal of Hydrogen Energy, 2021. **46**(8): p. 6014-6027.
4. Diab F, L.H., Zhang L, Ali S. , *An Environmentally-Friendly Tourist Village in Egypt Based on a Hybrid Renewable Energy System—Part One: What Is the Optimum City?* Energies, 2015. **8**(7): p. 6926-6944.
5. Bahramara S, M.M., Haghifam M. , *Optimal planning of hybrid renewable energy systems using HOMER: A review*. Renew Sustain Energy Rev, 2016. **62**: p. 609e20.
6. Dreglea, I., Foley, A., Häger, U., Sidorov, D., Tomin, N., *Hybrid renewable energy systems, load and generation forecasting, new grids structure, and smart technologies*, in *Solving Urban Infrastructure Problems Using Smart City Technologies*, J.R. Vacca, Editor. 2021. p. 475-484.
7. Babatunde, O.M., Munda, J. L. and Hamam, Y. *Hybrid energy system for low-income households*. in *IEEE Africon 2017*. 2017. Cape Town: IEEE.
8. Sawle, Y., Gupta, S.C., Bohre, A. K., *Review of hybrid renewable energy systems with comparative analysis of off-grid hybrid system*. Renewable and Sustainable Energy Reviews, 2018. **81**(2): p. 2217-2235.
9. Fazelpour, F., Soltani, N., Rosen, M.A. , *Feasibility of satisfying electrical energy needs with hybrid systems for a medium-size hotel on Kish Island, Iran*. Energy exploration and exploitation, 2014. **73**: p. 856–865.
10. Fazelpour, F., Shariatzadeh, M. and Soltani, N. . *Techno-economic feasibility of grid-connected photovoltaic power plant in Qeshm Island, Iran*. in *2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC)*. 2016. Florence, Italy.

11. Rehman, S., El-Amin, I., *Study of a solar pv/wind/diesel hybrid power system for a remotely located population near Arar, Saudi Arabia*. Energy exploration and exploitation, 2015. **33**(4).
12. Erdinc, O., Uzunoglu, M., *Optimum design of hybrid renewable energy systems: Overview of different approaches*. Renewable and Sustainable Energy Reviews, 2012. **16**: p. 1412-1425.
13. Palej, P., Qusay, H., Kleszcz, S., Hanus, R., Jaszczur, M., *Analysis and optimization of hybrid renewable energy systems*. POLITYKA ENERGETYCZNA – ENERGY POLICY JOURNAL, 2019. **22** (2): p. 107–120.
14. Kit Gan, L., Shek, J., Mueller, M., *Hybrid wind–photovoltaic–diesel–battery system sizing tool development using empirical approach, life-cycle cost and performance analysis: A case study in Scotland*. Energy Conversion and Management, 2015. **106**: p. 479–494.
15. Diab, F., Lan, H., Zhang, L., Ali, S., *An environmentally friendly factory in Egypt based on hybrid photovoltaic/wind/diesel/battery system*. Journal of Cleaner Production, 2016. **112**: p. 3884-3894.
16. Alzaid, O.S., Salim, B., Orfi, J., Khan, S., Alshehri, H., *Hybrid Solar and Wind Power Generation in Saudi Arabia*. Energy and Environment Research, 2020. **10**(2): p. 25-38.
17. Major, I.E., Oshiemele, B., *Simulation Of Wind-Diesel Hybrid Power System For A Rural Community In Nigeria*. Nigerian Journal of Technology (NIJOTECH), 2019. **38**(3): p. 636 – 646.
18. Ani, V.A., *Design of a Reliable Hybrid (PV/Diesel) Power System with Energy Storage in Batteries for Remote Residential Home*. Journal of Energy, 2016. **4**: p. 1-16.
19. Nurunnabi, M., Roy, K., Hossain, E., Pota, H. R., *Size Optimization and Sensitivity Analysis of Hybrid Wind/PV Micro-Grids- A Case Study for Bangladesh*. IEEE Access, 2019. **7**: p. 150120-150140.
20. Rehman, S., *Hybrid power systems – Sizes, efficiencies, and economics*. Energy Exploration & Exploitation, 2021. **39**(1): p. 3–43.
21. El Khashab, H., Al Ghamedi, M., *S2314-7172(15)00022-7,P:1-12., Comparison Between Hybrid Renewable Energy Systems in Saudi Arabia*. Journal of Electrical Systems and Information Technology, 2015. **2**(1): p. 111-119.
22. Jasim, K., Abdul-hussien, M., Sarhan, M., *Design of Hybrid Solar PV Diesel Mini Grids in Iraq*. Journal of the College of Basic Education, 2015. **21**: p. 109-128.
23. El Attafi, S., *Design and Optimisation Of a Hybrid System (PV and Wind) With Grid Connection: Case Study a Typical Refrigeration Unit*. 2019, Al Akhawayn University: Moraco. p. 63.
24. Ali, S.a.J., C., *Evaluation of PV-Wind Hybrid Energy System for a Small Island*, in *Wind Solar Hybrid Renewable Energy System*, K. Okedu, Tahour, A. and Aissaou, A., Editor. 2020, Intechopen: United Kingdom.
25. Diab, F., Lan, H., Zhang, L., Ali, S., *An Environmentally-Friendly Tourist Village in Egypt Based on a Hybrid Renewable Energy System—Part One: What Is the Optimum City?* Energies, 2015. **8**(7).
26. Costa, T.S., Villalva, M. G., *Technical Evaluation of a PV-Diesel Hybrid System with Energy Storage: Case Study in the Tapajós-Arapiuns Extractive Reserve, Amazon, Brazil*. Energies, 2020. **13**(11).
27. Falama, R., Welaji, F., Dadjé, A., Dumbrava, V., Djongyang, N., Salah, C., Doka, S., *A Solution to the Problem of Electrical Load Shedding Using Hybrid PV/Battery/Grid-*

- Connected System: The Case of Households' Energy Supply of the Northern Part of Cameroon*. Energies, 2021. **14**(10).
28. Richa, A., Karaki, S. H. . *Optimal Design of Hybrid Renewable Energy Systems in Lebanon*. in *2018 IEEE International Multidisciplinary Conference on Engineering Technology (IMCET)*. 2018.
 29. Canziani, F., Vargas,R., Gastelo-Roque,J., *Hybrid Photovoltaic-Wind Microgrid With Battery Storage for Rural Electrification: A Case Study in Perú*. 2021. **8**(347).
 30. Bahta, S., *Design and Analyzing of an Off-Grid Hybrid Renewable Energy System to Supply Electricity for Rural Areas (Case Study: Atsbi District, North Ethiopia)*, in *Division of Heat and Power Technology*. 2013, KTH School of Industrial Engineering and Management: Stockholm p. 96.
 31. Alayan, S. *Design of a PV-Diesel Hybrid System with Unreliable Grid Connection in Lebanon*. 2016.
 32. Maoulida, F., Rabah, D., El Ganaoui, M., Aboudou, K. , *PV-Wind-Diesel System for Energy Supply on Remote Area Applied for Telecommunication Towers in Comoros*. Open Journal of Energy Efficiency, 2021. **10**: p. 50-72.
 33. Hassan, Q., Jaszczur, M., Abdulateef, J., *Optimization of PV/WIND/DIESEL Hybrid Power System in HOMER for Rural Electrification*. Journal of Physics: Conference Series, 2016. **745**: p. 032006.
 34. Nour, M., Rohani, G., *Prospect of Stand-Alone PV-Diesel Hybrid Power System for Rural Electrification in UAE*. International Journal Of Renewable Energy Research, 2014. **4**(3): p. 749 – 758.
 35. Sawle, Y., Gupta, S.C., Bohre, A. K., *PV-wind hybrid system: A review with case study*. Cogent Engineering, 2016. **3**(1): p. 1189305.
 36. Chauhan, A., Upadhyay, S., Khan, M.. T. , Hussain, S. M. S. and Ustun, T. S., *Performance Investigation of a Solar Photovoltaic/Diesel Generator Based Hybrid System with Cycle Charging Strategy Using BBO Algorithm*. Sustainability, 2021. **13**: p. 8048.
 37. Palestinian Central Bureau of Statistics, G.A.o.G.S., Department of Natural Resources Statistics, *Renewable energy in Palestine*. 2015: Palestine. p. 1-5.
 38. Ajlouni, E., Alsamamra, H., *A Review of Solar Energy Prospects in Palestine*. American Journal of Modern Energy, 2019. **5**(3): p. 49-62.
 39. Yaseen, B.T., *Renewable Energy Applications in Palestine*. 2015: Palestine.
 40. Juaidi, A., Montoya, F. G., Ibrik, I. H., Manzano-Agugliaro, F., *An over view of renewable energy potential in Palestine*. Renewable and Sustainable Energy Reviews, 2016. **65**: p. 943-960.
 41. Albisher, H., Alsamamra, H., *An Overview of Wind Energy Potentials in Palestine*. Journal of Energy and Natural Resources, 2019. **8**(3): p. 98-108.
 42. Salem, H.S., *The potential of wind energy in Palestine with healthcare and residential examples int he West Bank and the Gaza Strip*. Journal of Nature Science and Sustainable Technology, 2019. **13**(2): p. 74-97.
 43. AlwatanVoice. 24 sep 2011.
 44. Abu taha, J., Shaheen, H. *PV Diesel Hybrid Energy Supply for Nasser Hospital in Gaza Strip*. in *2019 IEEE 7th Palestinian International Conference on Electrical and Computer Engineering (PICECE)*. 2019. Gaza, Palestine: IEEE

45. Abu Dabousa, T.I., Abdelati, M. M. , *Modelling, Simulation, and Optimization of a Hybrid PV Solar System*. Journal of Al Azhar University-Gaza (Natural Sciences), 2018. **20**(2): p. 63-80.
46. Alaydi, J.Y., *A parametric study of solar and wind energy in Gaza strip*. International Journal of Scientific & Engineering Research, 2013. **4**(12): p. 140-147.
47. Abu Dabousa, T.I., *Comparative Study of Photovoltaic Solar Systems Installed in Gaza Strip*, in *Electrical Engineering*. 2018, Islamic University of Gaza: Gaza, Palestine.
48. Nassar, Y.F., Alsadi, S. Y., *Economical and Environmental Feasibility of the Renewable Energy as a Sustainable Solution for the Electricity Crisis in the Gaza Strip*. International Journal of Engineering Research and Development, 2016. **12**(3): p. 35-44.
49. Kreitem, G.M., Al-khatib, I. A., *Renewable Energy Exploitation in Palestine: Current Practice and Future*. 2018, Germany: LAP LAMBERT Academic Publishing.
50. Nassar, Y.F., Alsadi, S. Y., *Wind Energy Potential in Gaza Strip-Palestine state*. Solar Energy And Sustainable Development, 2018. **7**(2): p. 42 – 57.
51. Elnaggar, M., Edwan, E. and Ritter, M., *Wind Energy Potential of Gaza Using Small Wind Turbines: A Feasibility Study*. Energies, 2017. **10**(8): p. 1-13.
52. Al Badwawi, R., Abusara, M. and Mallick, T., *A Review of Hybrid Solar PV and Wind Energy System*. Smart Science, 2015. **3**(3): p. 127-138.
53. MOEHE, *Solar system to power schools in Gaza*. 2017: Gaza.
54. WHO. *Corona virus disease (COVID-19)*. 12 Oct 2020.
55. AlwatanVoice2. 11 Aug 2020.
56. El-Khozondar, H.J., El-batta, F. *Hybrid energy system for Dier El Balah quarantine center in Gaza Strip, Palestine*. in *2021 International Conference on Electric Power Engineering – Palestine (ICEPE- P)*. 2021. Palestine: IEEE explore.
57. El-houari H., A.A., Rehman S., Buker M.S., Kousksou T., Jamil A., El Amrani B., *Feasibility evaluation of a hybrid renewable power generation system for sustainable electricity supply in a Moroccan remote site*. Journal of Cleaner Production, 2020 **277**: p. 123534.
58. EPA, *Center for Corporate Climate Leadership GHG Emission Factors Hub*. 2020.