INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
M. O. a. El-Raouf et al., Vol.12, No.3, September 2022

Techno-Economic Analysis (Design) of on-grid hybrid power system considering MPPT

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Received: 19.06.2022 Accepted: 22.07.2022

Abstract- The production of electric energy from renewable sources has become inevitable due to economic and environmental importance. One of the important obstacles to increasing the integration of these sources into the electrical grid is their high initial cost. The optimum design of such renewable energy systems is the most powerful solution to this obstacle. This paper proposes an optimum techno-economic design of a hybrid power model consisting of two renewable sources that are PV and wind, which are also fed by the electrical grid. The optimal design aims to find the minimum energy cost per kilowatt by determining the optimal number of components for the hybrid system, whether photovoltaic panels or wind turbines, while achieving continuity of energy production to fulfill the intended consumption. This optimization is performed using the Hybrid Optimization Renewable Energy Model (HOMER) simulation tool. In addition, this paper presents the maximum energy harvesting that can be obtained for the two energy sources used in the system during changes in environmental conditions. This study was simulated using MATLAB / SIMULINK. It was found from the application of the study that the grid / photovoltaic wind is the most effective assembly of the system with the lowest price of energy was $0.15/Kw, this lowest cost was obtained at the optimal hybrid system with 5.2 MW and 7.5 MW for PV and wind system, respectively. Also, the study revealed that the proposed hybrid system was also more successful in providing stability for both voltage and frequency while obtaining maximum power from the system and the electrical grid.

Keywords Hybrid System, Photovoltaic (PV), Wind Turbine (WT), Grid, Maximum Power Point Tracking (MPPT).

1. Introduction

Global concern is growing about the lack of traditional energy resources such as burning coal, oil, and its derivatives, pumping natural gas, and others. In addition, these sources constitute pollution to the environment, Therefore, it is necessary to test clean sources, such as exploiting the energy of the sun, whether light or heat, extracting energy from wind as well as other energies such as tides and others, as alternative sources [1]. There are some drawbacks when using renewable energy including the interruption of the extracted energy according to the continuous change of environmental conditions, such as solar radiation, and wind speed in addition, to their high capital cost. Recently, many types of research have been done on integrating many renewable energy sources into one hybrid system to ensure continuity and reliability in remote regions [2]. The hybrid succeeds in achieving several influential factors compared to other systems in terms of quality, and the emission of carbon dioxide is reduced due to the increase in the non-polluting energy part, as well as raising the reliability [3]. The integration of both solar energy and wind energy has taken the greatest interest in the field of research as a hybrid system [4-7]. AZEREFEGN, et al. (2020) [8] Present 4 different scenarios for integrating the hybrid system of solar panels to represent the energy of the sun and wind turbines with the electric grid in 3 different regions in Ethiopia using the HOMER-Pro program, and the results showed low cost, low emissions, and reliability. Tawfiq, Aiman Abd Elkader, et al. (2021) [9], she studied the optimal size of the solar system to achieve maximum power and reliability with grid connectivity using a modified PSO algorithm. Ahmad, Tanveer, and Dongdong Zhang (2021) [10], The effects of the hybrid system consisting of photovoltaic and wind, if it is connected to the electric grid, were presented economically and technically, and the results showed that the cost of the grid connection is two times less than the cost of the island, more reliable and sensitive. Ospino-Castro, Adalberto, et al. (2017) [11] Assess the suitability of a hybrid renewable system in a residential area consisting of the electrical grid connected to the energy of solar panels as well as the energy of wind turbines in Sanlus Potoisi, Mexico to achieve a balance between three aspects: economic, environmental, and energy availability, the best result by trying different cases has been carried out. Alharthi, Yahya Z, et al. (2019) [12], studied hybrid renewable energy connected to a grid system in the city of Riyadh in Saudi Arabia to reach the optimum point to reduce carbon dioxide emissions from an environmental point of view and reduce costs economically. The system simulation was applied using HOMER software, and it was extracted that the best proposal which yields the lowest price with the highest availability is the wind connected to the grid system. Elkadeem, M. R., et al. (2019) [13], He studied a hybrid power system that includes generators connected to the PV system, diesel, and WT with batteries with the application of converters in order to deliver electricity to an agricultural area in Sudan, resulting achieve economic improvement while reducing the impact of harmful emissions on the environment by experimenting with several methods of blending and hybridization on the HOMER Pro program. The result also indicated that PV/WT/diesel/batteries could be the best solution for feeding this area. Abuelrub, Ahmad, et al. (2019) [14], implemented an optimization technology for a grid-connected regeneration system to discover the best hybrid system integration ratios through two-stage SP technology, achieving annual energy cost reduction while ensuring energy reliability in North Texas. Babatunde, O. M., et al (2017) [15], simulate hybrid renewable energy systems (PV-Wind) with battery and diesel generators, given the prevalence of poverty in developing countries, especially in Abadam Nigeria, the finding that renewable energy can provide more than 50% of the total energy production. Azaroual, et al. (2019) [16], reduced the cost of electricity as well as selling and exporting electricity produced from renewable energy. The system consists of a battery charged from the solar energy system and a wind turbine energy. Two optimization methods have been applied to reach optimal control, namely genetic algorithm, and linear programming techniques. The control system based on linear programming is more economical than the genetic algorithm. In this paper, the Ras Gharib region in Egypt [17], was chosen for study, due to the sunny climate throughout the year and the presence of wind speeds suitable for the presence of many wind turbines. This region is the second city on the Red Sea in terms of a population of about 100,000 people. Many projects have been carried out to generate electricity in this region [18,19]. The output power from renewable energy sources is largely affected by some environmental conditions like sun irradiance and temperature for the PV systems and wind speed for the wind energy systems. These environmental variations lead to changes in the generated power from renewable energy sources. Thus, control design means should be used to improve performance in integrating the sources with the electrical grid as well as obtaining the maximum power from it (MPPT) [20]. MPPT is implemented by regulating DC voltage output from renewable sources through DC-DC converters, which qualifies to ensure working at maximum power point. [20-21]. The main objective of this paper can be outlined as:

- A hybrid system consisting of PMSG of wind turbines and photovoltaic power with grid connection will be offered. The aim of this research is to reach the minimum generation cost by achieving the design of the optimal ratings for both photovoltaic and wind energy systems. This optimization problem is performed using HOMER software.
- Incremental conductance based on MPPT technology is introduced to track the maximum available energy for each of the components of the hybrid system, both PV and WT, in order to extract the maximum amount of system energy. The control process was also helped by the DC-DC converter connected to the main inverter connected to the electrical grid through the duty cycle. MATLAB / SIMULINK program was used to develop and simulate the complete system.

2. System Description

The model under study is constructed from two renewable sources which are PV and wind as shown in Fig.1, These two renewable generation sources are feeding some loads in the Ras Gharib region in Egypt is considered as one of the most encouraging sites. In this paper, the area was chosen due to the availability of access to the sun's energy and the high percentages and strength of winds in the region, as the Ras Gharib region is one of the important tourist areas that contain many tourists' villages [22]. According to the website of the Red Sea, Ras Gharib contains about 60,000 inhabitants by utilizing natural resources, electricity can be generated, thus reducing the costs of delivering electricity from the electric grid. Ras Gharib is located on latitudes 24.5 feet above the ground, wind strength is measured at 28.33 degrees north latitude and 33 degrees east longitude [23]. As shown in Fig.2, From the results of the Egyptian Sun Atlas, the maximum value of the radiation power is 270 kilowatts in the month of July, while the minimum value is 120 kilowatts in the month of December. The ideal tilt angle for Egypt is also measured at 24 degrees when adjusting photovoltaic panels [24]. According to the Ras Gharib Meteorological Authority in Egypt, at a height of 100 meters above the surface of the earth shown in Fig.3, the average monthly wind speed is estimated and shows that the maximum value of wind speed is 15.5 m / s in June and the minimum value is 9.7 m / s in January [25]. At the DC voltage output on the photovoltaic part, the voltage is regulated by connecting a DC-DC converter connected to a common DC link. This converter can also be used to get the maximum power in the PV part using the IC method. The synchronous generator with permanent magnets is chosen to configure the wind system [26]. The PMSG generator has a lot of benefits. As the PMSG has a moveable magnetic source, it can be considered from the most efficient generators. The use of permanent magnets for excitation does not require any additional electrical power. As a result, there is no copper loss in the exciter, and the lack of a mechanical commutator, brushes, or slip rings ensures reduced mechanical friction losses in addition to the small size. A detailed comparison of all generators used in wind systems with the advantages of PMSG is presented in [27]. The AC output of the PMSG is converted to DC. Then this DC is connected to the DC-DC converter in order to work on the MPPT and then linked to the DC link. The inverter is placed to convert DC volts to AC for alternating current loads, and thus the loads are fed through the alternating current carrier connected to both the inverter and the electrical grid as in Fig.1.

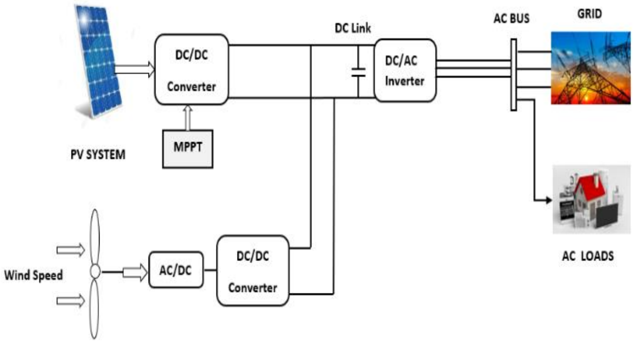

Fig. 1. The structural form of the units for the proposed system.

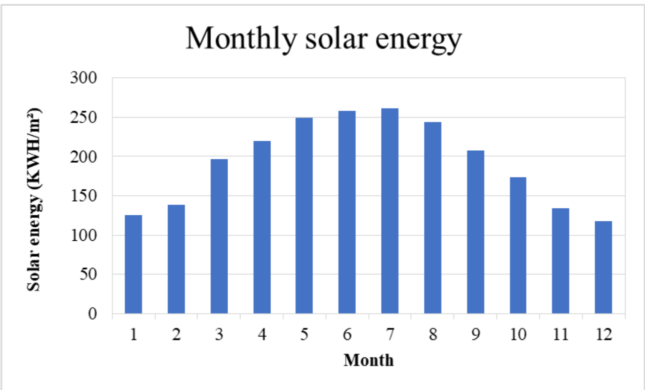

Fig. 2. Solar energy for the PV system.

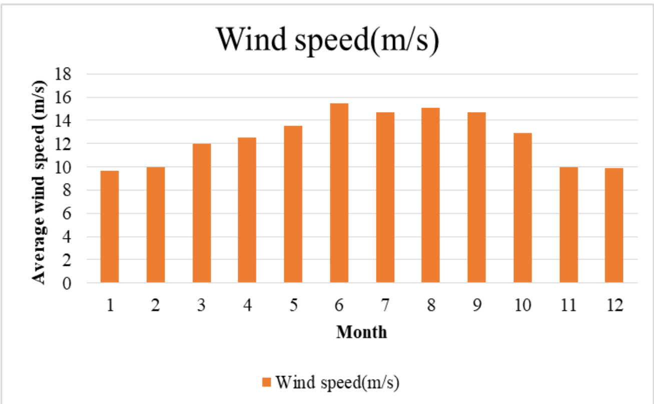

Fig. 3. Monthly wind speed in Ras Gharib

3. System Modelling

The photovoltaic system includes the amount of power desired and the number of panels used. which comprises a set of PV units connected to each other in series and parallels to achieve the required capacity of the system and to reach the highest possible PowerPoint with environmental changes, MEPV 400-HC has been selected to deliver 5.2 MW of power through the system as each module covers an area of 1.98 m2 (1979 mm×1002 mm). Table 1, shows the details of the PV module. The cost is about $0.18144/WP, with very low operating and maintenance costs. The wind system is modeled to extract mechanical energy through changes in wind speed using PMSG wind turbines [28]. Although there are many types of wind generators, the permanent magnet synchronous generator (PMSG) is the most widely used because it achieves high torque at small speeds, has no gearbox in its structure, has simplicity of design, stable performance with electronic transformers and low operating cost and maintenance [29]. Enron 1.5 MW turbines were selected costing around $1,300,000/MW, Table 2, shows the data of the wind turbine. According to the potential of the winds in the Ras Gharib region, it was found in studies that the higher the hub height of the turbine, the better the performance [30], and in this study, the heights of the turbine used range from 65 to 100 meters. The electric grid is more reliable than solar PV and wind turbine systems, which rely exclusively on renewable sources. When the energy generated from the system exceeds consumption, this excess can be sold to the grid, thus reducing the total cost of energy [31]. Accordingly, electricity prices are changed every period, as shown in Table 3, Which presents a comparison of the electricity tariff for the last two years in Egypt, including domestic and commercial uses. The DC-DC converter is also used as a connector between the maximum output power and the loads. The boost converter used in this study, which works to raise the output voltage, appears in Fig. 4. The rectifier is also used in the wind energy part to convert the power of the wind turbines to direct current to connect it to the DC line. Then the inverter is used to convert the DC bus current to alternating current to feed the AC loads and connect to the AC bus that is also connected to the electrical grid. And in this study, it was selected using a rating of 20% more than peak demand [32].

3.1. MPPT Using Incremental Conductance

It is recommended to make the hybrid system to achieve the maximum benefit from it, both the amount of energy produced, and the costs and economic return, so it is designed to adapt to the continuous environmental changes and get the maximum possible power from it. It was found that there are many techniques to obtain maximum power during the design of the renewable system [33]. In this study the incremental conductance method was applied, which is based on a comparison of the instantaneous conductance [34], The idea of this technique is that the slope of the curve between the power and the voltage generated by the system has a positive value on the left side of the MPP, and a negative value on the right side, and its value vanishes at the MPP. Also, Fig.5, shows the IC flow chart.

Table 1. Specifications of (MEPV 400-HC) solar panel

Voltage in an open circuit (Voc)	49.8 V
Maximum power current (Impp)	41.7 A
Maximum strength (Pm)	400 W
Current in a short circuit (Isc)	10.36 A
Maximum power voltage (Vmpp)	9.6 V

Table 2. Wind turbine data

Parameters	Specifications
Rated power	1500 KW
Number of turbines used	5
Rated wind speed	11.8 m/s
Cut out wind speed	25 m/s
Cut in wind speed	3 m/s
Generator type	(PMSG)
Rated Rotor Speed	10-18 RPM
Rated voltage	690 V
Rated power	1500 KW

Table 3. Selling electricity prices in Egypt

	Tariff for a year 2019/2020 (penny/KWH)	Tariff for a year 2020/2021 (penny/KWH)
Household uses	2019/2020	2020/2021
0-50	30	38
51-100	40	48
0-200	50	65
201-350	82	96
351-650	100	118
From 651 to less than 1000	140	
From 0 to less than 1000		118
From 0 to more than 1000	145	145
Commercial loads	2019/2020	2020/2021
0-100	65	65
0-250	115	120
0-600	140	140
601-1000	155	155
From 0 to more than 1000	160	160

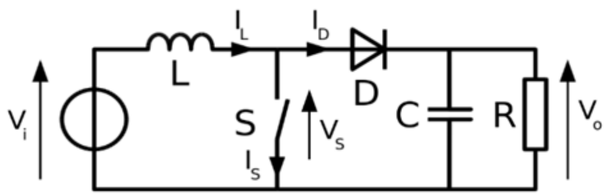

Fig.4. Boost converter schematic.

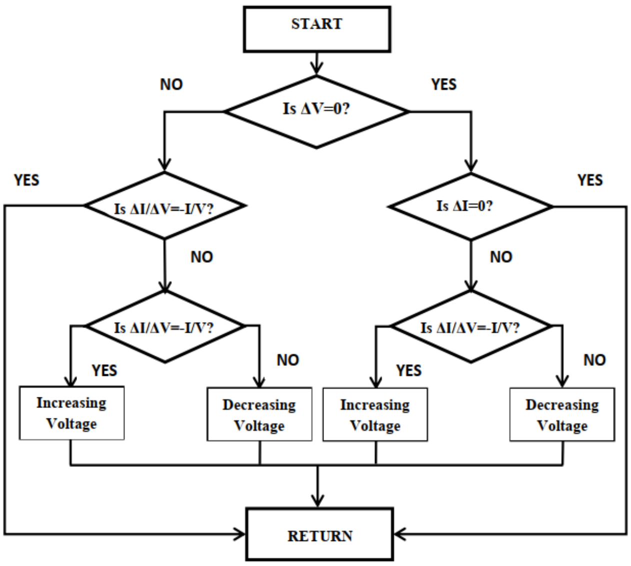

Fig.5. Flowchart of incremental conductance algorithm.

3.2. Economic Model

The HOMER PRO program is based on two main factors, namely (NPC) and (LCOE) which are net present value and levelized cost of energy [35]. Where NPC is represented in the total costs during the project without the profit during the period of operation of the system. It can be calculated from Eq. (1), Also LCOE has represented the price of system power actually used and is measured in \$/kWh. It can be calculated from Eq. (2).

$$NPC\ (\$) = \frac{TAC}{CRF} \tag{1}$$

$$LCOE = \frac{TAC}{R_{prim} + R_{tot.grid\ sales}} \tag{2}$$

So that (TAC) represents the total annual cost of the system, (CRF) represents the capital recovery factor, it is calculated from the relationship in Eq. (3), ($R_{prim} + R_{tot.grid\ sales}$) represents the total electricity consumption and is measured by KWH per year, (R_{prim}) represents the main load in the AC system, and ($R_{tot,grid\ sales}$) represents the total grid sales.

$$\mathrm{CRF} = \frac{i(i+1)^N}{(i+1)^{N-1}} \quad (3)$$

So that (N) represents the total number of years and (i) represents the real annual interest rate (%).

4. Simulation Results

4.1. MPPT Results

As it passes through the transient state during the period from t = 0 to t = 0.4. Then it stabilizes at 3 MW as irradiation is half the standard value. If irradiation = 1000 W/m from t= 1 to t= 2.5 sec as shown in Fig. 7. Then it reaches the MPP (6 MW) at t = 1.1 sec. Also, in the case of the wind system, as shown in Fig. 8, The maximum overshoot occurs at t=0.07 at an output power of 9500 kW. Then the transient phase ends and settles at t = 0.12, achieving the maximum power output of 7500 kW. The total load is changed during the simulation process from t = 0 to the point at t = 2.5 s, as shown in Fig. 9

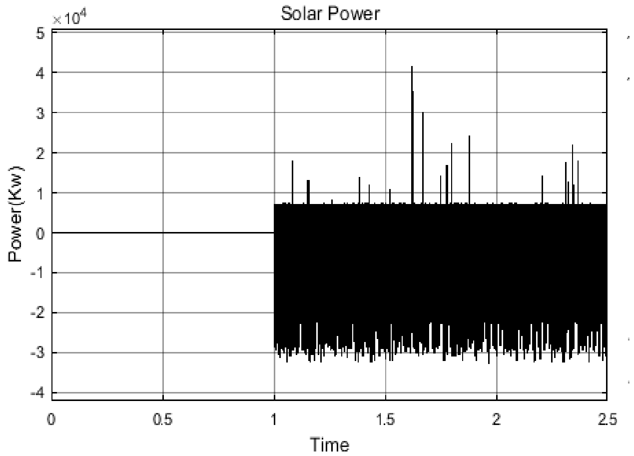

Fig.6. Power output of PV without MPPT.

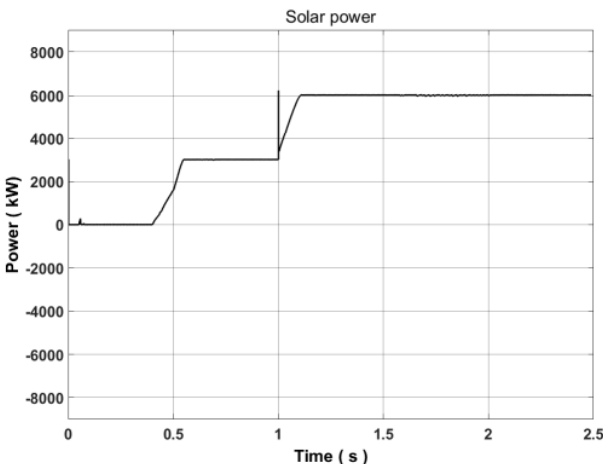

Fig.7. Power output from PV under the influence of MPPT

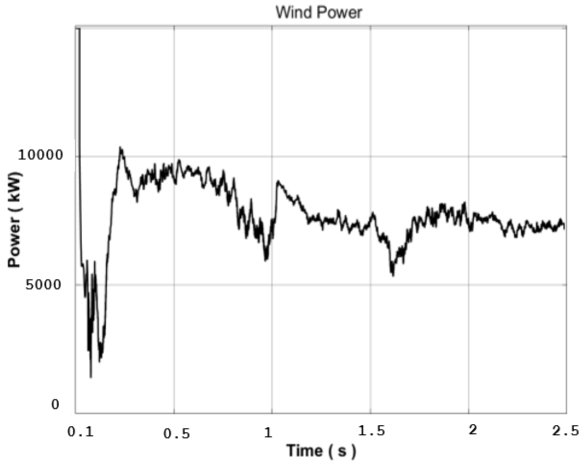

Fig.8. Wind output power.

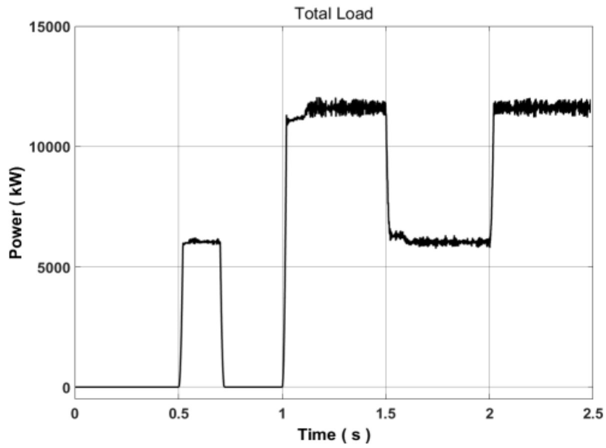

Fig.9. Total load power.

All electricity-generating components PV and wind are assembled by a DC bus and the output volt is valued at 260 V as in Fig. 10, where coupling occurs at a constant maximum voltage and has a capacitor with a value of c = 300 µF.

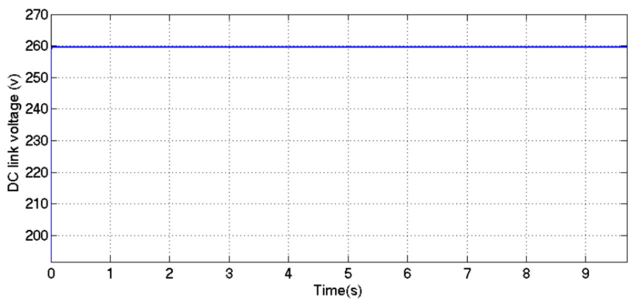

Fig.10. Common DC Link voltage.

As shown in Fig. 11, a three-phase volt (Vabc) converter from the inverter to alternating current from the current of the DC bus. As depicted in Fig. 12, the frequency of the system is fixed at 50 Hz.

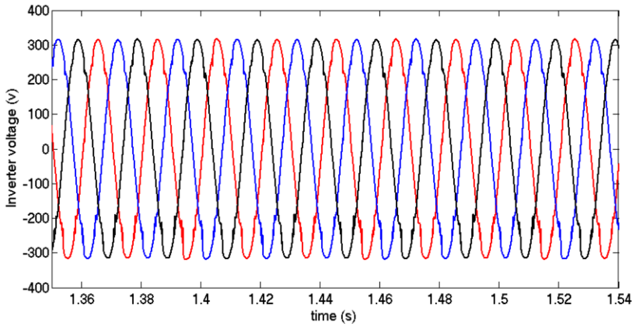

Fig.11. Three-phase voltage inverter.

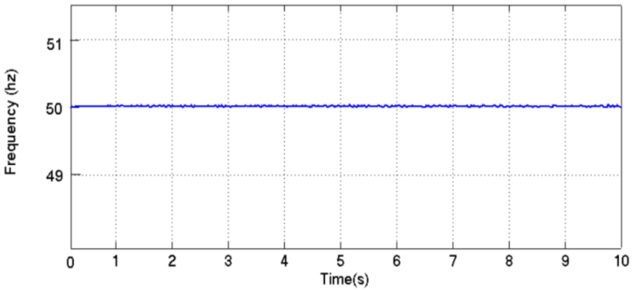

Fig.12. Frequency of grid.

4.2. Optimization Results

By analyzing the results, it appears that the production of the hybrid system is about 14 MW, so it can feed all loads under normal conditions. The optimization results show the output of 5.2 MW from the PV plant with a 15000 PV panel with a capacity of 400 W and 7.5 MW from the wind farm with a 5- wind turbine with a capacity of 1.5 MW, and the grid can be relied upon in the event of any malfunction in either of the two systems. Details of power generation and costs appear in Table 4,5,6,7.

Table 4. Total present costs of the system

Element	Capital (1000$)	Replacement (1000$)	Operation and maintenance (O&M) (1000$)	Total (1000$)
Wind farm	9750	3900	1462,5	15112,5
PV array	1088,64	217,728	130,6368	1437
Grid	0	0	500	500
Converter	480	480	39,1248	999,125
System	11318,6	4597,728	2132,2616	18048,6

Table 5. Comparison of optimization options

Architecture				Cost	
PV (MW)	Wind G1500	Grid (MW)	Converter (MW)	NPC (1000$)	Capital (1000$)
5.2	-	8.3	5.35	21874	17693,62
-	5	6	-	18112,5	12750
-	-	13.5	-	135000	-
5.2	5	1	5.35	18048,6	11318,8

Table 6. Total cost summaries

Total net cost	18,048,6298 $
LCOE	0
Operation cost	-2,132,2616$/year

Table 7. Total power production

Component	Production (KWH/year)	Fraction
PV plant	5200	38.519%
Wind farm	7300	54.074%
Grid purchases	1000	7.407%

4.3. Sensitivity Results

The sensitivity of the system was analyzed using different lifetime assumptions for all system components, as well as hub height for wind turbine and solar panel size, as shown in Table 8.

Table 8. Sensitivity cases

PV time (years)	G1500 Lifetime (years)	G1500 Hub Height (m)	PV (kW)	G1500	Grid (kW)	Conveter	NPC ($)	Replacement ($)	Operating cost ($/yr)	Capital cost ($)
20	20	100	5,509	5	1,053	480	$18.08M	-$4.64M	-$2.13M	$11.31M
20	25	100	5,472	5	1,072	472	$18.08M	-$4.61M	-$2.11M	$11.28M

20	20	80	5,45	5	1,092	479	$18.06M	-$4.65M	-$2.11M	$11.30M
20	25	80	5,351	5	1,102	481	$18.07M	-$4.61M	-$2.16M	$11.30M
25	20	100	5,782	5	0,980	480	$18.07M	-$4.58M	-$2.17M	$11.32M
25	25	100	5,745	5	0,992	483	$18.06M	-$4.62M	-$2.13M	$11.31M
25	20	80	5,745	5	0,995	480	$18.05M	-$4.56M	-$2.18M	$11.31M
25	25	80	5,745	5	0,996	479	$18.07M	-$4.59M	-$2.16M	$11.32M

As shown in Fig. 13 the sensitivity results are shown in a graphic showing the relationship between the size based on the renewable fraction of the PV panel and WT, which shows the Which shows the high value of the contribution of renewable energy to meet the demand of the load. Also shown in Fig. 14 is the relationship between the lifetimes of both the solar system and the wind system in an optimal system, which shows the large renewable fraction over many years. In addition to, the economic return in the year is greater in the case of the hybrid study system than in the traditional system as shown in Fig. 15 which shows the relationship between the lifetime of both systems In the case of the NPC.

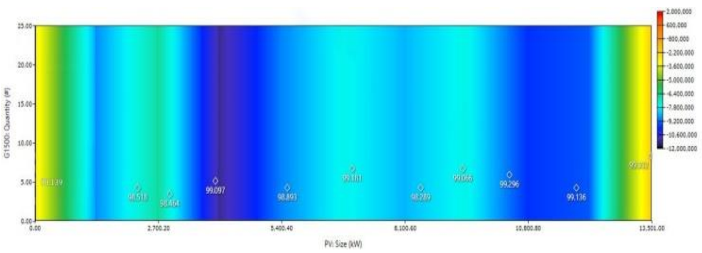

Fig.13. Optimal system type plot with a lifetime of components.

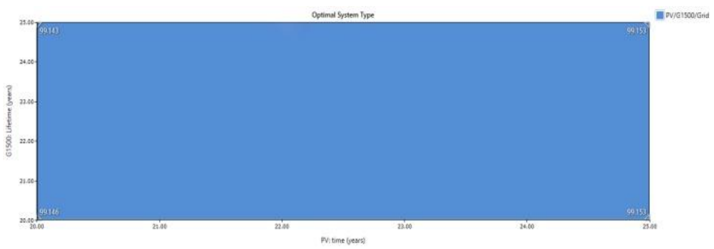

Fig.14. Optimal system type plot with renewable fraction.

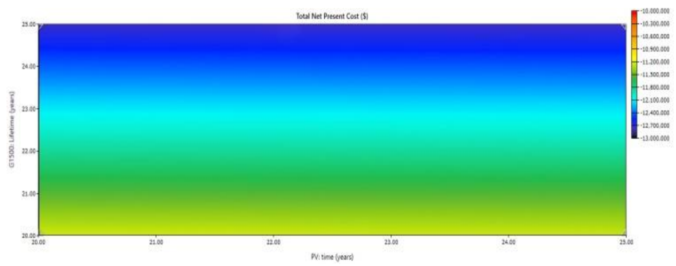

Fig.15. Surface plot of net present cost with renewable fraction.

4.4. Emission

The Noticeable difference appears between the rates of emissions of gases polluting the production of electricity between the proposed hybrid energy system and the traditional system, where the amount of carbon dioxide emission decreases by 97%. Table 8 also shows the amount of harmful gases emission resulting from the study system.

Table 8. Emission summary

Emission gas type	Hybrid system (Kg/yr)	Base system (Kg/yr)	Emission reduction (Kg/yr)
Carbon Dioxide	308.03	10536.32	10228.29
Carbon Monoxide	1.15	60.23	59.08
Particulate Matter	0.092	3.1	3.008
Sulfur Dioxide	1.335	24.0024	22.6674
Nitrogen Oxides	6.75	11.7384	4.9884

5. Conclusion

This paper studies different aspects of the hybrid system PV/Wind connected to a grid for the Ras Gharib area in the Red Sea Governorate in Egypt. To increase the reliability and performance of the system, MPPT has been applied to the system. And uses lower costs to reach the required power capacity of electrical loads. By optimizing the system, it was found that the optimal solution is 5.2 MW from the PV plant and 7.5 MW from the wind farm, at a total cost of about 18,048,6298 $. The system achieves a flow of power at a constant frequency, and when the electrical grid is connected to the AC bus, which is also connected to the output of the hybrid system (PV-WT), the energy produced is also at a constant volt to feed the AC loads.

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