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Dynamic Simulation of the Annual Performance of PV-Wind System for Hydrogen Generation in Egypt Using TRNSYS

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Abstract- Hydrogen generation from new and renewable energy sources such as solar and wind energy has become the focus of attention of the world countries because of the advantages enjoyed by green hydrogen, that is produced using new and renewable energy. In this research, a large-scale hydrogen generation system using a hybrid Solar -Wind power system has been studied and simulated under Cairo's climate. Two other regions in Egypt (Aswan and ElZafranah) were also chosen to conduct these studies. Each region has an abundance of one renewable energy source, Aswan has a high solar radiation capacity throughout the year, as well as the ElZafranah region. While ElZafranah region has an abundance of wind energy throughout the year. Dynamic simulation for the hybrid PV-Wind system to generate hydrogen was carried out using the TRNSYS17 software. From the simulation results, it was found that ElZafranah has the best hydrogen production from wind energy, where the annual hydrogen produced was about 760*103 m3/year, and Aswan came as the best location for hydrogen production from PV cells, as the annual hydrogen produced was 499*103 m3/year. The annual electricity production for the hybrid PV-wind turbine systems, for ElZafranah, Cairo, and Aswan were 3244, 1507.1, and 2281.6 MWh, respectively. Also, an economic analysis of hydrogen production from renewable energy sources was carried out in this study.

Keywords Photovoltaic, wind turbine, hydrogen production, electrolyzer, electricity production, dynamic simulation.

1. Introduction

The global demand for energy increases with the increase in population, and thus the use of fossil fuels increases with the resulting harmful environmental problems. Scientists tended to use non-polluting energy sources such as green hydrogen [1]. The majority of the generated hydrogen globally (95 %) is produced from the methane-steam reforming process [2]. The hydrogen produced from new and renewable energy sources is called green hydrogen. Due to increasing the electric energy generated from solar PV, thermal power plants, and wind turbine farms, the excess electrical energy from these sources is used to generate hydrogen gas from the electrolysis of the water [3, 4]. Scientists and decision-makers are concerned with research and development in three areas related to the production and use of hydrogen (1) replacing the sources of energy that produce the carbon dioxide gas with hydrogen gas; (2) Injecting hydrogen gas into the natural gas pipeline network to reduce the use of natural gas, as well as saving for the establishment of a hydrogen network; (3) Using hydrogen in transportation instead of traditional fuel and natural gas. Often, all the electrical energy generated from new and renewable energy sources isn't used; this is evident in the huge stations. So, many research and discussions were conducted to use this excess energy to generate hydrogen gas from water [5, 6]. In Jordan, a study was conducted to use the surplus energy generated from three renewable energy (RE) systems in hydrogen production. It was found that the wind-based system proved a more economical choice and shows the highest annual production of hydrogen (172.1 × 10^3 tons) and the lowest hydrogen cost (1.082 USD/kg) [7].

Different techniques for generating H_2 by electrolyzing the water with the use of a hybrid solar PV-Wind energy system as electrolyzer electric energy sources were investigated and used different water electrolyzers in this investigation [8-10]. A simulation study was conducted using the TRNSYS platform to investigate the integration of a solar heating system into a hydrogen generation system from a hybrid PV-wind system to capture the thermal energy generated from fuel cells for increasing the system efficiency [11]. The performance of different hybrid wind turbines, PV and fuel cell systems as electricity sources was investigated by different researchers [12]. The effect of various parameters on the performance of the hydrogen production system from renewable energy system was also investigated [13]. Different methods for implementing solar thermal collectors in producing hydrogen in South Africa have been investigated and it was found that PV and wind electricity have become cheaper than coal as an energy source, but these sources still cannot compete with the hydrogen produced from the process of steam/methane reforming. The water splitting using the Cu Cl cycle proved very good results with the solar thermal power plant that used molten salt as a heat transfer fluid. It needs smaller electric energy than a water and steam electrolysis plant [14]. TRNSYS software to simulate the energy generation capacities of two systems was developed. The first system was based on PV panels, and the second was based on wind turbines. It was found from the study that solar PV cells have high capabilities compared to wind turbines [15]. An electric supply model consisting of a solar PV and wind hybrid system coupled to lead-acid batteries was developed for a remote area. The results proved wind turbines and solar cells can be sources of electricity complementing each other throughout the day, and so can reduce the capacity of the batteries used by 57 %. The proposed hybrid system showed an increase in the period of generating electricity by about 3-4 hours per day [16]. An investigation of hydrogen production performance from solar PV panels in Morocco was carried out. The investigation included an economic study for 76 locations in Morocco. The results showed that the cost of electricity production ranged from 0.077 to 0.099 $/kWh while the cost of hydrogen production ranged from 4.64 to 5.79 $/kg, respectively [17]. Panayiotou et al. developed a simulation process with TRNSYS software, to get the optimal size of the renewable energy system with the minimum cost for two cities in France and Cyprus [18]. An economic study was conducted for hydrogen production from PV-Wind systems in several regions inside Iraq. The study concluded that it is possible to produce hydrogen with a cost of 0.752 $\$/m^3$ H_2. It also indicated that this cost can be reduced to 0.723 $\$/m^3$ H_2 in the case of selling excess electric energy to the grid [19]. The transient simulation program TRNSYS and the optimization program GenOpt were used to simulate and optimize a hydrogen production and storing system using solar PV as an electric source in several regions of Turkey. The amount of electrical energy generated from each region and the amount of hydrogen generated in these regions were calculated [20].

This work aims to study theoretical the performance of a hybrid renewable energy system, PV-Wind turbine system, to supply energy for a small community and store the excess energy in the production of hydrogen. The performance of the proposed system was investigated through a simulation program using the TRNSYS platform. The study includes the effect of metrological parameters for different locations in Egypt on the output power of each renewable energy source and the quantity of hydrogen produced. The annual and monthly electric energy and the volume of hydrogen produced were computed for different regions in Egypt. Also, an economic analysis was conducted for the hydrogen production in the selected region.

2. Description of the System

The system under investigation includes a 605 kW PV plant, and the PV plant consists of 1120 monocrystalline modules of 540 W each. The technical specifications of the solar cells used in the simulation belong to Trina Solar Company, and one of the panels with a large capacity was chosen, which is TSM-DE19 540 W [21]. The system includes also a Wind turbine with a rated capacity of 600 kW (Enercon E40/6.44) [22], an alkaline electrolyzer, a power conditioner, a gas compressor, and a hydrogen storage tank. The alkaline electrolyzer consists of 200 single cells connected in series per stack and three stacks are connected in parallel. Each cell has an area of 125 cm^2. A schematic diagram of the hybrid PV-wind turbine system that was constructed for this study is illustrated in Fig. 1.

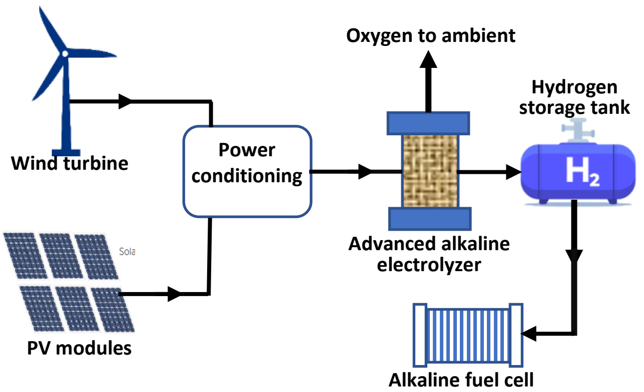


Fig. 1. A schematic diagram of the PV-Wind turbine system for hydrogen production.

The specifications and the technical data of the PV modules and the wind turbine are given in Table 1

Table 1. The technical data of the PV modules and the wind turbine [21, 22]

Items	Quantity	Unit
PV modules		
Maximum power	540	W
Maximum power voltage	31.2	V
Maximum power current	17.33	A
Open circuit voltage	37.5	V
Short circuit current	18.4	A
No. of modules in series	20	module
No. of modules in parallel	56	module

Wind turbine		
Rating power	600	kW
Rotor diameter	43.7	m
Rotor height	46	m
Swept area	1521	m^2
Rated speed	12	m/s
Cut in wind speed	2.5	m/s
Cut out wind speed	28	m/s

3. Modelling of the System

A model for a hybrid electricity generation system of renewable energy has been developed to study the effect of meteorological variables on the hydrogen generation system. The hybrid system consists of PV panels and a wind turbine. The model was built using the TRNSYS17 platform. Transient systems can be studied well by performing simulations in this software. TRNSYS is a large library of components (types), each of which models the performance of one system component. The model developed in this work consists of several components. A description of each component will be presented in the following.

3.1. Photovoltaic panels

Type 194 computes the electrical output from photovoltaic panels. The equations in this type are used to calculate the current and voltage from PV panels that give the maximum output power. The equations that are used to calculate the current (I_{mp}) and voltage (V_{mp}) at the maximum power point are as follows [23, 24]:

$$I_{mp} = \frac{G_T}{G_{T,ref}}\left[T_{mp,ref} + \mu_{IC}\left(T_c - T_{c,ref}\right)\right] \quad (1)$$

$$V_{mp} = V_{mp,ref} + \mu_{Voc}\left(T_c - T_{c,ref}\right) \quad (2)$$

The maximum output power (P_{mp}) from the PV panel can be calculated from the product of I_{mp} and V_{mp} as follows:

$$P_{mp} = I_{mp} * V_{mp} \quad (3)$$

Where

$I_{mp,ref}$ is the output current at the maximum power point.

$V_{mp,ref}$ is the voltage at the maximum power point.

T_c is the module temperature.

$T_{c,ref}$ is the module temperature at reference conditions.

μ_{Isc} is the temperature coefficient of I_{sc} at the reference condition.

μ_{Voc} is the temperature coefficient of V_{oc} at the reference condition.

The reference conditions are as follows:

(The ambient temperature Ta = 25 °C and the solar radiation $G_{T,ref}$ = 1000 W/m^2).

The PV panel characteristics (I-V and P-V curves) are illustrated in Fig. 2. The figure illustrates also the maximum power point P_{mp} occurs at a voltage of V_{mp} and a current of I_{mp}.

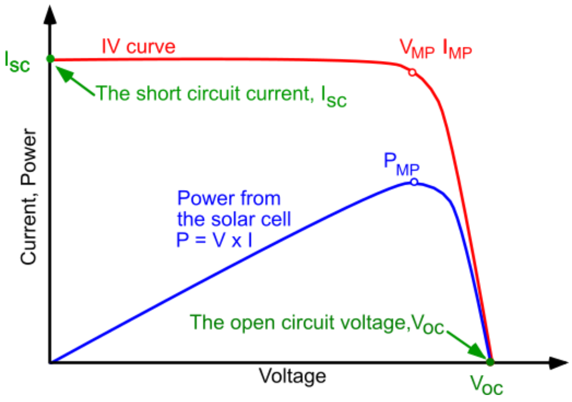


Fig. 2. Typical I-V and P-V curves for a PV module.

3.2. Wind turbine

The calculations in this model are based on an external file that contains various values of wind speeds and the corresponding output power from the wind turbine. This type models the effect of changing the air density and wind speed through the height and its impact on the turbine output power. A schematic diagram of the wind turbine is illustrated in Fig. 3. The main equation for calculating the power output from the wind turbine is as follows [25]:

$$P = C_p \, \rho \, A_R \, U_o^3 \quad (4)$$

Where

P is the wind output power.

Cp is the wind turbine power coefficient.

ρ is the air density.

A_R is the wind-swept area.

U_o is the wind speed.

The wind turbine power coefficient, C_p, is defined as the output electric power from the wind turbine to the power in the wind [26]

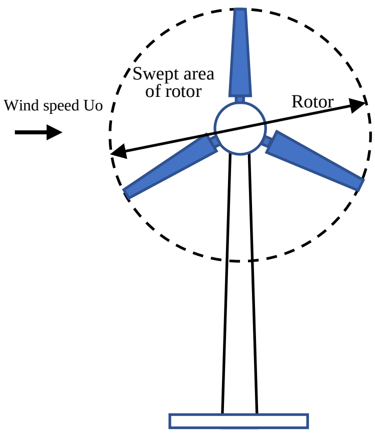


Fig. 3. Swept area of the wind turbine.

3.3. Electrolyzer

This electrolyzer type includes equations for simulating the performance of an alkaline water electrolyzer. The thermodynamic equation that governs the performance of the electrolyzer, the heat transfer theories, and the electrochemical relationship were included in this model [27, 28]. Hydrogen can be separated from water by passing an electric current (DC) between two electrodes separated by ionized water, which causes the water to decompose into two gases, hydrogen, and oxygen as shown in Fig. 4. The reaction equation for splitting water into two gases is as follows [29]:

$$H_2O(l) + \text{Electric Energy} \Rightarrow H_2(g) + ½\, O_2(g) + \text{heat} \quad (5)$$

For an alkaline electrolyzer, the potassium hydroxide (KOH) is used as an electrolyte, where the potassium ion K^+ and hydroxide ion OH^- are responsible for the movement of the electrons. The anodic and cathodic reaction equations are as follows [30]:

$$\text{Anode: } 2OH^-(aq) \Rightarrow ½O_2(g) + H_2O\,(l) + 2e^- \quad (6)$$

$$\text{Cathode: } 2H_2O\,(l) + 2e^- \Rightarrow H_2(g) + 2OH^-(aq) \quad (7)$$

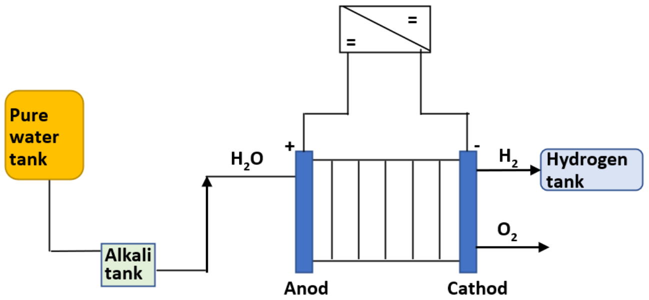


Fig. 4. Alkaline -Water electrolyzer for hydrogen production

In the alkaline electrolyzer, the anode is made of nickel, iron, and cobalt (Ni, Co, Fe), the cathode is made of nickel with a catalyst made of potassium and activated carbon (Ni, C-Pt), and diaphragms made of nickel oxide (Ni O). According to Faraday's law, the total hydrogen produced in this electrolyzer, which consists of several cells connected in series, can be computed as follows [30]:

$$n_{H_2} = \eta_f \; N_C \; I_e \; F \quad (8)$$

Where

n_{H2} is the number of hydrogen moles.

I_e is the cell current.

N_c is the number of electrolyzer cells.

F is the Faraday constant.

η_f is Faraday efficiency and it was calculated as follows [30]:

$$\eta_f = \left[\frac{I_{den}^2}{a_1 + I_{den}^2}\right] * a_2 \quad (9)$$

Where I_{den} current density per cell, a_1 and a_2 are Alkaline Electrolyzer constants.

3.4. Compressed gas storage

The gas storage type simulates the performance of compressed gas storage. This type calculates the tank's pressure using the van der Waals equation for real gases. The van der Waals equation is a relation between the pressure, volume, and temperature of real gasses, the pressure of the hydrogen in a storage tank can be calculated as follows [31]:

$$P = \frac{nRT}{Vol\text{-}n\,b} + a\frac{n^2}{Vol^2} \quad (10)$$

Where

R is the universal gas constant,

n is the number of moles of gas,

T is the temperature of the gas

Vol is the volume of the storage tank.

a & b are constants of the Van Der Waals equation and can be calculated as follows [31]:

$$a = \frac{27{*}R^2{*}T_{cr}^2}{64{*}P_{cr}} \quad (11)$$

$$b = \frac{R{*}T_{cr}}{8{*}P_{cr}} \quad (12)$$

Where T_{cr} and P_{cr} are the critical temperature and pressure of the gas, respectively. The model calculates the pressure based on a mass (or moles) balance of the storage tank's inlet and outlet gas, determining the mass of hydrogen remaining in the tank. In this model, excess hydrogen is removed from the tank if the pressure exceeds a specified value

3.5. Alkaline fuel cell

This model simulates the performance of an Alkaline Fuel Cell (AFC). TYPE 173 has been modelled for a specific Alkaline Fuel Cell from ZeTek in mind [31, 32]. A schematic diagram of the Alkaline fuel cell is illustrated in Fig. 5. The model was built using equations for calculating the current and voltage output from the cell and, consequently, the electric power. Chemical reactions for the anodic and cathodic occur in the fuel cell, which is fed with an oxygen-containing cathode gas and hydrogen-containing anode gas

$$\text{Anode: } H_2(g) \Rightarrow 2\,H^+(aq) + 2e^- \quad (13)$$

$$\text{Cathode: } 2H^+(aq) + 2e^- + ½\,O_2(g) \Rightarrow H_2O\,(l) \quad (14)$$

The total fuel cell reaction is:

$$H_2\,(g) + ½\,O_2\,(g) \Rightarrow H_2O\,(l) \quad (15)$$

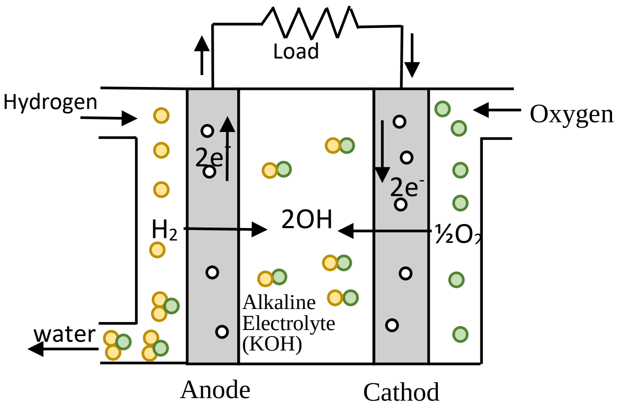


Fig. 5. Schematic diagram of alkaline fuel cell.

The equations used for calculating the Cell, module, and stack voltage of the fuel cell are as follows [30]:

$$V_m = V_o - b * \log(I_{st}) - R_{ohm} I_{st} \quad (16)$$

$$V_c = \frac{V_m}{n_{c,ser}} \quad (17)$$

$$V_{st} = n_{m,ser} * V_m \quad (18)$$

Where

V_c, is the cell voltage.

V_m, is the module voltage.

V_{st} is the stack voltage.

R_{ohm} is the internal resistance.

V_o is the open circuit voltage.

I_{st} is the stack current of the fuel cell.

b is the Tafel equation constants.

$n_{c,ser}$, is the number of cells in series.

$n_{m,ser}$ is the number of modules in series.

Cell current (I_C) and stack current (I_{st}) are calculated from the following equations [31]:

$$Ic = \frac{I_{FC}}{n_{c,par} * n_{st,par}} \quad (19)$$

$$I_{st} = \frac{I_{FC}}{n_{c,par}} \quad (20)$$

Where I_{FC} is the fuel cell current and $n_{st,par}$ is the number of stacks in parallel per FC unit. parallel. Stack power (P_{st}) is calculated from the following equation [30]:

$$P_{st} = V_{st} * T_{st} \quad (21)$$

Energy efficiency (η_E)is calculated from the following equation:

$$\eta_C = \frac{V_C}{V_{tn}} \quad (22)$$

Where V_{tn} is the thermoneutral voltage.

The fuel cell was used to consume the hydrogen production throughout the year to keep the pressure of the hydrogen in the storage take within the permissible levels. The TRNSYS platform used all previous components (types) to form a complete model for the Hybrid PV-Wind System for hydrogen production and electricity generation as shown in Fig. 6. The simulation was carried out for one year, and the calculation was done every 0.5 hours. The weather data for Cairo, Aswan, and El Zafranaha were used to perform the annual simulation.

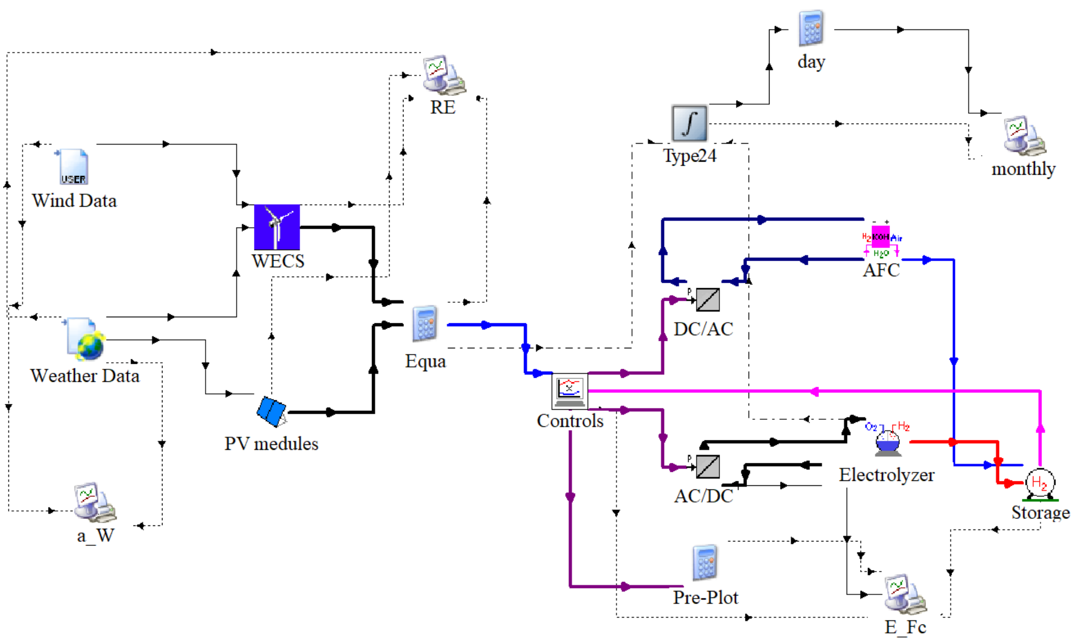


Fig. 6. View of the TRNSYS project for hydrogen production using renewable energy.

4. Economic Analysis

Comparing the cost of hydrogen production from the different renewable energy sources with the hydrogen cost that is produced from natural gas is an important issue for policymakers. In this study, the levelized cost of Energy (LCOE) is calculated for the PV system and wind system from the following equation for a lifetime of N year, assuming 20 years for the wind turbine and 25 years for the PV system, and a project discount rate of 4 %: the levelized cost of Energy from the PV system ($LCOE_{PV}$) is calculated as follows [33]:

$$LCOE_{PV} = \frac{C_{PV} - C_{SV,PV}\left[\frac{i(1+i)^N}{(1+i)^N - 1}\right] + C_{O\&m,PV}}{\sum_{t=0}^{t} E_{PV,t}} \tag{23}$$

Where

C_{PV}	is the capital cost of the PV
$C_{O\&M,PV}$	is the operating and maintenance cost of the PV
$C_{SV,PV}$	is the salvage value of the PV
N	is the no of the Year
i	is the discount rate
E_{PV}	is the energy from the PV
t	is time in hours

The above equation is used to calculate the levelized cost of energy from wind turbines ($LCOE_{Wi}$). The levelized cost of hydrogen production (LCOH) is calculated from the following equation, including the cost of the electrolyzer (EZ) [33]:

$$LCOH = \frac{\left(C_{EZ} - C_{EZ,SV}\right)\left[\frac{i(1+i)^N}{(1+i)^N - 1}\right] + \left[LCOE_{PV}\sum_{t=0}^{t} E_{PV2EZ,t}\right] + C_{O\&M,EZ}}{\sum_{t=0}^{t} H_{dis,t}} \tag{24}$$

Where

E_{PV2EV}	is the PV energy consumed by the electrolyzer.
H_{dis}	is the hydrogen discharged from the electrolyzer.

5. Results

The annual performance of the hybrid system for hydrogen production and electricity generation was investigated through a dynamic simulation program TRNSYS. A summary of the results obtained from the simulation program is presented in the following section. The simulation of the PV-Wind system was carried out under the meteorological conditions of Cairo, Egypt (30° 02' N, 31° 14' E). The Typical metrological year (TMY) is synthetic weather data that can be implanted in the simulation of the solar system. The TMY weather data includes twelve months of hourly data. [34]. Figure 7 presents the instantaneous global solar radiation on a horizontal surface for Cairo through one year while Fig. 8 presents the wind speed and the ambient temperature for the same site. the climatic parameters were obtained from the Type 15 implemented in the TRNSYS program. Figure 7 shows a high potential of solar irradiation for Cairo in the summer months. The value of solar radiation at noon ranges from 800 to 875 W/m^2 in the summers. The wind speed for Cairo range from 3 to 15 m/s over the whole year as shown in Fig. 8.

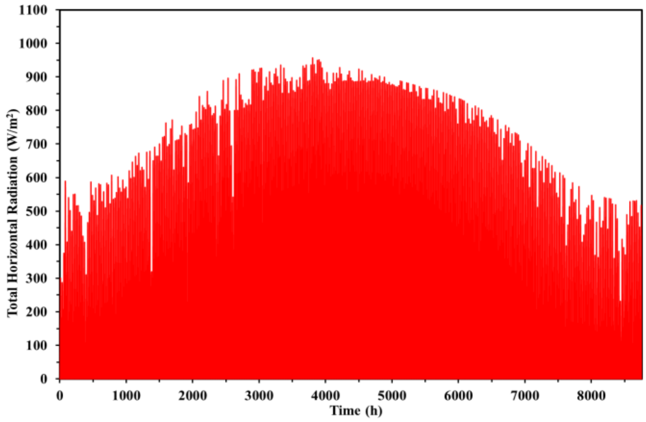


Fig. 7. Instantaneously global solar radiation on a horizontal surface for Cairo.

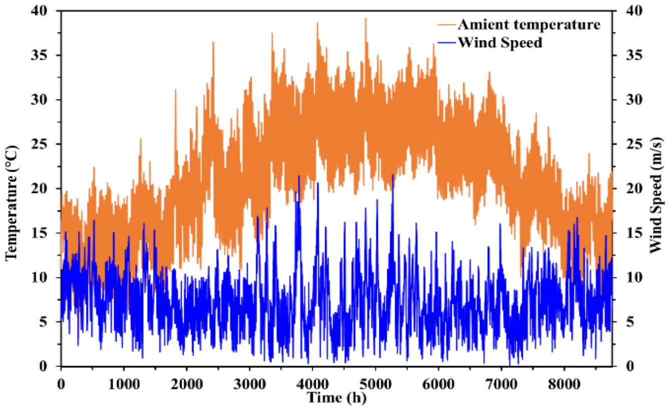
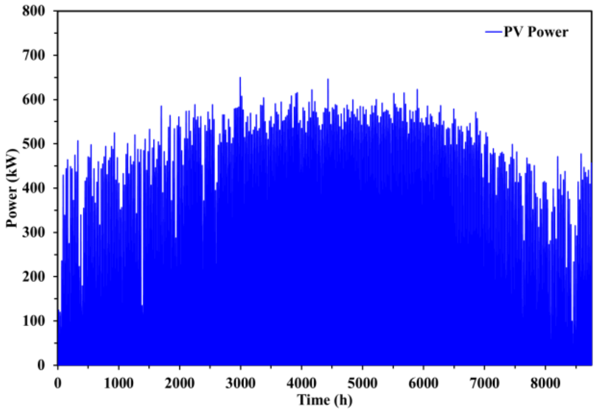
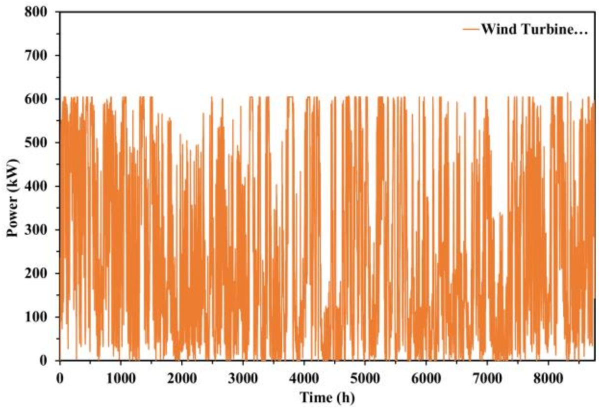


Fig. 8. Ambient temperature and wind speed through one year for Cairo.

Figs. 9 a) and b) present the electric power generated by the photovoltaic cell and the wind turbine over one year. The simulation result shows a variation in the electric power generated by PV throughout the year, with the maximum power produced in the summer months ranging from 530 to 615 kW and from 440 to 495 kW in the winter months.



a)



b)

Fig. 9. The electric production by a) PV panels b) Wind turbine through one year.

The electric power produced by the wind turbine has a big fluctuation ranging from 600 kW which is the rated power of the turbine to less than 30 kW depending on the wind speed. This fluctuation in power generated from the PV panels and the wind turbine can be attributed to the fluctuation in wind speed and solar radiation throughout the year as can be seen in Figs. 7 and 8.

Figure 10 presents the daily production of hydrogen by m^3/day through one year in Cairo based on electricity produced by the hybrid PV-wind System. From the figure, it Can be observed that the daily fluctuation in hydrogen production ranges from 700 to 2700 m3/day. This fluctuation can be attributed to the fluctuation in the electric energy produced, as shown in Fig. 11, where the daily energy produced fluctuated throughout the year from 2.98 to 10.66 MWh/day.

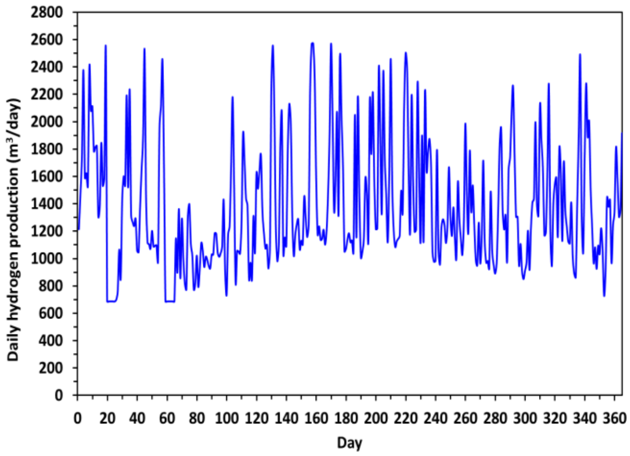


Fig. 10. The daily production of hydrogen in Cairo.

The annual electric energy produced by each of the PV panels and the wind turbine for different locations in Egypt was evaluated using the simulation program. To study the best renewable energy configuration for each city, the annual hydrogen production was calculated based on each renewable energy source throughout a year. The annual electric energy production from the PV plant and the wind turbine for selected three regions in Egypt is presented in Fig. 12.

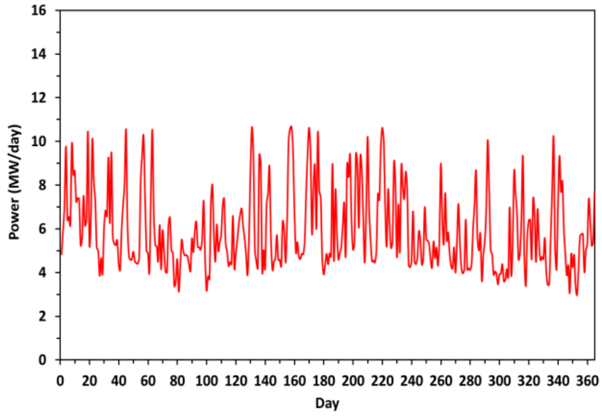


Fig. 11. The daily electric energy consumed by the electrolyzer.

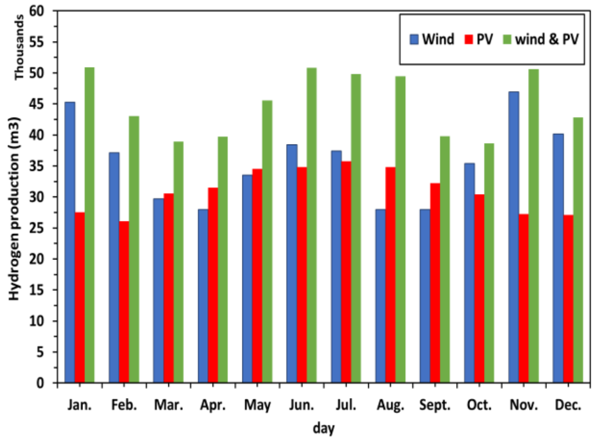


Fig. 12. The monthly hydrogen production at different renewable energy sources.

From the figure, it can be observed that the highest electricity production from the wind turbine can be found in El Zafranah city, with an electricity production of about 2131 MWh/year, and the lowest electricity production was recorded for Cairo, with an annual electric energy of 416 MWh/year. The highest annual electric energy produced from the PV modules was recorded for Aswan with a value of 1466 MWh/year, and the lowest electricity production was recorded for Cairo with a value of 1090 MWh/year. These results are reflected in the amount of hydrogen produced from each source. That can be attributed to the higher potential of solar radiation in Aswan City and the low value for Cairo relative to the other locations.

Figure 13 presents the annual electric energy produced from the PV modules and the wind turbine for the three selected regions in Egypt. From the figure, it can be observed that Elzafaranh is the highest area for producing electricity from the wind where the annual electricity production was 2131 MWh, while Aswan and Cairo produce 815.2 and 416.8 MWh of electricity from the wind turbine annually, respectively. Aswan is the best choice for the PV plant, where it produces electricity of 1466.4 MWh annually, while Elzafranah and Cairo produce electricity of about 1113 and 1090.3 MWh annually. These results significantly and clearly impact the amount of hydrogen produced by the same hybrid PV-Wind system in these regions. Figure 14 presents the quantity of hydrogen produced from the wind and PV units separately in each of the selected regions. From the figure, it can be found that the hydrogen generated in Elzafranah from Wind energy is about 0.76 Mm^3 representing 63.9 % of the total hydrogen produced by the hybrid system and the hydrogen generated from the solar energy (PV modules) is about 0.43 Mm^3. While for Aswan, the hydrogen generated from Wind energy is about 0.215 Mm^3 representing 37.2 % of the total hydrogen produced by the hybrid system and the hydrogen generated from solar energy (PV modules) is about 0.5 Mm^3.

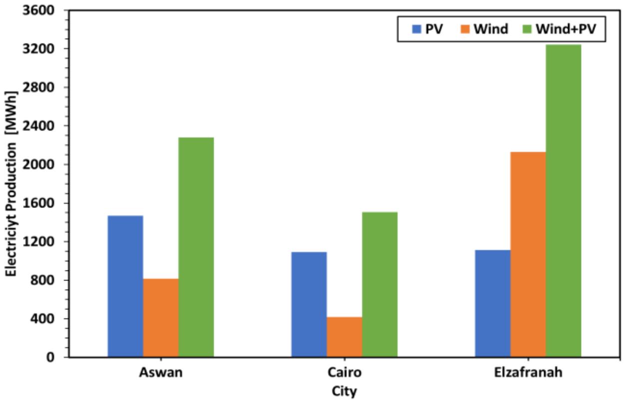


Fig. 13. The selected regions' monthly electricity production at different renewable energy sources.

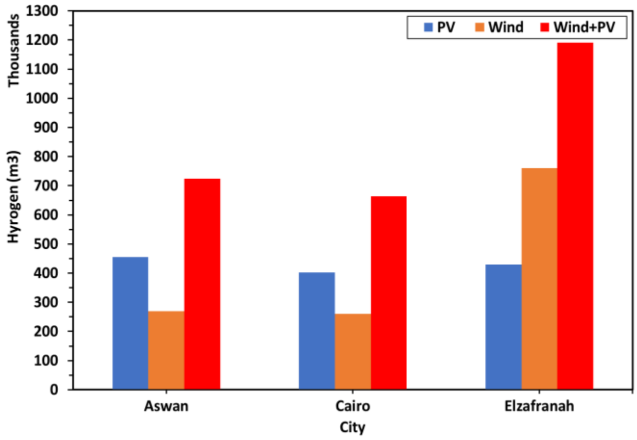


Fig. 14. The monthly hydrogen production at different renewable energy sources for the selected regions.

Table 2 summarizes the electric power generated by solar PV and wind turbines. Consequently, the hydrogen produced throughout one year from each energy source for Cairo, Aswan, and El Zafranha cities, respectively. From the table, it can be observed that Elzhfahana city has the highest electric generation. Consequently, it has the highest hydrogen production, which can be attributed to the high potential of wind speed in this region and the high potential of solar radiation.

Table 2. The power and hydrogen produced from PV and Wind turbine systems throughout the year for different regions

City	Power(MWh)			Hydrogen (m^3)		
	PV	Wind	PV+Wind	PV	Wind	PV+Wind
Cairo	1090.3	416.8	1507.1	403E+03	261E+03	663E+03
Aswan	1466.4	815.2	2281.6	455E+03	269E+03	724E+03
ElZafranha	1113	2131.3	3244.3	430E+03	760E+03	1190E+03

Equation 23 was used to calculate the LCOE from PV cells and wind turbine systems while Eq. 24 was used to calculate the LCOH for each renewable energy source and compare it with the LCOH produced from natural gas published in the literature. The economic study found that hydrogen produced from natural gas (blue hydrogen) is still the cheapest method, where its cost is about 2.55 \$/kg H_2 [35]. In the case of using solar cells, the cost rises to 4.19 \$/kg H_2 and reaches \$3.62 \$/kg H_2 in using wind turbines case as a source of electrical current for the electrolyzer. Table 3 compares the LCOH using PV, wind turbine, and natural gas.

Table 3. The levelized cost of electric energy and the hydrogen produced from each source

RE sources	LCOE (\$/kWh)	LCOH (\$/kg)
PV sustem	0.025	4.19
Wind Turbine system	0.021	3.62
Natural gases [35]	-	2.55

6. Conclusion

This paper presents a dynamic simulation of the performance of a hybrid PV/ wind turbine system for producing green hydrogen. The modelling and simulation were carried out using the TRNSYS17 platform to study the hybrid system's ability to produce hydrogen stably in several locations in Egypt with different weather conditions.

Producing hydrogen from new and renewable energy has the advantage of exploiting the surplus in producing electricity from these sources, which is difficult to store. The simulation results show that the Hydrogen produced in Cairo city represents 60.7 % and 39.3 % if it is produced from PV and wind turbines, respectively. For El Zafranaha City, the hydrogen production from PV and wind turbines represents 36.1 % and 63.9 %, respectively. Meanwhile, for Aswan City, the hydrogen produced from the PV system and wind turbine represents 62.8 % and 37.2 %, respectively. Combining the electrical energy produced by the PV modules and wind turbines leads to the production of hydrogen of about $6.63*10^5$, $7.24*10^5$, and $11.9 *10^5$ m^3 for

Cairo, Aswan, and El Zafranaha, respectively. Referring to the production cost, producing hydrogen from natural gas came as the best economic choice with a cost of 2.55 $/kg relative to the hydrogen produced from PV and wind turbines with a cost of 4.19 and 3.62 $/kg, respectively.

Although the hybrid solar and wind energy system has helped to partially solve the problem of energy instability, there is a need for further studies to increase the stability of the energy or hydrogen generated, and this may be by introducing another source that is not affected by weather conditions, such as biomass energy

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