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HYBRID RENEWABLE ENERGY SYSTEM FOR WATER DESALINATION: A CASE STUDY FOR SMALL GREEN HOUSE HYDROPONIC CULTIVATION IN EGYPT

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ABSTRACT

Energy and water availability are the most important factors for developing agriculture activities in arid and remote areas. This study aims to investigate the feasibility of using hybrid renewable energy systems to drive a reverse osmosis water desalination unit used for a greenhouse protected hydroponic cultivation in arid remote site located outside El-Tor city, South Sinai Peninsula, Egypt. The present study describes the installed PV water desalination system for driving water for a small green house hydroponic cultivation. For optimization purposes, the study presents a theoretical economic analysis of two hybrid systems; Photovoltaic/wind turbine (PV/WT) with and without backup diesel generator. In both cases the cost of wind turbine is considered actual and international cost (0.7 of PV cost). Both the photovoltaic and wind turbine each of 1 kW rated power with required electrical devices and storage batteries. HOMER software is used to simulate and analyze the system performance over 15 years lifetime based on the Net Present Cost (NPC) and the Cost of Energy (COE). Also, the capacity shortage is used as an evaluation criterion. The results showed that COE of PV/WT system is less than that of PV/WT/Diesel, while there is no capacity shortage in case of PV/WT/Diesel.

Keywords: renewable energy, hybrid PV/wind system, desalination system, hydroponic cultivation, water desalination.

1. INTRODUCTION

Availability of energy and water has a significant role in developing agriculture activities to produce food in remote arid and semi-arid villages in Middle East and North Africa regions. Water supplying and treatment need energy, and the food production required both of water and energy. Therefore, comprehensive approaches must be applied to solve scarcity problems of those three issues together rather than to solve each problem apart from the others [1]. Solving this problem in arid areas are not practical by building more conventional power plants or water delivery and using the traditional treatment facilities or the same old methods in growing crops. It must be solved in sustainable smart ways that would not only handle with their scarcity but also must concern about cost effective technologies for best use of energy and water to grow food [2].

Sustainable water production is by using non conventional water desalination of shallow depth brackish ground water which is abundant in those regions. Since 1960th, wide desalination technology applications are viable for areas where water is limited. Saline water desalination systems have been technically feasible but the economical feasibility is another important factor as desalinating brackish water is still expensive due to the high cost of required energy. Therefore reducing water desalination costs is an issue that is addressed in developing desalination technologies. Comparing different desalination technologies costs show that recently, Reverse Osmosis (RO) system besides providing desalinated water for drinking, can be feasible to supply water in cost effective for controlled agriculture and irrigation [3,4,5].

Moreover, effective approach adopted to meet the challenge of scarce energy resources in arid remote regions is by utilization of Renewable Energy (RE) technologies as those regions enjoy abundant solar energy and favorable wind energy. Small scale hybrid RE system has an important role to play in the sustainable use and management of the energy, water and food. In addition, hybrid RE systems can help to solve the intermittent nature of solar and wind energy problem [6, 7].

Using desalinated water for agriculture would be cost effective in case of controlled environment; as in protected hydroponic cultivation green houses technologies where most-effective water irrigation methods are used in cultivation. As irrigation does not require strict drinking-water standards, the cost of producing a lower desalinated water quality for irrigation purposes could be reduced [8, 9]. In the same time, combining greenhouses with one or more renewable energy desalination systems can help to widen the development of small scale cultivation in places where only saline or brackish water is available. Water requirements of crops in protected cultivation have a diurnal and seasonal fluctuation which is similar to the productivity variation of solar desalination as both processes are depend on solar irradiation [10]. Adding to what previously mentioned water use efficiency is improved in protected hydroponic cultivation which could generate much better income for the small-scale producers in arid remote regions [11]. Hydroponic systems might considerably improve the water use efficiency in greenhouse crops than in open fields as there is considerably less wind, reduced solar radiation, and higher atmospheric humidity.

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Therefore, this work aims to study the feasibility of using optimized stand alone hybrid renewable energy systems for brackish water RO desalination unit to be used for small greenhouse hydroponic cultivation in arid remote area located outside El-Tor city, South Sinai Peninsula, Egypt. The current study describes the installed PV water desalination system using RO technology in the above location to produce desalinated water for green house hydroponic cultivation purposes. The study also presents the design and economic analysis of the hybrid renewable energy systems that consist of photovoltaic (PV) panels and a small wind turbine (WT); each of 1 kW rated power, as well as necessary electrical devices and storage batteries. This study includes the first part of results of an applied project funded by the Science and Technology Development Fund (STDF), Egypt.

HOMER software package is used to simulate four cases for the two hybrid PV/wind turbine system performances and to reach the optimum configurations based on the objective criteria. The two systems are Photovoltaic/vertical axis wind turbine with and without backup diesel generator. In simulating the tow systems the cost of the wind turbine can be considered either actual or international cost (cost of WT is 0.7 of PV cost). The actual costs of the WT are high due to the cost of shipment, transportation and custom fees. This applied project is conforming with the Egyptian Government plans to build new communities in the Egyptian deserts gifted with abundant solar energy, favorable wind conditions besides the availability of large quantities of underground brackish water.

2. WATER DESALINATION USING RENEWABLE ENERGIES

2.1. Water desalination technologies

Fresh water is extremely valuable in remote arid areas. About 20% of the world's population lives in regions that don't have enough water for their needs (according to the World Health Organization). With the global population increasing, third of the planet will face water shortages by 2025 [12]. One of the most promising technologies adopted to get fresh water is water desalination. Although the major use of desalination is for drinking-water, yet, it can play an important role in achieving food security. In the last few decades, technical and economic studies show that, several technologies of water desalination systems for irrigation and drinking needs in remote arid areas became more viable. Based on installed capacity, the desalination technologies can be categorized as follows; i) about 44% of the installed desalination systems use membrane technology of RO, ii) the second capacity, 40% of the total capacity, is the thermal desalination process using multistage flash, iii) 7% of the total capacity is divided between different thermal technologies; such as 4% of the total capacity multiple-effect and 3% vapor compression, iv) the remaining 6% of the total capacity is membrane desalination such as electro dialysis and v) the last 3% is other new technologies [4].

The desalination technology is determined depending on the type of the water to be desalinated. Water has less than 10 g/liter of salt concentration (brackish water) can be desalinated using reverse osmosis or electro dialysis, while water has more than 30 g/liter of salt concentration (seawater) can be desalinated using distillation or reverse osmosis. It can be seen that RO is widely used because the advanced technologies in membrane enhance the desalination capabilities via modular construction to verify various needs of desalination water volumes [13].

2.2. Hybrid renewable energy systems

In remote and rural areas it is difficult and more expensive to extend electricity grid due to the nature of these communities, small and far from each other. So, renewable energy is appropriate solution to feed electricity for these areas, especially in case of use hybrid energy systems that incorporate more than one type of renewable energy such as solar and wind in the form of PV/WT systems. This hybrid system is more suitable according the site location weather conditions. Using different hybrid renewable energy technologies in a site can help to mitigate the effect of intermittent nature that some of them exhibit.

Results of theoretical and experimental studies of hybrid renewable energy systems have shown that the energy demands may be most cheaply met with a hybrid system than a WT or a PV system alone. This can only lead to better ways of using alternative sources of energy for the electric supply of a load. Different applied researches had been carried out show the better gain of energy as a result of combining more than one type of RE. Bekele and Palm [14] illustrated the use of hybrid PV/WT system in rural area in Ethiopian as a model for renewable energy dependence community. Other investigations are carried out using hybrid PV/WT with and without diesel system in Algeria [15,16] and Malysia [17] for rural electrification.

Different researches had been carried out on the performance of hybrid power systems in Egypt which enjoys abundant solar energy and favorable wind conditions indicating that the combined use of photovoltaic and wind turbines have good results for most of the day-night period and also for a very long period of the year [18].

2.3. Hybrid renewable energy system for RO-desalination plant

The most two cost effective membrane desalinations are electro dialysis and RO. Electro dialysis desalination is suitable for brackish water with TDS < 5000 ppm while RO desalination is more suitable for brackish water > 5000 ppm. In general using renewable energy for all desalination units and particularly RO and electro dialysis methods will reduce the negative effect on environment due to the high energy consumption which increases the generated CO_2 as well as the large amount of brine produced. The advantages of using renewable energy to drive desalination system rather than conventional fuel

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appears in protecting environment, and it is the only way to produce energy for scattered remote small areas to get their needs from fresh water for drinking and irrigation specially areas enjoyed abundant solar energy or favorable wind energy. The costs of water production will reduce remarkably with the development of advanced renewable energy technology and costs.

The economic feasibility of the different water desalination systems can highly affected by the required energy driving these systems, which arises the great advantages of using renewable energies in these applications [5]. Setiawan *et al.*, developed different methodologies using renewable energies driving water desalination systems using some developed criteria [19]. Forstmeier *et al.*, showed that desalination using RO can be used economically with the renewable energy and 51% of the world installed desalination systems are RO systems [20]. Between the renewable energies, the photovoltaic and wind energy can be considered more suitable for RO desalination systems in arid and remote areas due to the shortage of electric grid and fuels and their small maintenance costs with lower environmental impacts [21]. Added to desalinating water reviewing studies, Gopal *et al*., [22] presented a literature survey for hybrid renewable energy pumping systems.

2.4. Protected green house hydroponic cultivation

The challenge of the agriculture sector is to increase the production of food from soil and water, the amount of water consumed in agriculture purposes can be considered the largest demands from other purposes such as domestic or industrial [23]. Hydroponic (Soilless) cultivation systems represent an alternative to traditional agriculture, as they offer the possibility to reduce water use and to design nutrient formulations of the hydroponic solutions in order to maximize yield and quality of the products. This type of cultivation may be adequate to the weather and type of irrigation and nature of soil in the arid remote areas. Protected cultivation without soil in green houses has many advantages. The most important benefits of such systems include reduced fresh water consumption, protection from harmful external conditions (e.g., insects, sandstorm, cold weather), and improved quality and high yield of production. The main advantages of closed green house as presented in the literature are the improvement of: energy efficiency, water conservation, production rate, system control, and sustainable management. Added to these advantages there is a decrease of pesticides usage and reduction in costs [24-29]. Increased use of renewable energy as energy is the largest overhead cost in the production of agricultural greenhouse crops in temperate climates, leads to reduce greenhouse gas emission from fossil fuels and consequently a cost benefit of the closed green house concept.

3. PROPOSED SYSTEM- CASE STUDY

The case study describes the installed PV/RO desalination system for supplying the required water for a small green house for hydroponic cultivation. The system consists of the PV array with the required storage battery and the RO desalination unit with the required accessories.

El-Tor city (or Tor Sinai) is the capital of South Sinai Governorate (Egypt). It is located at 410 km east of Cairo (latitude of 28.22 ºN, Longitude of 33.61 ºE and Elevation of 483 m). The annual average wind speed about 5.5 m/s and the annual average daily horizontal solar radiation is; 5.74 kWh/m^2. Table-1 represents the site climatic data.

Choosing the location of the study is attributed to the fact that except for eight urban centers in South Sinai, the rest of the governorate is remote areas deprived of most basic services. The location is “Gabal El-Tour” 15 Km outside the city of El-Tour. It is an open area and plans are set to develop this area and encourage Bedouins to settle in it.

3.1. Load

The power required for the desalination unit is 400 watts in addition to the power of a small motor (1/3 HP) which is about 250 watts. Hence, 650 watts are required for 8-10 hours per day to store about 2 m^3 of desalinated water for green house, hydroponic cultivation. The well salinity is 3000 ppm which is not suitable for drinking or agriculture.

Table-1. Climatic data at Tor Sinai city.

Month	Air temp. °C	Relative humidity %	Earth temp. °C	Daily solar radiation horizontal kWh/m²/d	Atmospheric pressure kPa	Wind speed m/s
Jan.	11.8	46.8%	12.8	3.75	96.2	4.70
Feb.	12.7	40.8%	14.6	4.61	96.1	5.00
Mar.	16.2	36.6%	19.2	5.73	95.9	4.70
April	21.0	29.1%	25.0	6.67	95.7	6.00
May	24.7	27.9%	29.3	7.38	95.6	6.50
June	26.8	30.0%	31.7	8.01	95.5	6.00
July	28.2	31.0%	33.4	7.67	95.3	5.90
Aug.	28.1	34.2%	33.0	7.10	95.4	7.00
Sept.	26.4	38.1%	30.4	6.15	95.6	6.00
Oct.	22.8	43.4%	25.6	4.80	95.9	5.30
Nov.	18.1	42.9%	19.6	3.72	96.1	4.90
Dec.	13.4	46.1%	14.3	3.33	96.2	4.30
Ann.	20.9	37.2%	24.1	5.74	95.8	5.525

3.2. Desalination unit

In the last few decades, costs of renewable energy systems tend to decrease which make combining those systems with desalination system is comparable to fossil fuel costs especially for remote areas which have low population and suffer from energy and potable water shortage. The most widely used method of desalination is RO method using semi-permeable membrane due to the large drop in its prices and the large development in the manufacturing membrane technology. In RO desalination method the saline water with the highest pressure is desalinated by allowing it to pass through the membrane to the low pressure side leaving salts and other material behind.

The RO method is very sensitive to the difference between osmotic pressure which increase with salinity, consequently, increase required energy consumption. Therefore RO methods are more suitable for desalinated brackish water in remote areas with small demands with salinity less than 30,000 ppm. As seawater salinity is higher than 30,000 ppm especially in the Red Sea and Arabian Gulf (40,000 to 45,000 ppm) more energy consumption is required raising costs of those systems [30]. Fouling effect of seawater [31] is another important factor must be taken into consideration in the economical evaluation of these systems as it also leads to speed up membrane deterioration and increase energy consumption. The installed RO plant configurations as follows (Figure-1);

- RO desalination unit, 400 Gallons/day discharge to desalinate brackish water of 3000 ppm.
- Cartridge filter (1-5 Micron), capacity 15-20 Gallon/day, material polyethylene.

- RO module:
  - Capacity 15-20 gallon/day.
  - Membrane filters tech or toray.
  - With housing.
  - Working pressure 8-12 bar.

3.3. System components

The installed hybrid renewable energy system, for water desalination using RO unit and the protected green house hydroponic system as shown in Figures (2-a to 2-c), consists of;

- 8 PV modules - 140 watts each.
- Vertical axis wind turbine (VAWT) - 1 kW.
- 8 Batteries -100 Ah, 12 V each.
- Controller - 5 kW.

Figure-1. Installed RO plant.

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a) PV system.


b) Vertical axis wind turbine.


c) Protected green house hydroponic system

Figure-2. Installed hybrid renewable energy system for water desalination using RO unit and the protected green house hydroponic system.

4. SIMULATION AND OPTIMIZATION RESULTS

A very important use of hybrid PV/WT is already evident in many developing countries. In these countries, water pumping for drinking-water supply and farm irrigation is very popular and in many cases necessary step preceding water desalination. Correct study of the location and water pump's features are needed for the construction of the hybrid PV-wind turbine with the best possible performance and result.

In the following sections, HOMER software package studies the economical analysis of alternative hybrid energy system components to reach the optimum system configurations. It also provides sensitivity analysis for different system input parameters. HOMER software package was applied on the desalination solar system for four cases; i) PV/WT with actual costs, ii) PV/WT with international costs (cost of WT is 0.7 PV cost), iii) PV/WT with a diesel generator as a backup source with actual cost and iv) PV/WT with a diesel generator as a backup source with international cost. The objective of optimization is to minimize the net present cost of the system (NPC) and the cost of energy (COE). The four systems include storage batteries. For comparison, the lifetime of each system is taken as 15 years. Beside the systems NPC and COE the allowable energy shortage (capacity shortage) and the renewable fraction in case of a conventional energy generator are also considered.

Case 1: PV/WT with actual cost

The system components are as follows:

- 8 PV modules - 140 watts each.
- VAWT - 1 kW rated power.
- 8 Batteries - 100 Ah, 12V each.
- Controller - 5 kW.

Figure-3 presents the VAWT power curve and Figure-4 illustrates the system block diagram, while Table-2 shows the simulation results (NPC and COE).

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Figures 5&6 illustrate the cash flow summary and energy summary of the same case.

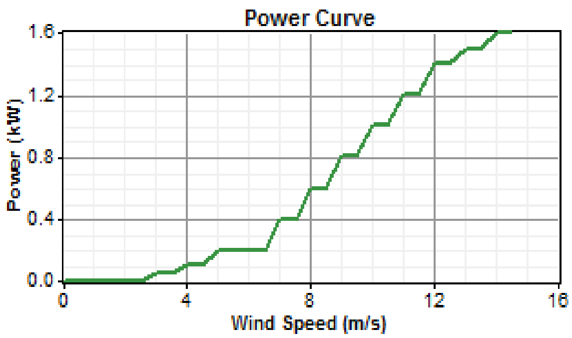


Figure-3. VAWT power curve.

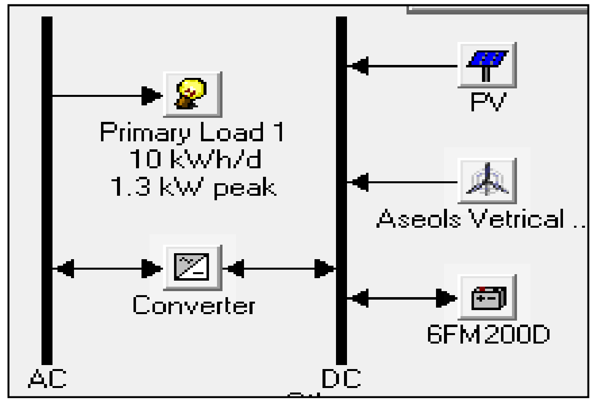
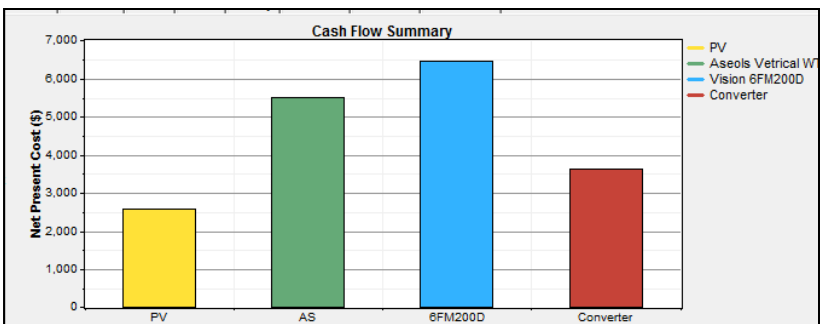


Figure-4. Block diagram of PV/WT hybrid system.

Table 2. NPC and COE of desalination unit with PV/VAWT energy system.

	PV (kW)	AS	6FM200D	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage
	1.2	1	4	5	CC	$ 10,251	801	$ 18,113	0.648	1.00	0.34
	1.2	1	4	5	LF	$ 10,251	801	$ 18,113	0.648	1.00	0.34



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	1,651	0	982	0	-71	2,562
Aseols Vetrical WT	5,000	0	491	0	0	5,491
Vision 6FM200D	1,800	2,799	1,964	0	-118	6,444
Converter	1,800	834	982	0	0	3,616
System	10,251	3,632	4,418	0	-189	18,113

Figure-5. Cash flow summary of PV/VAWT energy system.

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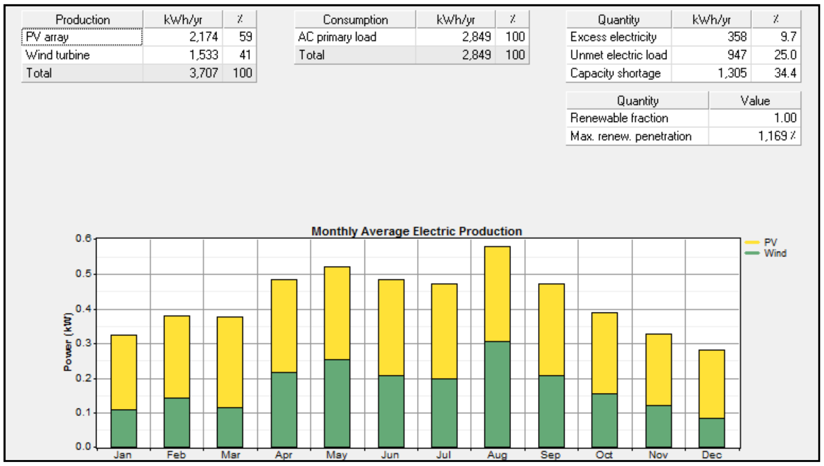

Figure-6. Energy summary of PV/VAWT energy system.

It could be seen in Figure-5 that the cost of WT is higher than the cost of PV panels, although it is known that the cost of WT is less than the cost of solar PV. The price of the procured wind turbine is high due to the cost of shipment, transportation and custom fees. Another run of the same system is presented using the international prices of wind turbines (Case 2). From table 2 the NPC of the system (case 1) is $18,113 and COE is $/kWh 0.648, which is high due to the high cost of the WT.

Case 2: PV/VAWT using cost of WT= 0.7 PV cost

Using the international prices of wind turbines (cost of WT = 0.7 PV cost) as an input to HOMER software, the results are illustrated in Figure-7 and Table-3. Both NPC and COE are $14,271 and $/kWh 0.51, respectively, which are less than case 1, due to the additional prices of shipment, transportation and custom fees of the WT, as shown in case 1. Table 2&3 show that the capacity shortage in both cases is 0.34.

Case 3: PV/WT with diesel generator

In this case a diesel generator of 1 kW is used as backup. The diesel fuel price is taken as $/L 0.4, due to the cost of transportation to Sinai. The NPC, COE and the renewable fraction; that is the percentage of energy supplied from PV and WT, are presented in Table-4. Figures 8&9 illustrate the cash flow and energy summary of the system.

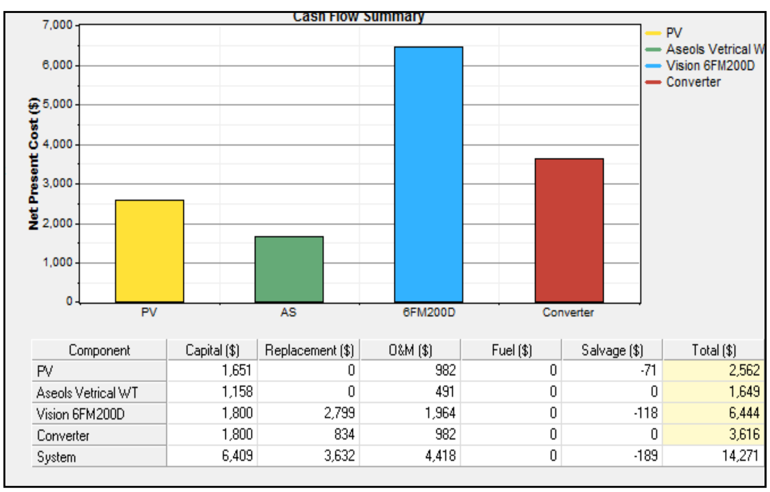

Figure-7. Cash flow summary of PV/VAWT energy system (modified WT cost).

Table-3. NPC and COE of desalination unit with PV/VAWT energy system (modified WT cost).

PV (kW)	AS	6FM200D	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage
1.2	1	4	5	CC	$ 6,409	801	$ 14,271	0.510	1.00	0.34
1.2	1	4	5	LF	$ 6,409	801	$ 14,271	0.510	1.00	0.34

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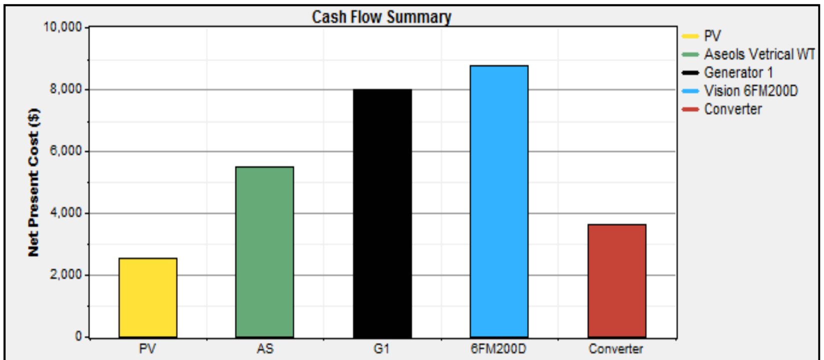
Table-4. NPC and COE of desalination unit with PV/VAWT/Diesel energy system.

	PV (kW)	AS	G1 (kW)	6FM200D	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	G1 (hrs)
	1.2	1	1	4	5	CC	$ 10,751	1,801	$ 28,436	0.763	0.63	0.00	463	1,403
	1.2	1	1	4	5	LF	$ 10,751	1,984	$ 30,232	0.811	0.74	0.00	433	2,316



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	1,651	0	982	0	-71	2,562
Aseols Vetrical WT	5,000	0	491	0	0	5,491
Generator 1	500	5,567	207	1,817	-81	8,010
Vision 6FM200D	1,800	5,097	1,964	0	-103	8,758
Converter	1,800	834	982	0	0	3,616
System	10,751	11,498	4,625	1,817	-255	28,436

Figure-8. Cash flow summary of PV/VAWT/Diesel energy system.

Production	kWh/yr	%
PV array	2,174	43
Wind turbine	1,533	30
Generator 1	1,402	27
Total	5,108	100

Consumption	kWh/yr	%
AC primary load	3,796	100
Total	3,796	100

Quantity	kWh/yr	%
Excess electricity	536	10.5
Unmet electric load	0.00000925	0.0
Capacity shortage	0.00	0.0

Quantity	Value
Renewable fraction	0.631
Max. renew. penetration	1,169 %

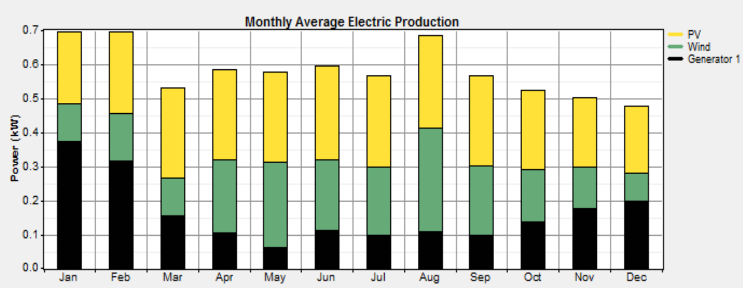


Figure-9. Energy summary of PV/HAWT/Diesel energy system.

From Table-4 it is clear that there is no energy shortage when diesel generator is used as a backup source (zero capacity shortage) whiles it was 0.34 in cases 1 & 2. The cost of energy is lower for the Cyclic Charging (CC) dispatching strategy ($/kWh 0.763) than the load following strategy (LF) ($/kWh 0.811). Both COE values in this case are higher than case 1 ($/kWh 0.648) and case 2 ($/kWh 0.510) due to the cost of diesel generator fuel consumption. These values do not take into consideration the cost of CO_2 emitted. Taking the cost of avoided CO_2 into consideration the modified COE will be $/kWh 0.673 [32].

From the cash flow summary, Figure-8, it could be seen that over WT lifetime (length of the simulation run; 15 years) the total cost of PV modules and WT is less than the total cost of the diesel generator as the increase in the renewable energy cost is due to the cost of batteries and inverter. Excess energy is about 10% of the energy generated from renewable resources. PV supports 43% of the load requirements, while the wind turbine supplies about 30% (Figure-9).

Case 4: PV/WT with diesel as backup, Cost of WT=0.7 PV cost

In this case; a diesel generator 1 kW is used as backup and the cost of wind turbine modified to be 0.7 of the PV cost. Table 5 illustrates NPC and COE while Figures 10&11 illustrate the cash flow and energy summary of the system in this case.

Table-5 shows that COE in this case is $/kWh 0.745 for CC dispatching strategy and $/kWh 0.794 for LF. Excess energy is about 10.5% of the energy generated from renewable resources. Figure 11 explain that the fraction of energy supplied by PV and WT remains the same as in case 3.

Table-5. NPC and COE of desalination unit with PV/VAWT/Diesel energy system (modified WT cost).

	PV (kW)	AS	G1 (kW)	6FM200D	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	G1 (hrs)
	1.2	1	1	4	5	CC	$ 10,751	1,733	$ 27,767	0.745	0.63	0.00	463	1,403
	1.2	1	1	4	5	LF	$ 10,751	1,919	$ 29,595	0.794	0.74	0.00	433	2,316

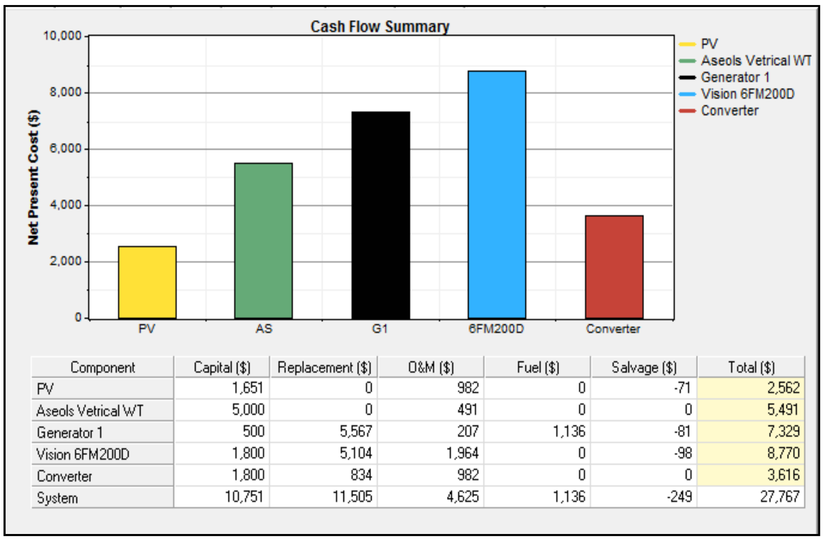


Figure-10. Cash flow summary of PV/VAWT/Diesel energy system (modified WT cost).

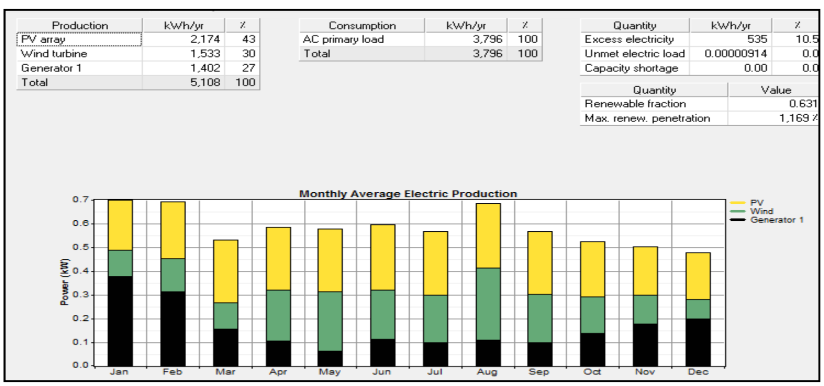


Figure-11. Energy summary of PV/VAWT/Diesel energy system (modified WT cost).

A summary of the economic results (NPC & COE) for the four simulated cases is exhibited in Table-6. The summary shows that PV/WT/DG system is more expensive (based on NPC of each case) and the cost of energy is higher. The only advantage is that the capacity shortage is zero.

Table-6. Summary of results (NPC & COE) for all cases.

System	NPC ($)	COE ($/kWh)	RF %	Energy shortage %	Excess energy %
PV/VAWT	18,113	0.648	100	34.4	9.7
PV/VAWT *	14,271	0.510	100	34.4	9.7
PV/VAWT/DG	28.436	0.763	73/27	0	10.5
PV/VAWT/DG*	27,767	0.745	73/27	0	10.5

*Case of reduced WT price = 0.7 PV cost.

5. CONCLUSIONS

The present paper presents a photovoltaic/vertical axis wind turbine driving reverse osmosis water desalination unit for hydroponic cultivation in controlled green house, in El-Tor city, South Sinai Governorate (Egypt). The installed PV/WT/RO system with the required storage batteries and controls was described. HOMER software package was used for economic optimization of four cases of the PV/WT with and without diesel generator with actual and international costs of the WT. The criteria used in economic optimization are the Net Present Cost (NPC) and the Cost of Energy (COE). For technical evaluation, the capacity shortage in the supplied energy is used as an evaluation criterion. The results showed that for PV/WT system the actual NPC over 15 years lifetime is $18,113 and COE is $0.648. The energy summary showed capacity shortage of about 34%. For PV/WT/Diesel, the NPC is found to be $28, 436 and COE is $0.763 with zero capacity shortage. Recorded excess energy suggests modification of desalination unit working schedule to run at excess power periods. This will reduce the capacity shortage and COE.

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