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Hybrid Nanocrystal Photovoltaic/Wind Turbine Power Generation System in Buildings

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ABSTRACT

With increasing concern of global warming and the depletion of fossil fuel reserves, world is looking at sustainable energy solutions to preserve the earth for the future generations. Renewable energy resources such as solar, wind and hydro power energy hold the most potential to meet our energy demands and protect environment. Many researches are presented to develop the solar panels and wind turbines through their power efficiency and reasonable price. Nanotechnology and Nanomaterials are used to improve the properties of the photovoltaic panels in order to produce more electricity power and increase their useful life. So, this research presents an optimal design of a hybrid Nanocrystal PV- Wind turbine energy system, where it can use both of renewable energy sources to generate the power with a main goal to minimize the plant establishment cost, utilize the land used and give earth a healthy environment. A proposed Nano hybrid system is applied to power eco-house in the western desert in Egypt as a case study. On a techno-economic basis, the proposed case study obtains the economical installation and operation costs of the hybrid system. Taking into account the life cycle costing method to evaluate the proposed system in order to encourage the householders and other buildings' owners to apply this system in their buildings particularly in the desert zone where the public utility is not available.

1. Introduction

World will face a global energy crisis due to a decline in the availability of fossil fuel and recommendations to decrease the dependency on it. Environmental pollution has shifted the researchers' focus towards non-conventional sources of energy due to the conventional sources of energy and its limited quantity, which are in plenty [1]. This has led to an increasing interest in alternate power/fuel research such as fuel cell technology, hydrogen fuel, biodiesel, solar energy, geothermal energy, tidal energy and wind [2]. Today, solar energy and wind energy have significantly alternated fossil fuel with big ecological problems.

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Nanotechnology is a technology that enables to develop materials with improved or totally new properties. It is an extension of the sciences and technologies already developed for many years to examine the nature of our world at an ever smaller scale. The use of nanotechnology materials and applications in the construction industry should be considered not only for enhancing material properties and functions but also in the context of energy conservation [3].

This research aims to introduce a prototype of family eco house that depends mainly on a hybrid Nano solar & wind energy system to run the electrical appliances in the Egyptian desert zones.

2. Renewable Energy

Energy resources can be classified into two categories: either renewable or non-renewable. Non-renewable resources are used faster than they can be replaced. Other resources that are called renewable will never run out. Oil, natural gas, and coal are currently abundant and relatively inexpensive, but using them causes air and water pollution, degrades large areas of land, and releases greenhouse gases to the atmosphere (as shown in fig. 1) [4].

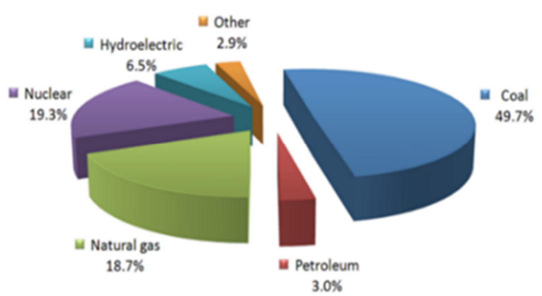

Fig. 1. Total pollution from power plants, 2012 [4]

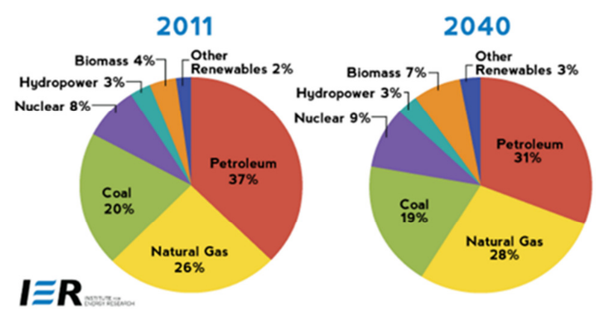

Fig. 2. Renewable, non-renewablee consumption in world in 2011 & 2040 [1]

There are several types of renewable energy resources as the following:
Solar: the conversion of solar energy into heat or electricity using solar panel or photovoltaic
Wind: the conversion of wind energy into electricity using wind turbines.
There are several benefits of shifting to renewable energy sources as the following:

- Less vulnerable and reduce air pollution,
- Improve national security and reduce trade deficits, create jobs and save money.

Figure 2 shows that predicted demand of renewable energy will be increased by 2040 [1].

2.1 Solar Energy

Solar energy is clean type of energy with a diversity of applications, decentralized nature and availability, it will represent a suitable solution for energy requirements especially in desert and rural areas. Solar energy will protect these areas from pollution and avoid large amounts of CO2 emissions. Due to its geographic location, Egypt enjoys sunshine all year, with direct solar radiation which reaches 6 - 7 KWh/m2/day [5].

2.1.1 Photovoltaic system (PV)

PV system consists of one or more modules, which convert sunlight directly into electricity, and a range of other system components that may include an AC/DC inverter, back-up source of energy, battery to store the electricity (as shown in figure 3) [6]. A typical PV module measures about 0.5 square meters and produces about 75 watts of DC electricity in full sun [7].

Disadvantages: Solar energy is not predictable and also the power generation depends on the amount of sunlight. Thus there is no generated power during nights and overcast conditions. The efficiency is only 17% and the payback period is large (approx. 8-10 years) [8].

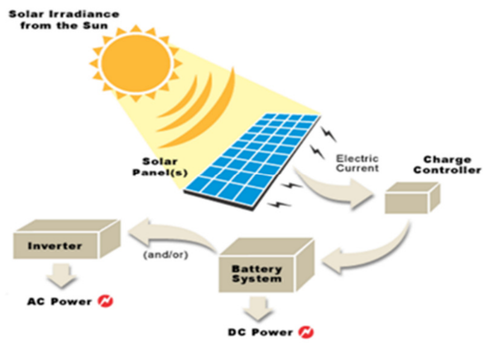

Fig. 3. Photovoltaic system components [3]

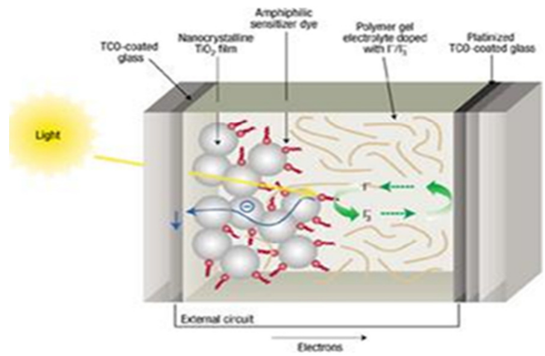

Fig. 4. A novel composite film comprising a mesoporous, nanocrystalline TiO2 film [9]

2.1.2 Nano PV system (Nanocrystal PV)

Nanocrystal solar cells are solar cells based on a substrate with a coating of nano-crystals. The nanocrystals are typically based on silicon, CdTe or CIGS and the substrates are generally silicon or various organic conductors (as shown in fig. 4). A thin film of nanocrystals is obtained by a process known as "spin-coating". Solar cells made of silicon nanocrystals could prove to be cheap, giving them a significant advantage over other approaches to high-efficiency solar cells. For example, advanced "multi-junction" cells have shown efficiencies of more than 40 – 65 percent [9].

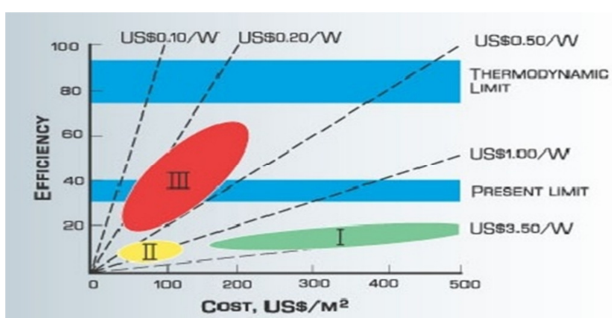

Fig. 5. Nano 3G PV Efficiency and Costs. Source: University of N. S. Wales [10]

Advanced types of photovoltaic panels like Nano-crystal, Nano-silicon, Perovskite and Biohybrid solar cells have high power efficiency and less environmental pollutant. Nano-solar has a carbon footprint of 14 grams of carbon dioxide equivalent per kilo Watt-hour (g CO2 eq/kWh) over the full product life cycle from aluminum to the recycling of the panel after 25 to 30 years. Nano-solar carbon footprint is similar to first solar and has almost 2.8 times fewer emissions than crystalline silicon solar modules [10]. Figure 5 shows the efficiency and costs projections for the first, second and third generation of PV technology (Thin films). Nano PV's (3G) efficiency will be 40 % and the production cost will be below 0.50$/W [10].

2.2 Wind Energy

The wind energy output for a wind turbine varies with geographical location, meteorological conditions and local positioning of the turbine. A wind turbine is a device that converts kinetic energy from the wind into electrical power. The two determining factors for power output from a wind turbine are the turbine diameter and the local wind speeds [11].

2.2.1 HAWT (Horizontal Axis Wind Turbine)

There are two types of turbines: vertical & horizontal axis turbine as shown in fig. 6.

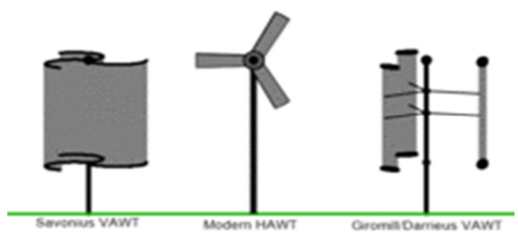

Fig. 6. Vertical & horizontal wind turbines [11]

Advantages: A gear based type of turbine is capable of smooth motion even at high velocity.

- Minimum requirement of wind is only 5 m/s which is easily available in an open land.
- It has a life span of 20-25 years and maintenance cost is just 1-2% of its installation cost.
- It is smaller in size, thus occupies less space and has a light weight.

***Disadvantages*:** The wind is irregular and consistent wind is needed for continuous power generation. Large area is required for sitting up of a wind generation system plus the capital cost is also quite high [4].

2.3 Hybrid Solar/Wind System

Hybrid system is made by combining two or more different elements; this research tries to combine nanocrystal photovoltaic panels and wind turbine for the following objectives: [12].

- Increasing output and less area is occupied and protect environment.
- System can be designed for both off grid and on grid.

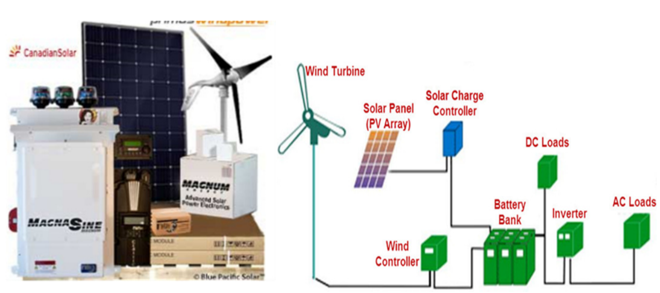

Fig. 7. Hybrid PV / HAWT System Components [12]

2.3.1 Hybrid nano PV/wind turbine system components

Nano PV Array Panels: Nano-Crystal PV panels are connected in series or parallel and in proper orientation. (As shown in fig. 7)
Wind Turbine: Installed on top of a tall tower, collects kinetic energy converts it to electricity.
Solar and Wind Controller: Control batteries bank is charged reasonably and safely.
Batteries Bank: Single battery or multiple batteries are connected together to provide backup in emergency cases. As well store charge during peak output period.
Inverter: A power converter that inverts the DC power from panels into AC power. However, by combining these two intermittent sources and incorporating maximum power point tracking (MPPT) algorithms, the system's power transfer efficiency can be improved significantly as shown in fig.8.

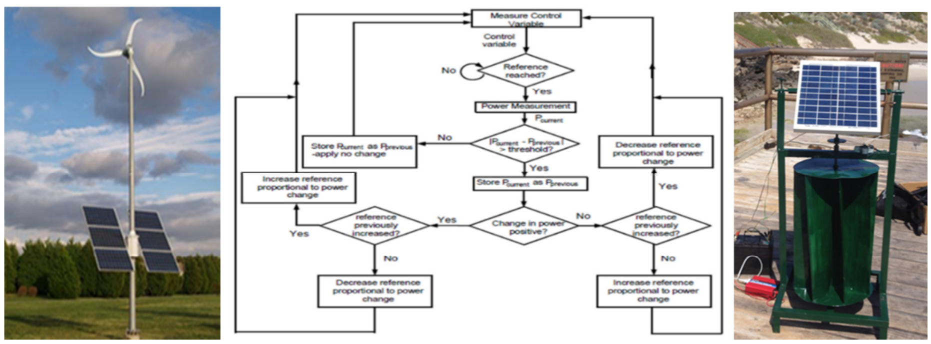

Fig. 8. MPPT, Maximum Power Point Tracking [12]

Advantages of hybrid system are low operating cost, easy to charge, high power quality and less area used. In addition, Nano hybrid system is more efficient, self-cleaning and low negative impact on environment.

3. Case Study

The proposed research case study is a new eco-house in the south western desert in Egypt which well be constructed by the private sector without governmental utility except the main roads and transportations. This case study encourages this sector to develop the huge desert areas in Egypt in order to create new settlements for Egyptian people far away the narrow and crowded Nile river valley. In addition, the Western desert is considered one of the promising areas in Egypt for future extensions due to its natural resources. This new eco-house depends mainly on solar & wind energy to run its electrical appliances. The average daily solar energy incident on the horizontal plane in the western desert is about 6 kWh/m2/day as shown in fig. 9 [13], which is considered to be a high solar energy input. The average wind velocity in this area is 6-7 m/s [14].

3.1 Environmental Data of Case Study Area

The site is located in the south of western desert in Egypt which has a high solar radiation and wind velocity.

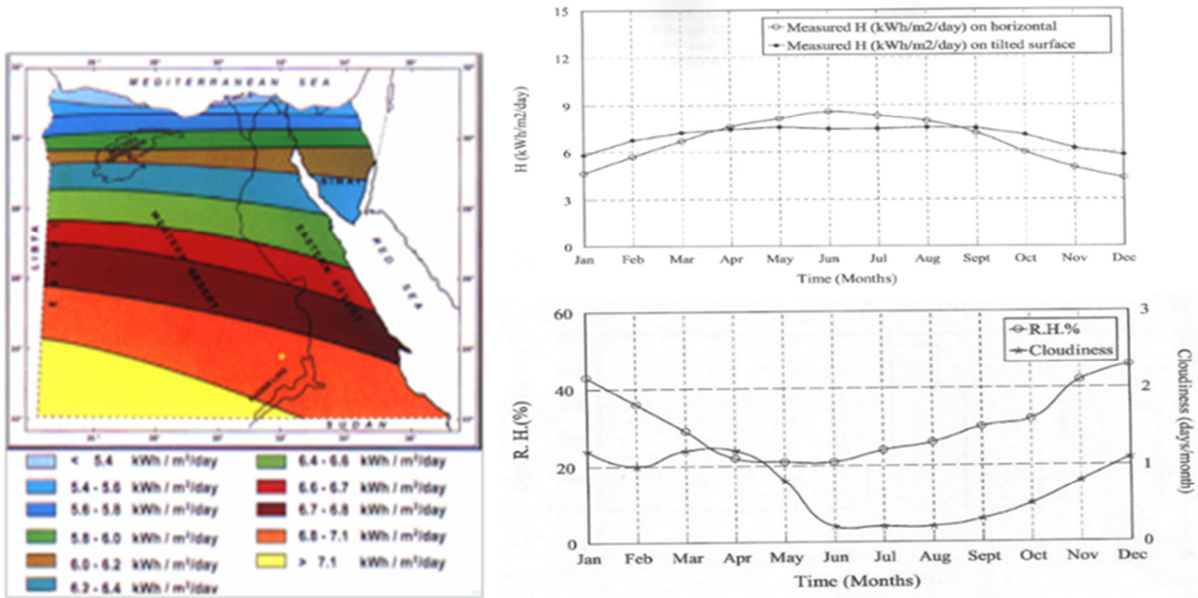

Fig. 9. Solar radiation on horizontal/ tilted surface and monthly mean values of R.H. and cloudiness in south western desert, Egypt with the latitude angle (j=25°) [13]

3.1.1 Solar radiation

Figure 9 shows the monthly mean values of relative humidity, and cloudiness (number of cloudy days per month) in the south the western desert and Oases [13]. It is clear that the relative humidity increases during winter months and decreases during summer. The maximum number of cloudy days is considered to be 2 days during winter and spring.

3.1.2 Wind speed

Wind speed in the case study area according to the wind atlas of Egypt which is showed in fig. 10 is between 5-7 m/s. The average wind speed is 7 m/s which is considered an adequate speed to power the wind turbine and generate electricity for the eco-house [14].

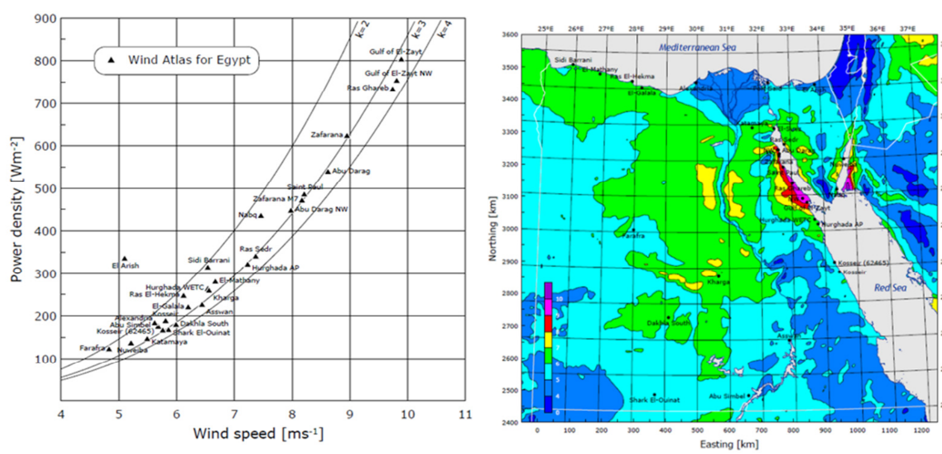

Fig. 10. Wind speed in Egypt m/s [14]

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3.2 Proposed Eco-house

The proposed family eco-house is 85 m^2 (shown in fig. 11) which contains: living, dining, two bedrooms, kitchen, bathroom, and terrace. According to the ecological strategy, there is no air

in eco-house

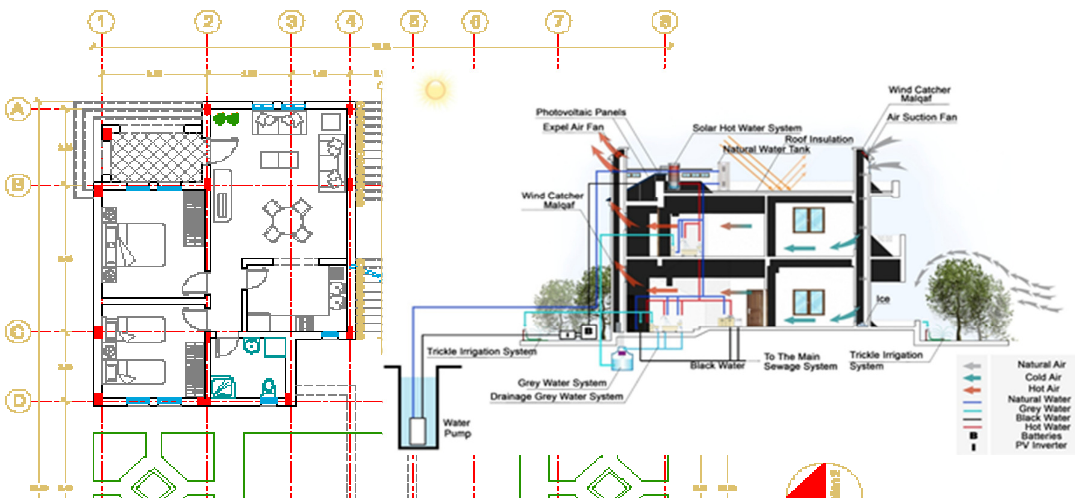

Fig. 11. Ground floor plan & schematic section for an eco-house (made by the researcher)

3.2.1 Photovoltaic System Design

- ***The average energy requirements of a typical house in desert zone***

The family houses in the south of western desert in Egypt are expected to be very simple and do not need large quantities of electrical energy for lighting or operating electric appliances. It is expected that most of these houses will have electrical loads as shown in Table (1). (Electricity load is calculated for an eco-house).

The average daily load energy of western desert family house = 4.85 kWh/day (1)

Water pumping is an important item in designing PV systems for these zones, as it is very important to obtain drinking water for people and animals. It was reported that the depth of the water level in the south western desert is ca 30 m underground [5].

If ca 1.5 m^3/day of water is required and taken from a depth of 30 m under ground level as an average consumption value, the following equation can be used

Pe = (p gh Q)/(ηp ηm) (Buresch, 1983)

Assuming that: ηp = 0.45, ηm =0.85, Q =0.5 m3/h and h= 33.5 m

Pe (Electrical Power) = 120 W (2)

- ***Photovoltaic system design for the western desert family house model***
- ***PV array sizing***

$$\text{PV Area} = \frac{E}{H \times \eta_{PV} \times TCF \times \eta_{out}} \quad [15]$$

Journal of Advanced Research in Materials Science
Volume 40, Issue 1 (2018) 8-19

If the cell temperature is assumed to reach 60 C˚, then the temperature correction factor (TCF) will be 0.8. Assuming η PV = 17%, η out = 0.765

PV (Area) = 4.85 / 6 × 0.17 × 0.8 × 0.765 = 7.77 m2 (based on equation no. 1 result) (3)

PV Peak Power = PV area × Solar Peak Power (1000W) × η PV = 1309 W
PV cost according to the market price = 4850 w/h × 0.7$ = 3395$ (4)

Table 1
The daily energy load for case study residential unit (Made by the researcher)

Load	No. of units	Load power (W)	Winter operating periods/day	Spring operating periods/day	Summer operating periods/day	Autumn operating periods/day
DC lamps (light)	3×15 10×5	Led 105	17.00 to 22.00	19.00 to 23.00	20.00 to 24.00	19.00 to 23.00
Refrigerator AC	1	100	24 h/day	24 h/day	24 h/day	24 h/day
TV & Receiver DC	1	80	17.00 to 22.00	18.00 to 23.00	17.00 to 24.00	18.00 to 23.00
Computer & Printer DC	1	100	17.00 to 19.00	18.00 to 20.00	19.00 to 21.00	18.00 to 20.00
Washing machine AC	1	250	12.00 to 14.00	12.00 to 15.00	12.00 to 16.00	12.00 to 15.00
Electric Fan DC	3	40	_	12.00 to 17.00	11.00 to 19.00	12.00 to 17.00
Motor + Pump AC	1	120	12.00 to 13.00	11.00 to 13.00	10.00 to 13.00	11.00 to 13.00
Total Energy (W h/day)			4145	5010	5170	5010

- ***Design of the Storage System (Batteries)***

Battery storage = NC EL / DOD × η out [15]
NC: Number of continuous cloudy days according to fig. (9) = 2 days
DOD: The allowable depth of discharge for the batteries

Battery storage = 4850 × 2 / 0.8 × 0.765 = 15850 W h (5)

If a 24 V system is chosen the required Amp. Hours of batteries = 15850/24= 660 AH
This battery bank can drive the loads for 2 days without any sunshine (according to fig. 9)

- ***DC/AC Inverter***

Total power of AC loads = 100 + 250 + 120= 470 × 1.2 = 564 W (according to table: 1) (6)
The specifications of inverter will be 564W, 24 VDC, and 220 VAC.

3.2.2 Wind turbine

Small HAWT (generates >5kWh), it fixed on roof or site with 12 m height from ground level.

3.2.3 Proposed hybrid nano-crystal PV/HAWT

The available Nanocrystal PV in the international market has 22 - 27% efficiency [9]. The eco-house electricity load should be covered by the Nano-hybrid system. Table 2 shows the available and suitable Nano-hybrid system in the market and explains its components and specifications as the following: (the system price is 9,759$) [16].

Table 2
The proposed hybrid system which is available with its specifications [16]

Items	Part Number	Array Size Watts	Daily PV Array / Wind Watts	Voltage DC / AC	Inverter Continuous AC Output Watts	Inverter Continuous AC Output
MidNite Magnum MNEMS4448PA	PRIMAG -48- 3900	3,900 W	19,500W - 1,440 Watts	48VDC / 120 | 240	4,400 @ 240VAC	30AAC

3.3 Economical Evaluation of Proposed Alternatives

To evaluate this proposed hybrid system through economical basis, it should be compared versus other power generation systems like public utility by calculation their installation and operation costs through life cycle of each system. Taking into account that the governmental subsidization of electricity won't be existed in the nearest future in Egypt. The economical techniques which used to compare between different alternatives are payback period & life cycle costing methods. The recent interest rate is 12% according to C.B.E [17].

3.3.1 Life Cycle Costing (LLC) Method Equations

F = $P\,(1+i)^n$ A = $\frac{P\,(1+i)^n \times i}{[(1+i)^n - 1]}$

where: P: Present amount of money - F: Future amount of money - I: Interest rate per period
N: No. of interest periods (years) - A: Uniform series of end of period (annual payments).

Alternative no. 1: PV Panel System

The initial cost of PV system = PV array cost (according to the market price) + first group of batteries cost + BCC cost + inverter cost + auxiliaries cost (based on the equations no. 3,4,5,6 results)
The initial cost of PV system = 4850 w/h × 1$ + 10% × 3,395$ + 2400$ + 1000$+ 600$ + 250$ = 9439.5$
Maintenance cost = 1% × 7,985$ = 79$ / year, PV useful life is 25 years

Alternative no. 2: Wind Turbine WT System

The initial cost of wind turbine cost = 4850W × 2000$ = 9,700$ (according to the market price)
Maintenance cost = 1% × 9,700$ = 97$ / year, WT useful life is 25 years

Alternative no. 3: Hybrid NCPV/HAWT System

Initial Hybrid system cost = 9,759$ [16] (according to table no. 2)

Maintenance cost = 1% × 9,759$ = 97.6$ / year, Proposed Hybrid system useful life is 30 years (Maintenance and replacement costs are assumed)

3.3.1.1 Present worth method (PW)

The PW method requires conversion of all present and future payments to a baseline of today's costs as shown in the table 3,

Table 3
Comparison between three alternatives through the present worth method

	Item	Alternative 1 PV Panels		Alternative 2 Wind Turbine		Alternative 3 Hybrid NCPV/HAWT	
		Original	P.W.	Original	P.W.	Original	P.W.
Initial	Initial Cost	9439.5$	9439.5$	9,700$	9,700$	9,759$	9,759$
	Useful life	25 years, i = 12%		25 years, i = 12%		30 years, i = 12%	
Replacement	PW of Replac -ement Cost P1 8 years, P2 16 years, P3 24 years, P4 30 years	2400$ P/F, I, n Every 8 years	$P = \frac{F}{(1+i)^n}$ P1 = 969.3 P2 = 391.5 P3 = 158.1 -	2,000$ Every 8 years	$P = \frac{F}{(1+i)^n}$ P1 = 807.8 P2 = 326.2 P3 = 131.8 -	1,000$ Every 10 years	$P = \frac{F}{(1+i)^n}$ P1 = 321.97 P2 = 103.66 P3 = 33.37
	Total PW Replac. Cost		1518.9$		1265.8$		459.00$
Salvage	Salvage Cost P/F, I, n	1,600$	$P = \frac{1,600}{(1+0.12)^{25}}$ (94.12$)	1,900$	$P = \frac{1,900}{(1+0.12)^{25}}$ (111.76$)	3,000$	$P = \frac{3000}{(1+0.12)^{30}}$ (100.13$)
Annual	PW of Maintenance & Operation Cost	79$	$P = A\frac{[(1+i)^n - 1]}{(1+i)^n \times i}$ 619.6$	97$	$P = A\frac{[(1+i)^n - 1]}{(1+i)^n \times i}$ 760.78$	97.6$	$P = A\frac{[(1+i)^n - 1]}{(1+i)^n \times i}$ 786.22$
	N P W	11,483.9$		11,614.8$		10,904.1$	
	Total Saving	579.78$		710.70$		-	

Alternative no. 3 (Nano hybrid system) is more economical proposal than the others.

3.3.2 Results (kWh electricity cost of the three alternatives)

The life cycle output energy= 4.850×365×25= 44256.25 kWh
The cost of 1 kWh from the PV = 11,483.9$/44256.25 = 0.259$/kWh
The cost of 1 kWh from the WT = 11,614.8$/44256.25 = 0.262$/kWh
The cost of 1 kWh from the Nano Hybrid sys. = 10,904.1$/53107.50 = 0.205$/kWh

Table 4
PV, Wind Turbine, Hybrid System and governmental electricity

Items	PV	WT	Nano Hybrid Sys	Public Utility
kWh Cost	0.259$	0.262$	0.205$	0.085$ *
Useful Life	25	25	30	-
Availability on Site	Available	Available	Available	NON

*Governmental electricity tariff of 1 kWh without subsidization according to the Ministry of electricity and renewable energy, Egypt 2017 [18].

- Comparison Result: The Proposed Nano hybrid system is the economical alternative 0.205$/kWh.

4. Conclusion

Renewable energy is the actual solution to face the future challenges in the energy demand in Egypt specially, solar and wind energy. In addition, they protect environment from CO2 and other green gas emissions which released from fossil fuel energy resources. Renewable energy is more effective when it uses in ecological buildings where no air conditioning, electrical heaters and heavy consumed energy appliances are. Eco-house depends mainly on the natural resources such as sun, wind, ground water and local materials.

Conventional PV panels have low efficiency comparing with the advanced types like Nano-crystal, Perovskite and Biohybrid solar cells and nanomaterials which are used in new PV production like TiO, CdTe, and GIGS. Proposed hybrid Nano solar and wind turbine energy is the optimum solution to power the building with a high efficiency throughout all seasons and it uses less area on building roof or site land and it self-cleaning system as well.

Hybrid NCPV/HAWT system is an adequate energy generation system for an eco-house in the desert or rural zone where the main services are not available such as electricity and drinkable water. Nanocrystal photovoltaic panels and wind turbines systems are not only clean and renewable sources of energy but also they don't cause pollution during their use. According to the economical vision; electricity which comes from the public utility is cheap compared with the renewable energy resources, but it isn't available in the desert zones. The proposed hybrid system used in the desert & rural zones to generate electricity is very effective particularly when its life cycle cost is competitive with the other types of conventional energy sources.

Western desert in Egypt is considered a high potential area for new communities' establishment due to its climate and natural resources such as sun radiations, ground water and wind speed particularly its middle and southern parts. Paved and lighted main roads and public transportations should be provided by the government to encourage the private sector to investment in the western desert.

Proposed hybrid Nano energy system can be used in a large scale to generate the energy demands for the residential, commercial, recreational and other types of new or existing buildings. On the other hand, the high initial costs, the lake of qualified skilled workers and the difficulty of convincing people to accept the advanced ideas represent the challenges of the sustainable technology applications. Finally, the public awareness is highly recommended.

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