Hybrid energy efficiency mapping in major Saudi locations using small wind turbine-solar systems

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Abstract. The use of fossil fuels of all kinds, such as natural gas, coal and petroleum in energy production, is the main cause of environmental pollution from air, water and soil, which is the direct cause of acid rain, the destruction of forests, the acidity of lakes, and the extinction of many living creatures that could not resist what happened Burning this fuel is due to a change in the surrounding environment. From this, it becomes clear to us the need for new sources to produce clean energy that does not pollute the environment, and work must be developed on these new sources for use in the production of clean energy in the coming years. The purpose of this work is to determine the efficiency of vertical axis turbines to be among the components of a hybrid system (solar/wind) to generate electric power in the Kingdom of Saudi Arabia. The work seeks to answer the research question, what is the efficiency of vertical axis turbines in generating electricity within a hybrid system (solar/wind) to generate electric power in the Kingdom of Saudi Arabia. The aim of the work is to analyze the vertical axis turbines and determine efficiency within the hybrid system in the regions of Saudi Arabia. There are many renewable energy sources (wind, solar thermal energy, solar photovoltaic, biomass, small and large hydropower and geothermal energy). But their efficiency is not stable from time to time, so the idea of hybrid energy came to make up for the shortage, by integrating the energy source Renewables with one or more other sources of energy (In 1999, McGowan and Manwell (1999) presented a summary of WND-PV-DSL HPS progress in the United States.) whether it is a non-renewable or renewable source [1].

Keywords: wind energy, renewable energy, solar energy, hybrid energy, wind energy in Saudi Arabia, renewable energy in Saudi Arabia, GHI in Saudi Arabia.

1. Introduction

1.1. Wind energy

Wind has kinetic energy that can be converted into electrical energy by turbines connected to fans of many types, and this type is abundant, renewable, widely distributed, clean, does not produce greenhouse gases emissions during operation, consumes no water, uses little land, and is less expensive than the physical aspect [2]. Wind energy can be classified into onshore and offshore according to the location of the facility. Offshore wind energy is characterized by stability, strength, and less visual impact, but the construction and maintenance costs are high [3]. Wind energy can be benefited from by connecting generators to the network, as is the case in large, medium, megawatt and even small systems that are usually separated from the network and used in isolated areas.

1.2. Solar energy

Solar energy is the cleanest source of energy, and it is transmitted in the form of electromagnetic radiation (or photons) of different wavelengths, of which it reaches the Earth for a period of 0.3-2.4 nanometer [4]. Solar energy can be converted into electrical energy by the following methods.

1.2.1. Solar cells (photovoltaic cells) (PV)

Each photon carries an amount of energy that it transfers completely to one of the electrons of the material falling on it, and if the frequency of the incident light is greater than the threshold frequency of the metal, then the electron is emitted from the surface of the metal, forming what is called the light current that is proportional to the intensity of the light (the number of photons) incident, this process is known as the photoelectric phenomenon [5].

1.2.2. Thermal conversion

Solar thermal energy is technologies that use heat energy from the sun directly to heat a carrier or heat carrier, which is most often water. The resulting hot water can be used for domestic and industrial purposes, and has virtually no carbon emissions because no fuel is burned to heat the water [6]. There are also advanced solar heat energy systems capable of trapping and collecting the sun's energy to produce steam that is used to drive turbines to produce electricity.

1.2.3. A review of the concept of hybrid energy and examples of it

A hybrid energy system is a system that combines two or more energy sources. The need to think of such systems is to reduce cost and reduce dependence on fossil fuels, and to find environmentally friendly systems with high efficiency, examples of which are:

– Geothermal+solarPV.
– Biomass+solarCSP.
– SolarPV+fuelcells.
– Wind+solarPV.
– Biodiesel+wind.
– Gas+solarCSP.
– Coal+solar CSP [7].

Our study in this paper focuses on small hybrid power installations that can provide a capacity ranging from 5 watts to 30 watts, which consists of a turbine to generate energy by wind in addition to solar panels, and work has been done on ten different regions in the Kingdom of Saudi Arabia and a study The efficiency of five different wind turbines.

2. Wind energy in Saudi Arabia

2.1. Wind speed in Saudi Arabia

The wind speed in the Kingdom ranges from (1.2-22.1) m/s and at a rate of 2.1 m/s at the standard height, and Table 1 shows the values of wind speed at the standard height in ten Saudi regions sourced from NASA [8].

The wind speed changes with the change in height from the surface of the earth, according to Eq. (1), and the Fig. 1 shows this change [9]:

$$V_z = V_g (Z/Z_g)^{1/\alpha}, \quad (1)$$

where V_z – mean wind speed at height Z above ground, V_g – gradient wind speed assumed constant above the boundary layer Z – height above ground, Z_g – nominal height of boundary layer, which depends on the exposure (values for Z_g are given in Fig. 1, α – power law coefficient).

We note from the observed values of wind speed that the winds are more active in the summer and spring seasons in the northern and central regions, while in the southern regions their average speeds are greater in the second third of the year [10], and this can be seen by looking at Fig. 2.

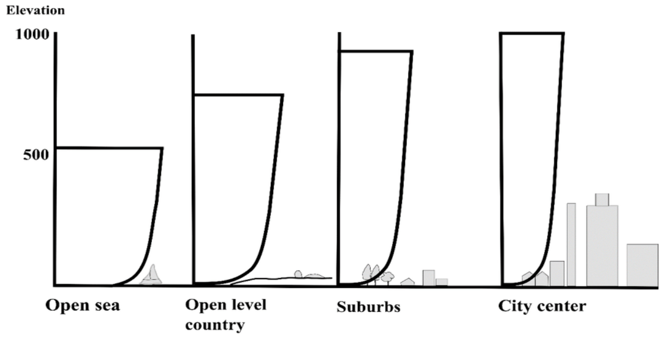


Fig. 1. The wind speed changes with height

Table 1. The mean and max of wind speed (m/s) at gradient height in the ten regions for every month, (NASA)

City month		Wind speed (m/s)									
		Riyadh	Makkah	Neom	Dammam	Al Jouf	Red Sea project	Hafar Al-Batin	Jeddah	Asir	Rub'-al Khali
Jan	mean	2	2.4	1.6	1.9	2.2	1.5	2.1	1.9	1.2	1.4
	max	6.3	7.4	8.1	8.3	10.7	4.9	13.8	8.5	5.6	8.2
Feb	mean	2	2.6	1.6	2	2.5	1.5	2.4	2	1.3	1.5
	max	4.6	10.2	8.6	6.6	11.7	7.4	13.5	10.3	8	7
Mar	mean	2.1	2.5	1.6	2.2	2.6	1.6	2.7	1.9	1.5	1.6
	max	5.7	9.3	7.4	5.7	14.5	7.4	16	9.2	8.5	9.2
Apr	mean	2.1	2.1	1.6	2.3	2.8	1.7	3.1	1.8	1.6	1.7
	max	4.9	8.2	7.1	6.9	13.8	7.1	14.9	8.1	9	8
May	mean	2.1	2	1.9	2.4	2.7	1.8	3	1.9	1.5	1.6
	max	7.8	7.6	7.1	9.8	13.8	7.1	14.6	8.2	6.6	7.2
Jun	mean	2.6	2.1	1.9	2.7	2.5	1.8	3.1	2.4	1.5	1.7
	max	7.7	8	6.8	8.7	9.9	6.8	13.2	9	9	8.2
Jul	mean	2.2	2.3	2.1	2.3	2.6	2	3	2.4	2.5	3.1
	max	6.7	8.2	6.8	9.7	9.6	6.8	11.6	7.8	7	11
Aug	mean	2.1	2.1	2	2.2	2.3	1.9	2.5	2.5	2.2	2.5
	max	7	8.2	6.6	8	8.8	6.6	9.3	7.7	5	8
Sep	mean	1.7	2.1	1.5	1.9	2	1.6	2.3	1.7	1.7	2.1
	max	7.1	9.9	5.2	9.1	8.8	5.2	9.9	7.7	8	8.2
Oct	mean	1.6	2	1.4	1.8	2.1	1.3	1.9	1.8	1.6	1.7
	max	6.7	8	4.3	9.7	9.3	4.3	22.1	4.8	5.3	11.1
Nov	mean	1.8	2	1.2	1.9	2	1.2	1.8	1.5	1.2	1.5
	max	5.4	6	4.1	5.8	11	4.1	12.1	5.2	6	12
Dec	mean	2.1	2	1.3	2.2	2	1.3	1.7	1.4	1.3	1.5
	max	6.7	6	3.5	8.7	12.1	3.5	13.2	8.1	5.2	8.2

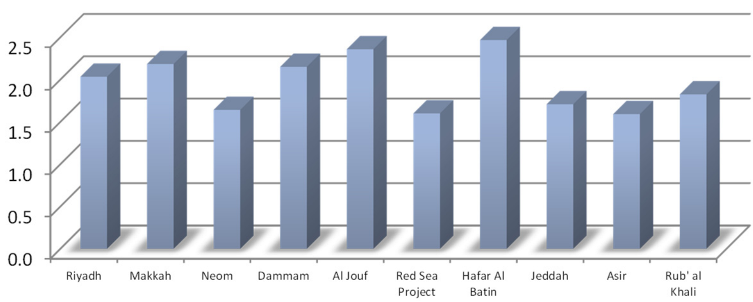


Fig. 2. The average annual wind speed in different cities in KSA

2.2. Renewable energy in Saudi Arabia and vision 2030

The National Renewable Energy Program was launched in the Kingdom of Saudi Arabia, which is a strategic initiative under the umbrella of Vision 2030 and the National Transformation Program [11]. The program is aimed at the sustainable increase in the resurrection of the resources of energy sources in the kingdom to reach 45.3 GW in 2020 AD, that is, equivalent to 4 % of the total production of the Kingdom and 3.27 GW by the year 2023 AD, that is, more than 10 % of the property The energy sector also aspires to be one of the main generators of jobs in the country in the next decade, amid promoting the necessary investments by relying on generating 30 % of energy by 2030 [12].

3. Wind turbines

3.1. Helical-Blade vertical-axis wind turbine

In this type of vertical wind turbine, the average output power is 100 watts when the average wind speed is 9 m/sec, and its operating speed is 3.5 m/sec and with a power factor of 0.15 [13], the Fig. 4 shows the power produced from this turbine when operating in a number of From the cities, by taking the average wind speed in these cities after ignoring the speeds that are less than 3.5 m/s [5].

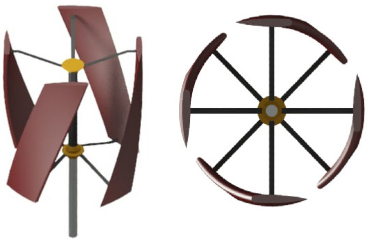
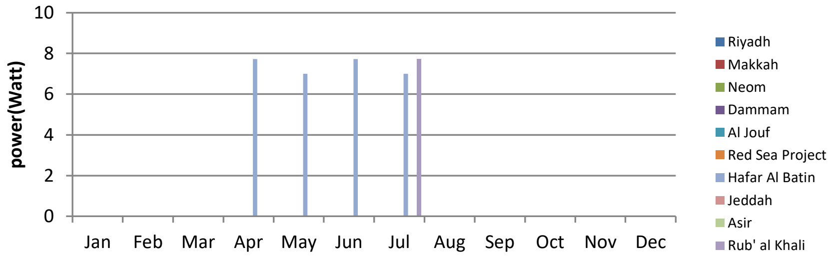
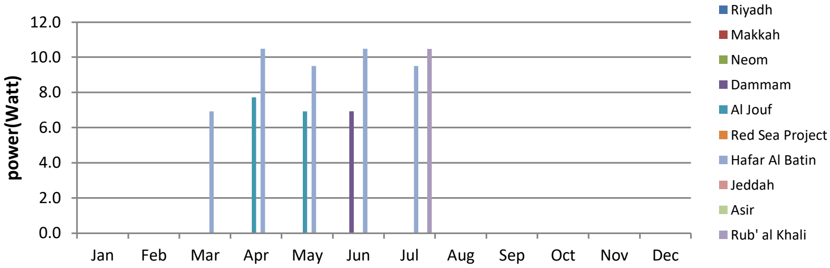


Fig. 3. Helical-blade vertical-axis wind turbine [2]

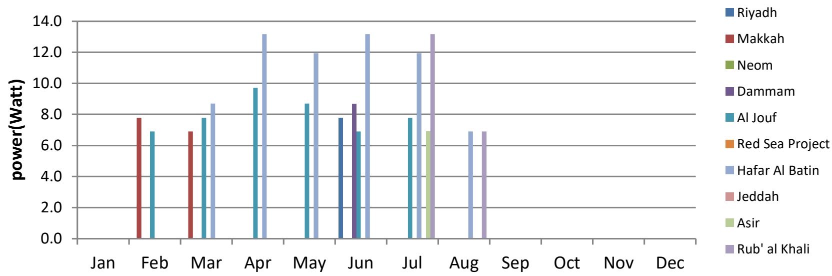
The electric capacity produced at several heights was calculated in the ten regions, and Fig. 4 the power values in the months of the year and in all the regions under study.



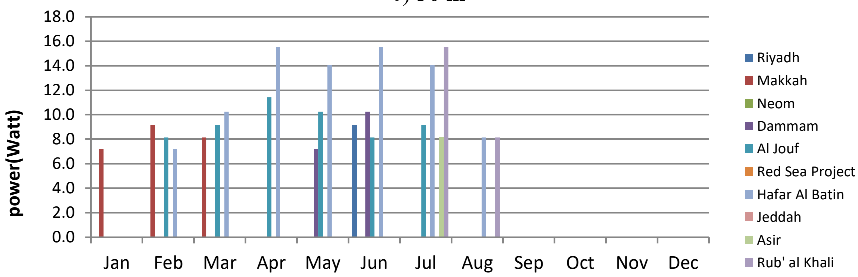
a) 10 m



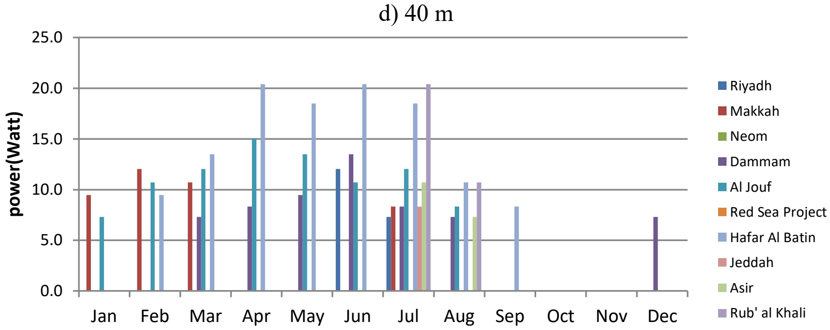
b) 20 m



c) 30 m



d) 40 m



e) 50 m

Fig. 4. The electrical power at different heights using Helical-Blade vertical-axis wind turbine

3.2. Small H-Type Darrieus vertical-axis wind turbine

Energy calculations were made on this type in the ten cities by taking the minimum wind speed required to operate the turbine, and the Table 2 shows the characteristics of this turbine and the following graphs show the electric energy produced at different heights [14].

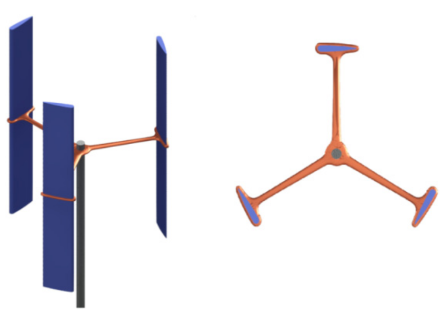
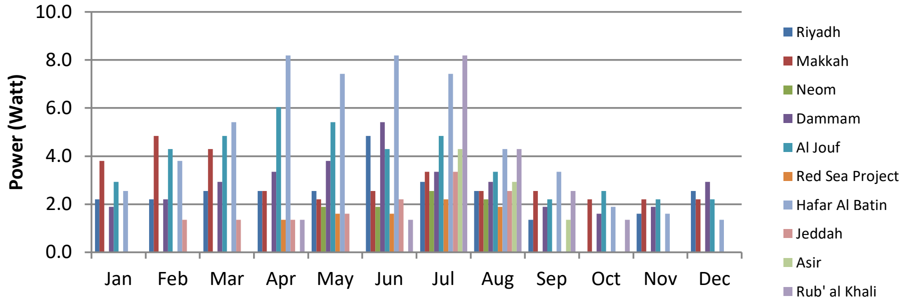


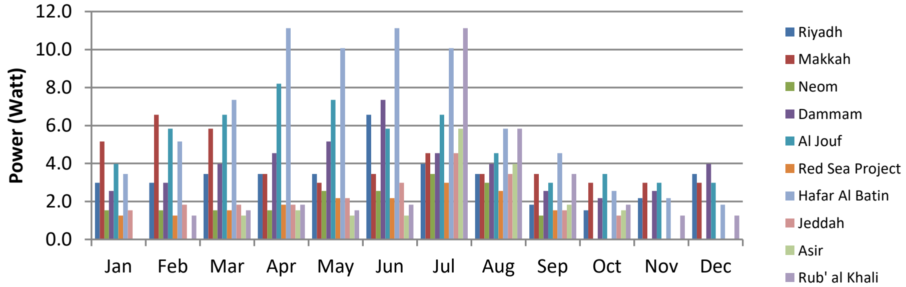
Fig. 5. Small H-Type Darrieus vertical-axis wind turbine

The characteristics of this turbine, are good for employment in small projects. It has a diameter that does not exceed one meter, and the length of the plates is 1.5 meters, and the operating speed is 2 m/s, and this speed is excellent compared to the rest of the small turbines, but what is wrong with this turbine is that the cutting speed is up to 12 m/s. This is a rather low speed, especially if we know that a number of regions have winds that reach much higher than this number for limited periods [15].

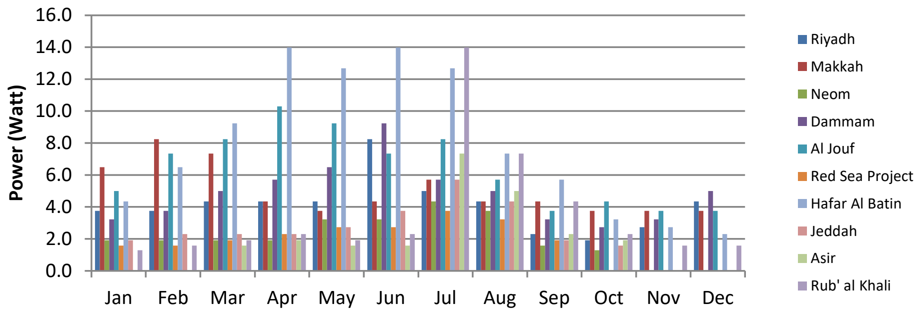
When operating this turbine in the areas concerned with the study, it was found that the electric power produced ranged between 8 watts at a height of 10 meters and 22 watts at a height of 50 meters [17], and these values are the maximum values in the different regions, as shown in Fig. 6.



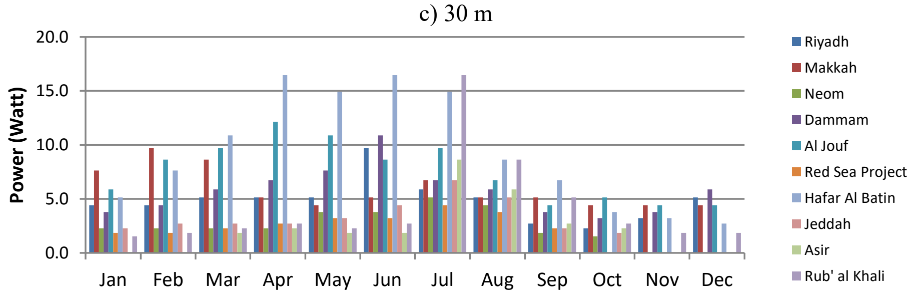
a) 10 m



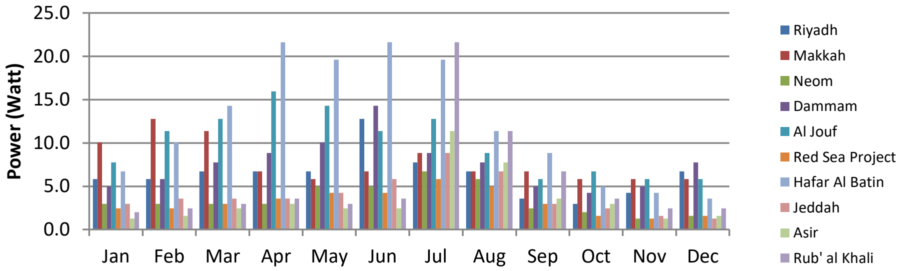
b) 20 m



c) 30 m



d) 40 m



e) 50 m

Fig. 6. The electrical power at different heights using Small H-Type Darrieus vertical-axis wind turbine

Table 2. Small H-type vertical axes wind turbine parameters [16]

Component	Parameter	Value
Rotor	Diameter	1 m
	Length	1.5 m
	Weight	15 kg
	No. of blades	3
	Materials	Expanded Polypropylene
	Cut-in wind speed	2 m/s
	Rated wind speed	9 m/s
	Cut-out wind speed	12 m/s
Generator	Type	Permanent Management 3-Phase AC Generator
	Rated power	33 W
	Rotor speed range	0-400 RPM
	Pole number	10
	Weight	18 kg

3.3. Savonius wind turbine

By taking a plate diameter of 60 cm and a height of 100 cm, the following graphs show the electrical energy produced at several heights.

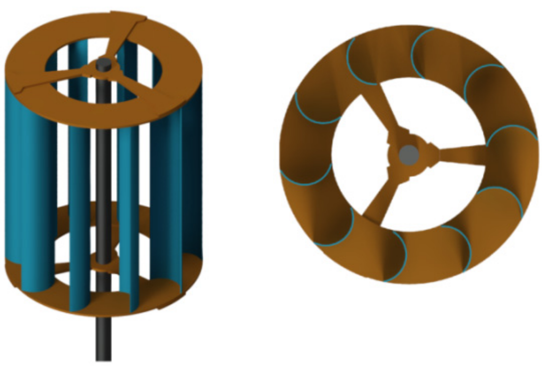


Fig. 7. Savonius wind turbine

The electrical energy produced when operating this turbine at altitudes of 10 m to 50 m ranges from 12 W to 30 W in the highest wind speed regions as shown in Fig. 8.

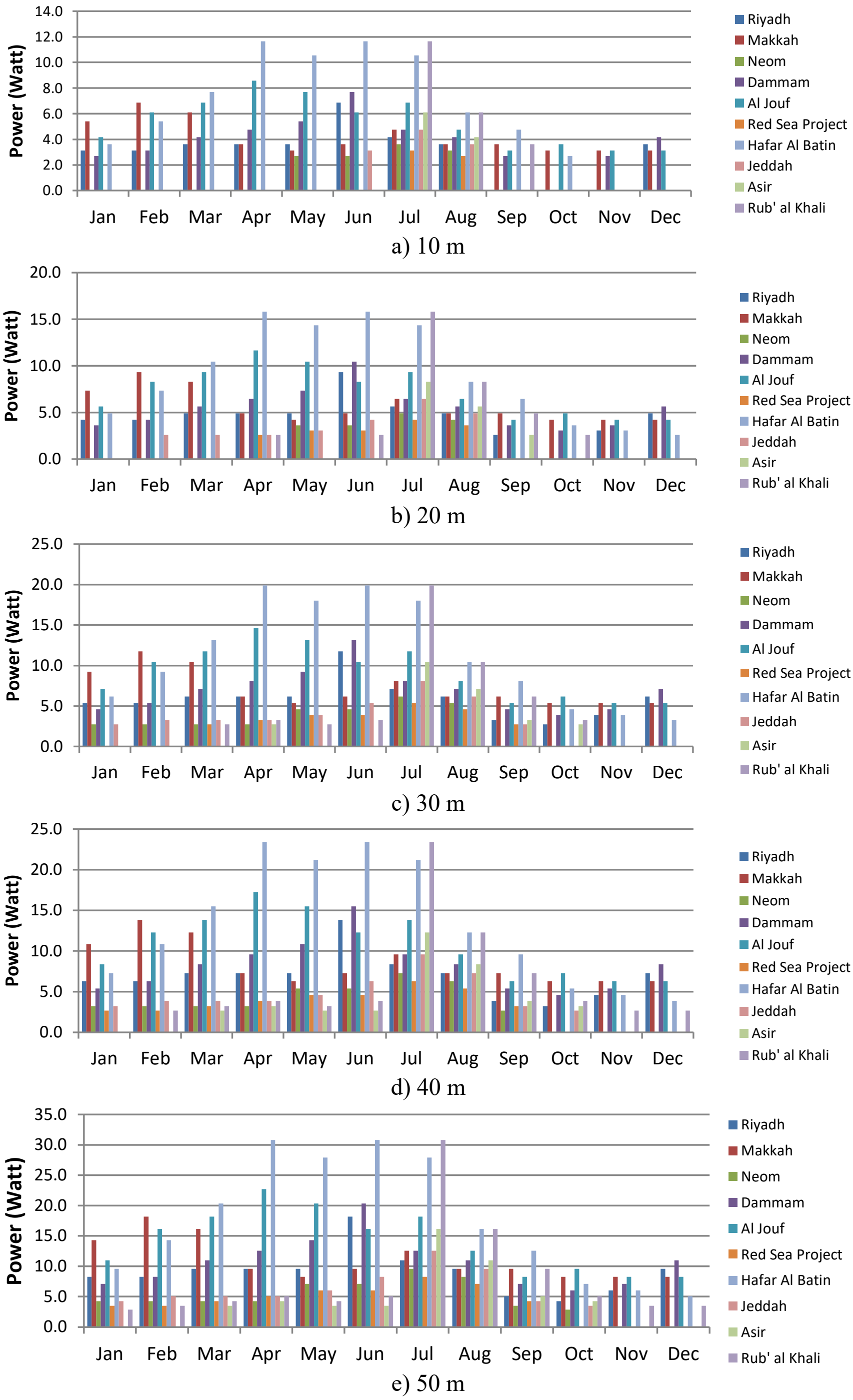


Fig. 8. The electrical power at different heights using Savonius wind turbine

4. Vertical wind turbine 10 kw

In this turbine, the electric power produced ranged from 8 watts to 22 watts, and this turbine is of the medium type that can be used as a supplier for some small stations or rural homes.

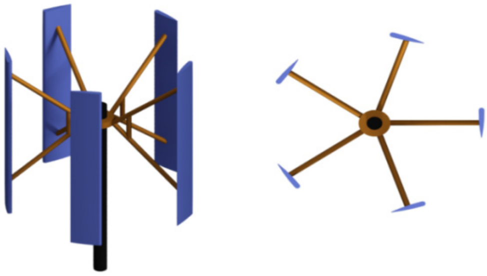
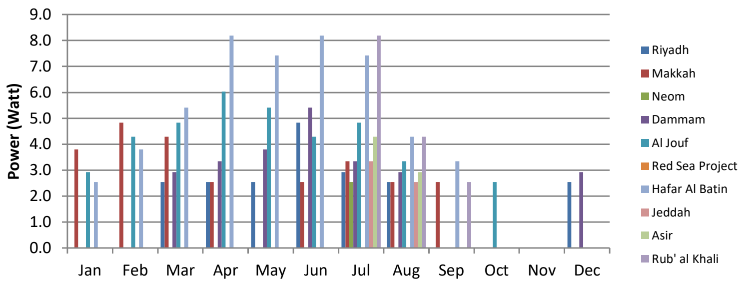
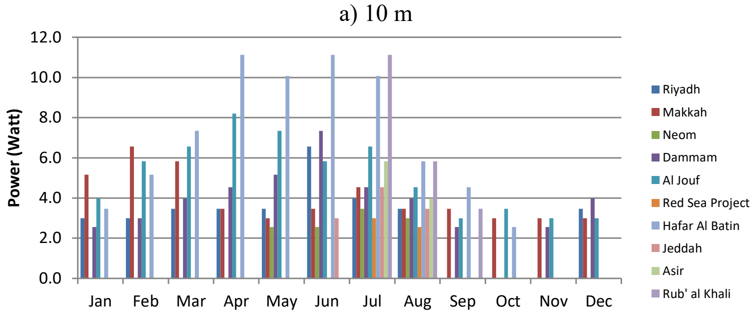


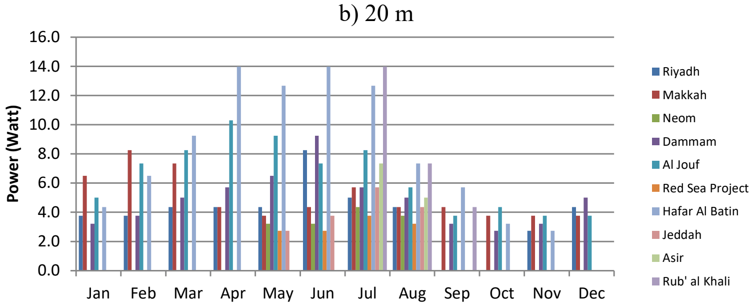
Fig. 9. Vertical wind turbine 100 kw



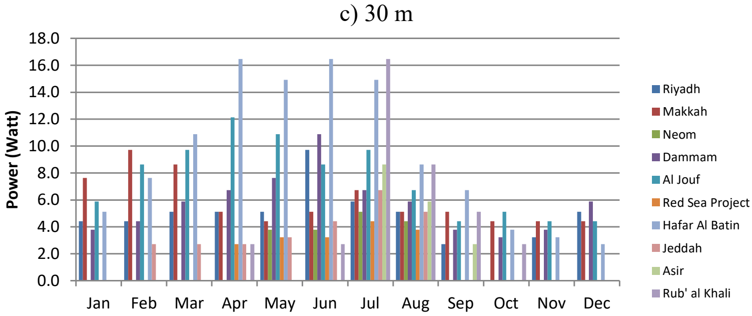
a) 10 m



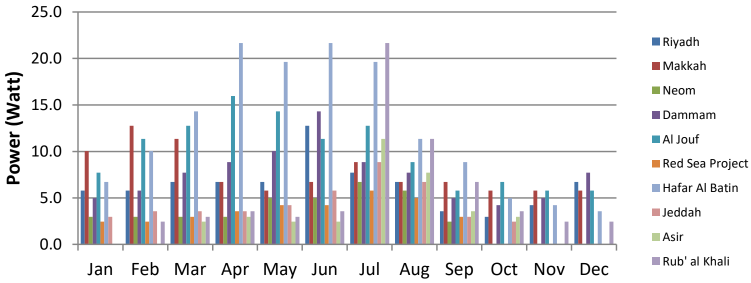
b) 20 m



c) 30 m



d) 40 m



e) 50 m

Fig. 10. The electrical power at different heights using vertical wind turbine 100 kw turbine

Table 3. Vertical wind turbine 10 kw parameters [18]

Rated power	10 kW
Maximum output power	12 kW
Output voltage	300/380 V
Rotor height	6.0 m (19.7 ft)
Rotor diameter	5.5 m (18.0 ft)
Start-up wind speed	2.5 m/s (5.6 mph)
Rated wind speed	11 m/s (24.6 mph)
Survival wind speed	52.5 m/s (117.4 mph)
Generator	Permanent magnetic generator
Generator efficiency	>0.96
Turbine weight	680 kg (1499.1 lbs)
Noise	<45dB(A)
Temperature range	–20 °C to +50 °C
Design lifetime	20 years

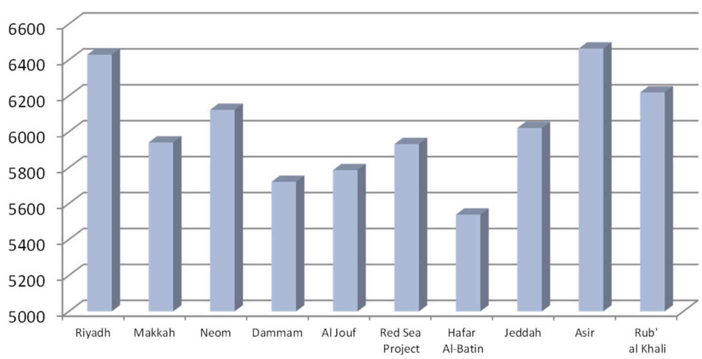


Fig. 11. Average annual GHI in different sites in Saudi Arabia

5. Solar energy

The values of radiation (GHI) rates for solar energy in all of the target areas in the study were taken from NASA website, as shown in the Table 4. The GHI values were calculated using Eq. (2):

$$GHI = DNI * \cos(SZA) + DHI, \tag{2}$$

where: GHI – Global horizontal irradiance, DNI – Direct normal irradiance, DHI – Diffuse horizontal irradiance, SZA – the solar zenith angle.

Table 4. GHI for several cities in KSA Over the year (Wh/m^2/Day) [19]

City month	Riyadh	Makkah	Neom	Dammam	Al Jouf	Red Sea Project	Hafar Al-Batin	Jeddah	Asir	Rub'al Khali
Jan	4270	4566	4370	3570	3390	4240	3230	4356	5295	4710
Feb	5310	5288	5330	4490	4440	5100	4230	5247	5831	5310
Mar	6510	6144	6210	5290	5560	6030	5230	6254	6711	6080
Apr	7430	6544	7530	6150	6780	6780	6070	6940	7190	6840
May	7870	6702	7970	7170	7390	7140	7180	7325	7224	7620
Jun	8580	7214	8234	8000	8360	7780	7940	7458	7262	7630
Jul	8320	6947	8245	7570	8150	7440	7850	7640	7073	7040
Aug	7770	6652	7325	7210	7570	6940	7340	7180	6921	6950
Sep	6930	6259	5458	6530	6460	6250	6330	6340	6871	6680
Oct	5570	5761	4625	5400	4760	5220	4910	5230	6494	6060
Nov	4590	4866	4215	4030	3550	4350	3390	4360	5577	5250
Dec	4000	4346	3956	3250	3030	3910	2770	3920	5114	4460
Average	6429	5941	6122	5722	5787	5932	5539	6021	6464	6219

Table 5. Electricity produced by solar panels of all types listed in all regions [1]

Solar plate	City									
	Riyadh	Makkah	Neum	Dammam	Al –Jouf	Red Sea Project	Hafar Al-Batin	Jeddah	Asir	Rub' al Khali
PERC	1607	1485	1531	1430	1447	1483	1385	1507	1616	1555
Monocrystalline	1286	1188	1224	1144	1157	1186	1108	1206	1293	1244
Polycrystalline	1029	951	980	915	926	949	886	965	1034	995
CIGS	900	832	857	801	810	830	775	844	905	871
CdTe	643	594	612	572	579	593	554	603	646	622
Amorphous silicon (a-Si)	450	416	429	401	405	415	388	422	452	435

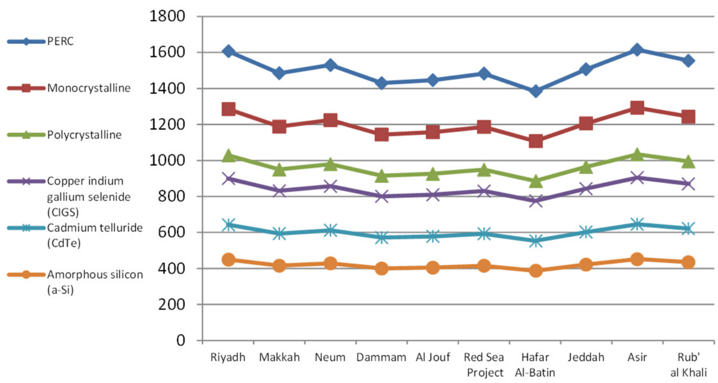


Fig. 12. Electricity produced by solar panels of all types listed in all regions 100 kw turbine

6. Results and discussions

We note that the first turbine starts working at a wind speed of 3.6 m/s, and this is a high speed that makes the application of this turbine in selected areas, of limited benefit at altitudes less than 30 m, but it is possible to apply it at a height of 50 m and more, which limits the possibility of practical applications to use this turbine, while we find that the second turbine operates at wind speeds of 2 m/s, and above and produces electrical energy from 2 watts to 18 watts at a rate of 5.2 watts, and increases its energy production in the summer and spring seasons [6]. As for the third type, it produces energies ranging from 12 watts at a height of 10 m and 30 watts at a height of 50 m, and with a slightly higher efficiency than the second turbine, the fourth turbine.

As for solar energy, the study shows that the first type of panels gives higher energies than the rest of the types, and therefore where one square meter of these panels produces between 1.4 watts, as in the city of Makkah, for example, to 1.8 kilo watts in Asir, compared to the rest of the panels. especially good that some panels give less than 0.5 watts.

The performance of the Helical-Blade turbine was very poor at normal altitudes in all the areas under study, and at higher altitudes, its performance was somewhat acceptable at a height of 50 m in the city of Hafr Al-Batin, but in the rest of the cities it is not convincing, and we also note that it does not work in a monthly 10 and 11 in all regions [20].

As for the rest of the turbines, the energy produced from them was acceptable, reaching 30 watts in some cities, as is the case for the Savonius wind turbine at a height of 50 m.

As for solar energy, we find that GHI rates are good in most areas. The energy values produced range between 400 watts and 1600 watts using different types of solar panels [21].

7. Conclusions

This study shows, that the use of the second type of wind turbine with the use of two solar panels of the first type can provide energy of up to 5 kilowatts at high altitudes (30 m and higher) sufficient to operate a communications tower, for example, and up to 2 kilowatts at a height 10 m and enough to operate lights and chargers for stretchers in the bus parking lot.

It is also not recommended to use the Helical-Blade turbine in different areas and at lower altitudes, and the Vertical wind turbine 10 kw can be used depending on the good results that have been achieved for this turbine.

In Hafr Al-Batin, most turbines can be used due to good wind speed rates, and in cities such as Riyadh and Asir, we find that solar energy is high, so it can be relied upon in many small projects, such as street lighting, for example.

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