Evaluating Performance of Utilizing Onshore Wind Turbines Specifically the Farm Turbines in Kuwait

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ABSTRACT

Renewable energy is considered one of the most important and clean sources; since it does not produce any type of emission or pollution. The wind energy in Kuwait is available in three prime locations – Ras Jal Aliyah, Bubian as well as Subiyah – while the characteristics are assessed depending on the data from the meteorological measurements. However, the characteristics of wind energy were evaluated from the meteorological data at 10m height. Additional studies were done to analyze the height effect on the wind density, wind speed, the maximum value of energy density as well as concerned with the characteristic parameters. As a result of studying Jal Aliyah, it is found a relation between the wind power and wind speed as the maximum magnitude of wind power is potential with the maximum speed of wind of 29.1 m/s, also the averaged value of the maximum wind power flux of 725.54 W/m2.While the studies of Bubidan Island and Ras Subiyah were predominant and display the direction of wind in the North-East quadrant with the most frequented speed are more than 10 m/s. Generally, Jal Aliyah showed higher polarized distribution in the north direction. Based on the results, the proper selection procedure and design of the wind turbines are suggested to the designers of wind paper.

Key Words: Renewable Energy, Wind Energy, Ras Jal Aliyah, Bubian, Subiyah, Wind Turbines, Wind Speed

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INTRODUCTION

In general, renewable energy is considered one of the most important and clean sources; since it does not produce any type of emission or pollution. The researchers nowadays are concerned in employing these sources efficiently so that the best potential energy is taken. Renewable energy technology is description for half capacity of the recent technologies that was developed for the purposes of achieving the occurred growing within energy insist throughout the recent years. Advanced technology is hydropower and wind. Increase in renewable Energy alternates because of the oil price; in case of high price, there will be an increase of the renewable energy share (wind and solar) within overall energy input. Consequently, the share of coal and gas will reduce, which in turns results in a lower share in renewable energy.

So due to price oil increase, wind energy is considered as an efficient substitute to produce the needed power with lower cost. The electrical energy is generated by wind turbine through converting the kinetic energy of the wind to rotational kinetic energy. Within the novel design of the horizontal wind turbine, the energy results in a rotation within in three or two blades that are placed around the rotor. Aerodynamics force is employed to provide the real process of transmission via creating a positive torque on the shaft that is rotating due to the blades. The wind should be obtainable at the same time when energy is being created from wind turbine because the wind could not be saved to be employed later (Bai et al, 2013).

Aims and Objectives

The aim from this paper is studying and estimating the performance of exploiting Onshore Wind Turbines particularly the farm turbines in Kuwait city. There are many objectives that should be followed to achieve paper aims, which are:

- To evaluate the wind energy performance in Kuwait,
- To find the appropriate model of Onshore Wind Turbine that can be utilized in order to produce power efficiently in Kuwait.
- To evaluate the feasibility of utilizing the chosen model of wind turbine when it compared with fossil fuels in terms of cost and environmental effect.

Methodology

In Kuwait city, electrical energy is regularly created using hydrocarbon fuels, which may produce all its energy demands. Actually, Kuwait is planning now to employ additional clean sources, such as; renewable energies due to the increased-demand because of the technological development to use about 11.5GW (Az-Zour, 2010). In general, the oil high cost and the renewable energy development are the two main reasons that direct Kuwait city to employ wind turbines.

Furthermore, the wind turbines can produce clean, reliable, sustainable and effective energy source with low cost. Figure 1 below shows the power generated by wind turbines throughout the previous few years consistent with Global Wind Energy Council (GWEC) statistics.

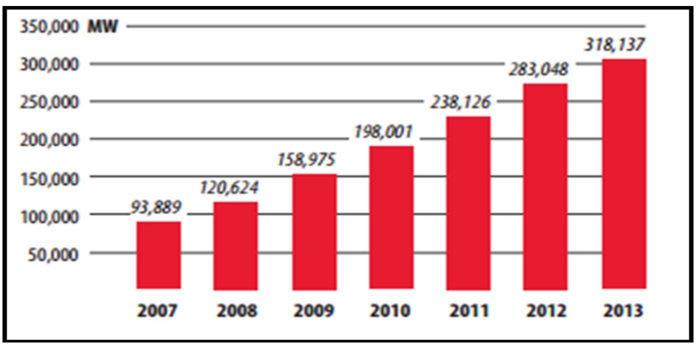

Figure 1: the cumulative wind turbines capacity in the world (GWEC, 2013)

The Locations of the Study

Setting up the turbines of wind energy in Kuwait city at Mubarak Al Kabeer can be evaluated via feasibility study making for installing the wind turbines in Bubiyan Island area. The location of Bubiyan Island is shown below in Figure 2 inside the red circle and it is located in the northeast area from Kuwait.

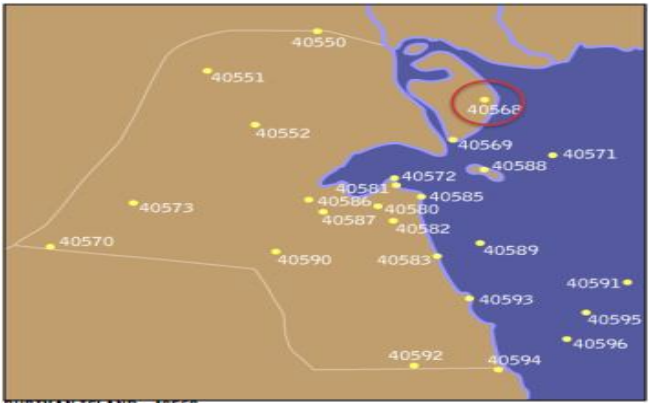

Figure 2: Bubiyan Island location

The Bubiyan Island location of is considered very active, it is placed along the coastal regions and it is also placed in the north-western country direction. The flow of the wind flow in the morning can be estimated beside coat the contours, which consequences from winds within the west regions beside to southern parts.

Theory and Assessment

The power of the wind in this study is probable in Kuwait for three different and well-known situations. Table 1 below includes the meteorological data for the three considered situations.

Table 1: The meteorological data for the three sites (Kuwait Meteorological Statistics, 2017)

Site	Elevation (m)	Latitude	Longitude
Jal Aliyah	119.10	"29° 36' 35""	47° 34' 36"
RasSubyah [6]	1	29°34'24"	48°10'17"
Bubian Island	4.53	29° 46' 05"	48° 22' 29"

The following equation can be employed in calculating the density of the wind ρ at changeable heights (S. Neelamani et al, 2013):

$$\rho(z) = \frac{353.05}{T} e^{-0.034(z/T)} \quad (1)$$

Where; z symbolizes the height over the level of the ground. To obtain the probable highest of wind energy, the wind, direction, velocities and temperatures are recorded each hour to examine the winds properties to acquire the highest energy that can be obtained from the wind. The next equation can be employed in calculating the velocity of the wind:

$$V(z) = V_r \left(\frac{z}{z_r}\right)^{\alpha} \quad (2)$$

The speed of the wind speeds is changeable with the heights. α denotes a factor that depends on the roughness of ground surface. The magnitude for α *equals* $1/7$ in this case. 'r'

denotes the reference level, which is equal 10m above the level of the ground. Different heights were considered, which are; 30 m and 50 m.

The following equation can be used in finding the density of the wind (ρ) for diverse heights;

$$\rho(z) = \frac{353.05}{T} e^{-0.034(z/T)} \quad (3)$$

Where, T represents the temperature in Kelvin. The obtainable wind turbine power (energy density) can be described as given below in the following equation;

$$P_I = \frac{1}{2} \rho V^3 \quad (4)$$

The obtainable power for the wind turbine of diameter d can be calculated using the following equation;

$$P = P_I \text{x} \frac{\pi d^2}{4} \quad (5)$$

The Evaluation of the Characteristics of Wind Energy

The following figures show the velocities and the power, which consequences for the three situations;

Ras Sabah

Figure 3 shows the estimated output power at 30m heights based on the data were taken each hour.

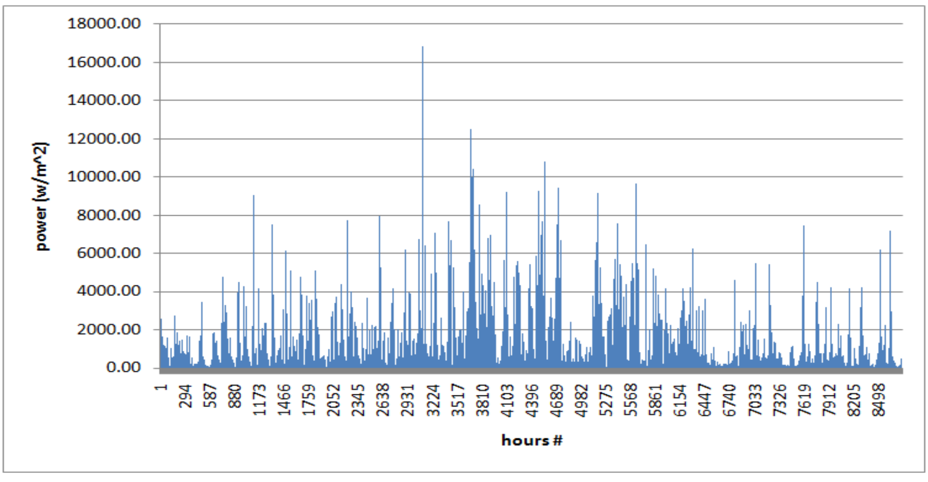

Figure 3: The histogram of the output wind power in RasSubyah obtained at 30m height

Figure 3 illustrates the power distribution that placed greater than 2000 w/m^2; the maximum obtained of the output power value occurs in the period from June to August. The energy of the wind had been studied in Kuwait city for three diverse major situations, which are; RasSubiyah, Jal Aliyah and Bubian Island. This study performed at different heights for the purposes of making a full analysis for the best situation that will be selected afterward to set up a planet of wind power. In addition, this study focused on the effect of different heights and how the speed will differ for different heights and locations.

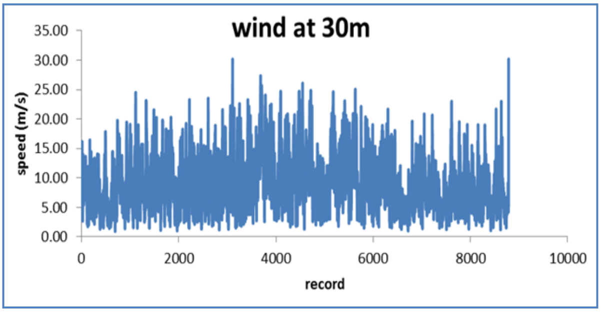

Figure 4: Wind speed at (altitude =30m)

The wind speed data has been changed at different altitudes; which are considered as typical altitudes (30m and 50 m). The first study for the speed of the wind was in RasSubiyah situation, and it happens at a 30 m altitude above the ground level according to Figure 4. A middle average speed is obtained at this altitude, where the highest speed = 30.2 m/s and the lowest speed = 0.97m/s, so the average speed was found to be 8.69 m/s.

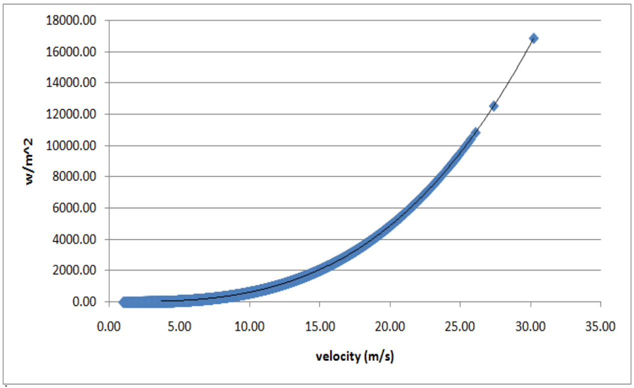

Figure 5: the output power in RasSubyah obtained at the 30 m altitude

Figure 5 shows the power for RasSubyah at diverse velocities. The highest speed is approximately 30 m/s as well as the highest power is approximately 17000 w/m^2. Figure 6 shows the histogram of the power at 50m altitude.

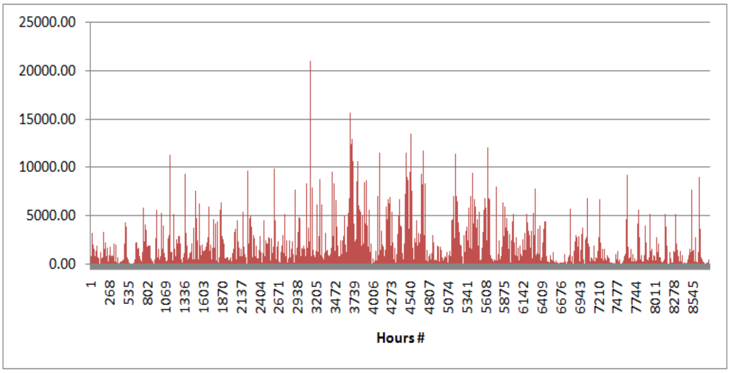

Figure 6: The histogram of the wind power for each hour in RasSubyah at 50m altitude

As shown in Figure 6, the power distribution was placed over5000 w/m^2, the highest output power were obtained in period from June to August. Figure 7 shows the power for diverse velocities where the maximum speed magnitude was approximately 33 m/s, and the value of the maximum power is approximately 21000 w/m^2.

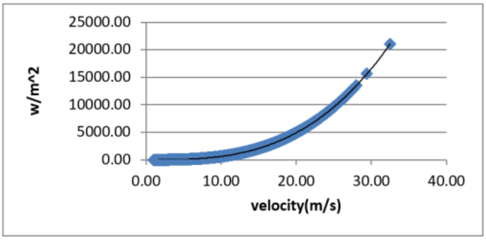

Figure 7: the output power for RasSubyah at (50 m altitude)

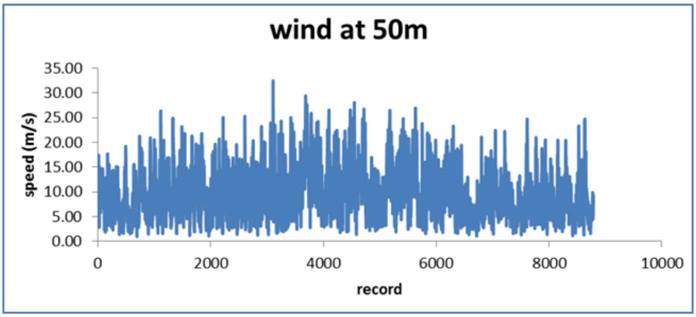

Figure 8: Wind speed at altitude =50m

Another standard altitude were chosen is 50m above the ground level in RasSubiyah. According to Figure 8, it is obvious that at 50m altitude, the best result had been obtained, where the highest speed = 32.48m/s and the lowest speed = 1.04 m/s. Consequently, it is observed that the average speed = 9.35 m/s. It can be noticed from the available data that high speed is produced when the wind turbine is established at a high height. Therefore, it can be concluded that the speed of the wind speed increases with increasing the height above the ground level.

Jalaliah

The created power for different wind speed is calculated using equation (4), Figure 9 shows the histogram of the wind power for recorded at each hour in Jalaliah at altitude = 30 m.

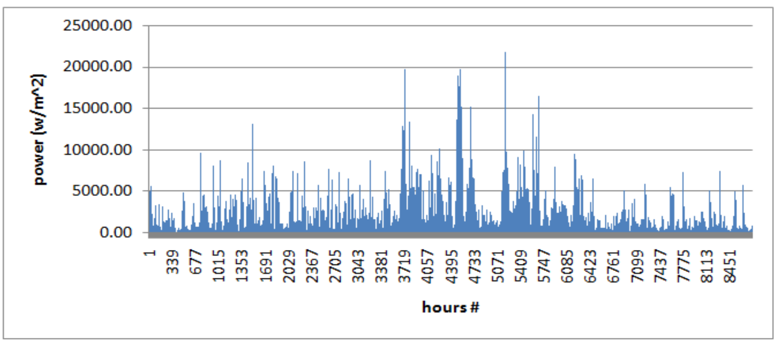

Figure 9: The histogram of the output power at altitude (30 m) in Jalaliah

As shown in Figure 9, the situated power is above 5000 w/m^2 and the highest power is obtained in hours between June and August. Figure 10 shows the power at diverse velocities and the highest speed of the wind speed is around 35 m/s, also the highest power magnitude is around 8000 w/m^2.

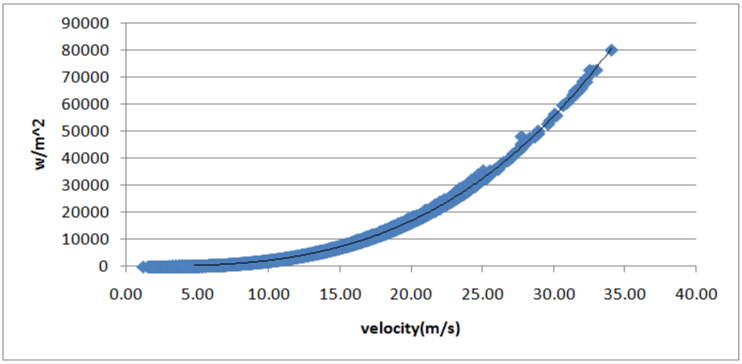

Figure 10: The output power at (30 m altitude) in Jalaliah

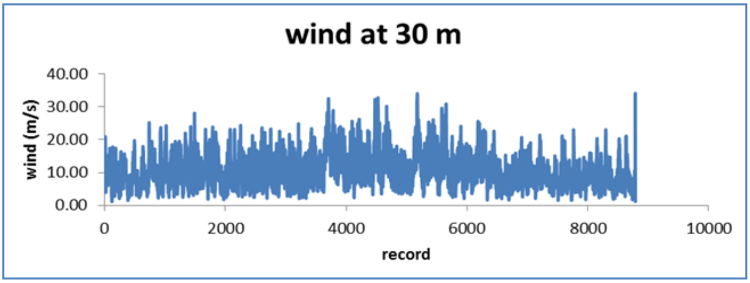

Figure 11: Wind speed at altitude = 30 in Jalaliah

As shown in Figure 11, the first standard altitude is 30m above the level of the ground where the highest speed = 34.04 m/s and the lowest speed= 1.17 m/s. Consequently, the average speed =10.42 m/s. Figure 12 shows the obtainable histogram of wind power that is recorded hourly at (50 m) altitude in Jalaliah.

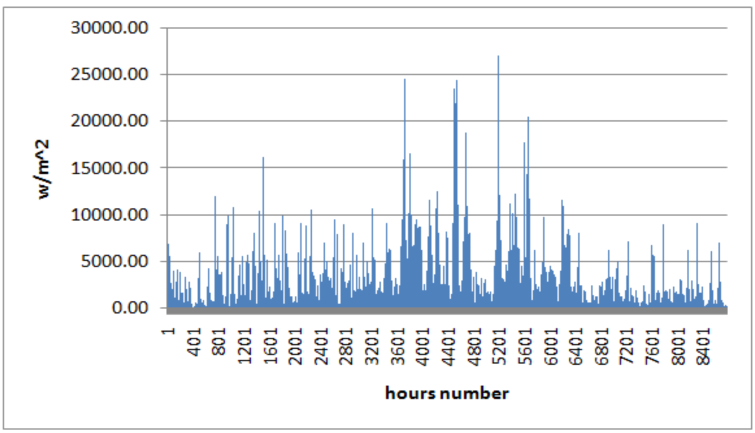

Figure 12: The histogram of the output power at altitude (50 m) in Jalaliah

As shown in Figure 12, the power distribution of is located above 6KW//m^2 and the highest power is obtained also between June and August. Figure 13 shows the power for different velocities of the wind, where the value of the maximum speed is approximately 35 m/s.

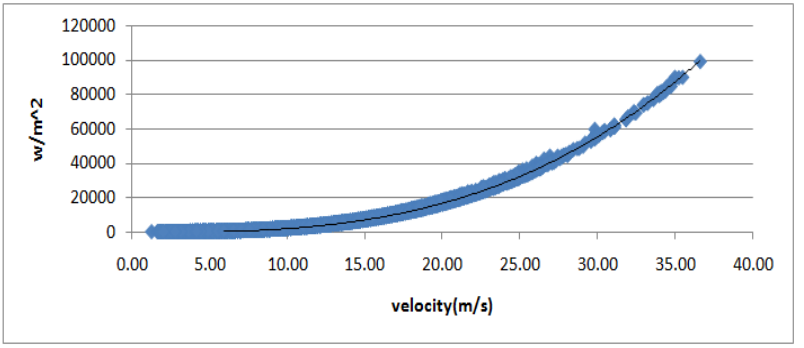

Figure 13: output power at (50 m altitude) in Jalaliah

The next standard altitude= 50 m, where at this altitude it can be obtained the highest value for the average speed of all the preceding data. It is found that the minimum speed = 36.62 m/s and the lowest speed = 1.26 m/s. Consequently, the average speed value = 11.21 m/s. In addition, these readings signs that Jalaliah situation has the optimal data results compared with the preceding two locations for similar altitude.

The obtained results at these diverse altitudes were predicted because of several reasons; the speed of the wind speed increases with increasing the height. This happens due to many reasons, which are; the friction of the surface, where the houses and the trees near the ground form a barrier that let reduces the air speed. The second reason is because of the density of the air, where the density close to the surface is very high and it requires a great force for pushing the air to produce a movement. The third reason is the pressure gradient between cold and warm air that raises with height.

Bubian Island

For different speed of wind, the output power is calculated through the obtainable power equations. Figure 14 shows the wind power histogram at 30m altitude in Bubian location.

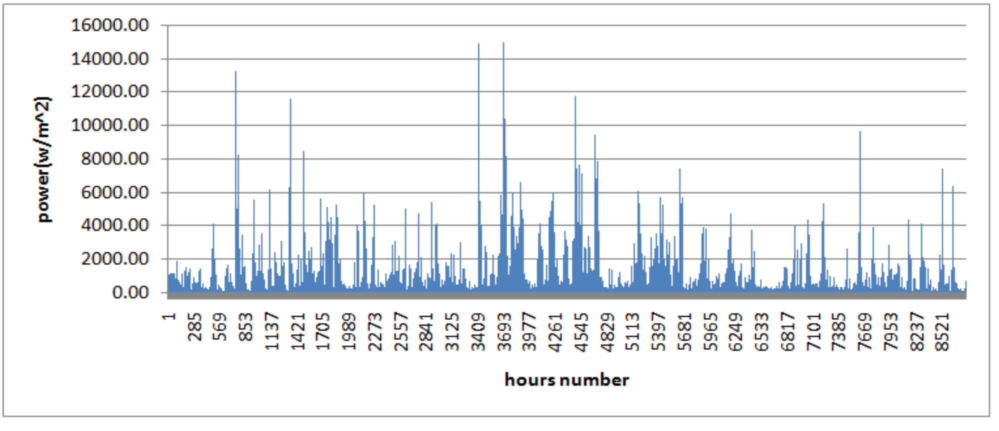

Figure 14: The output power at 30m altitude in Bubian

As shown in Figure 14, the power distribution is above 16KW//m^2 and the highest output power value is obtained also form June to August. Figure 15 shows the output power at diverse velocities, the highest speed of wind is approximately 30 m/s.

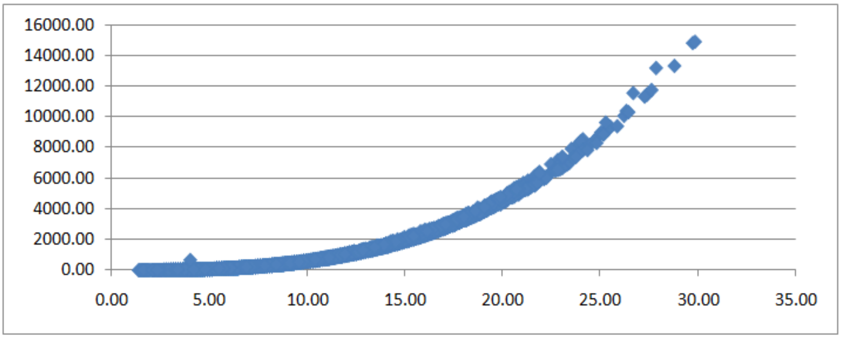

Figure 15: The output power histogram at (30 m) altitude in Bubian Island

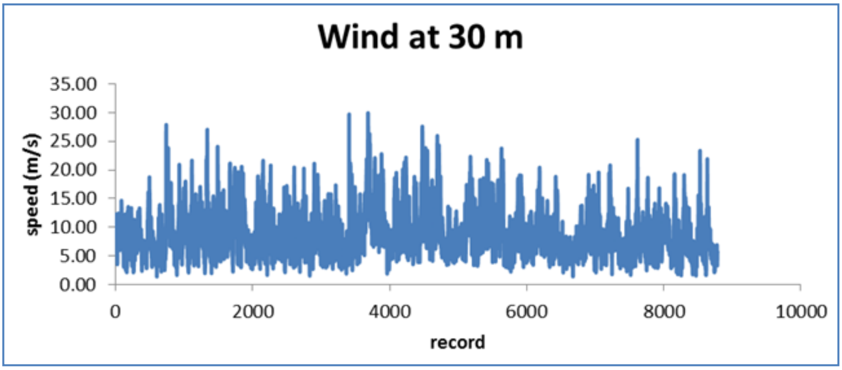

Figure 16: Wind speed at altitude =30m

As illustrated in Figure 15, at altitude 30 m, the highest speed =28.83 m/s and the lowest speed = 1.4 m/s. Consequently, the value of the average speed = 8.67 m/s, it's a middle result between the speed at 50m and 10m altitudes. Figure 17 shows the wind power histogram of at (50 m) height in Bubian Island.

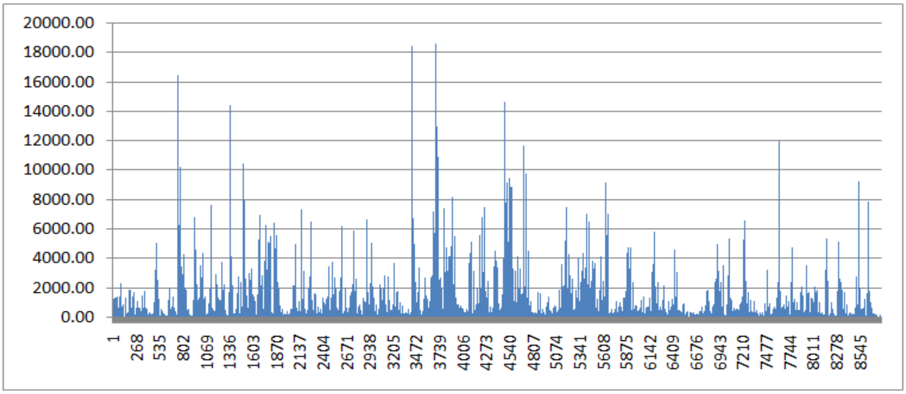

Figure 17: The output power at 30m altitude in Bubian Island

As shown in Figure 17, the power distribution is above 2 KW//m^{2}and the highest output power magnitude obtained also from June to August. Figure 18 shows the output power at diverse wind speeds and the highest wind speed is approximately 32 m/s.

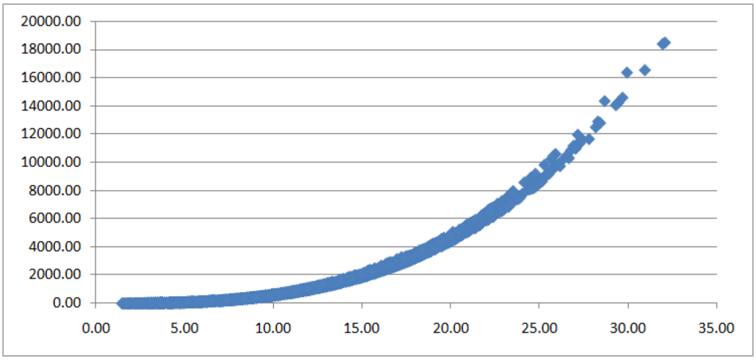

Figure 18: The output power histogram at 50m altitude in Bubian Island

Average Hourly Output Power

Table 2 shows the yearly average output power that measured in the three considered locations.

Table 2: The hourly average of output power

Highest	Bubian Island	RasSubyah	Jalaliah
30 m	671.01	755.75	1159.12
50 m	833.34	940.71	1439.55

Figure 19 shows the average power plotted for the three location. The highest average of output power was obtained in jaliah locatiob at 30 and 50 m altitudes.

Figure 19: The output power for the three situations

Wind turbine characteristics assessment for recommended station

The impact of height in the wind power density and the distribution of wind speed are defined in this paper. Where the speed of wind is increase with increasing the height affecting the maximum amount of generated wind energy, at all wind speeds. Also, the wind turbine systems' designers need to evaluate the power properties of the wind turbines to select the most efficient turbine system. The value of availability factor, which is used in the most effective wind turbine is in range of (0.95 - 0.99) that is known as a benchmark factors. The second property is the capacity factor that should be in range of (0.25 - 0.40). There are many companies that manufacture the commercial types of wind turbine in the market for instance; Nordex, Siemens and Mitsubishi. These types are assessed based on their features such as; wind speed ,cut-out speeds, cut-in speeds, rated output power in addition to efficiency of wind turbine. Table in (Appendix 1) illustrates some of the operational characteristics of wind turbine models in addition to the required specifications of design.

Equations (5) is utilized in order to evaluate the efficiency of wind turbines, which can be used to operate the models that are in range of (0.15 - 0.50). The selected turbine should be operate effectively at average wind speeds of (716 m/s - 16 m/s).

Wind Turbine Performance

The capacity factors (C_F) for the diverse turbines are approximately within the range within 0.11 – 0.20, which make JalAliyah location to be the best suggestion model to be employed. However, the model of SWT-6.0-120 has the best efficiency and can provide 6000 kW or 6 MWh. The performance coefficient (Cp) is also found by Figure 20 for three blades type at tip speed of (5.044)

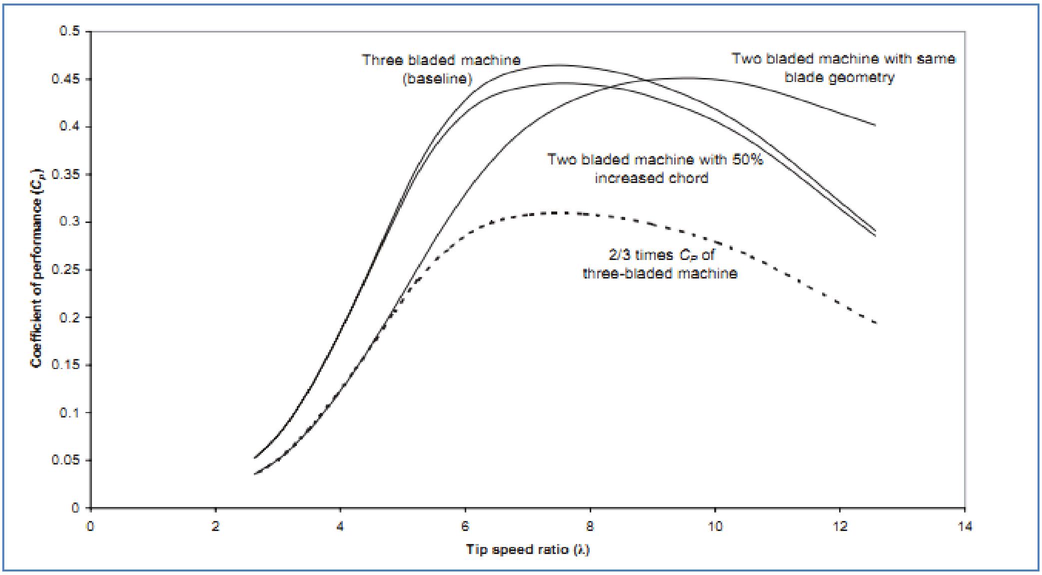

Figure 20: The performance coefficient (Cp) Vs. Tip speed (λ)(T. Burton, 1947).

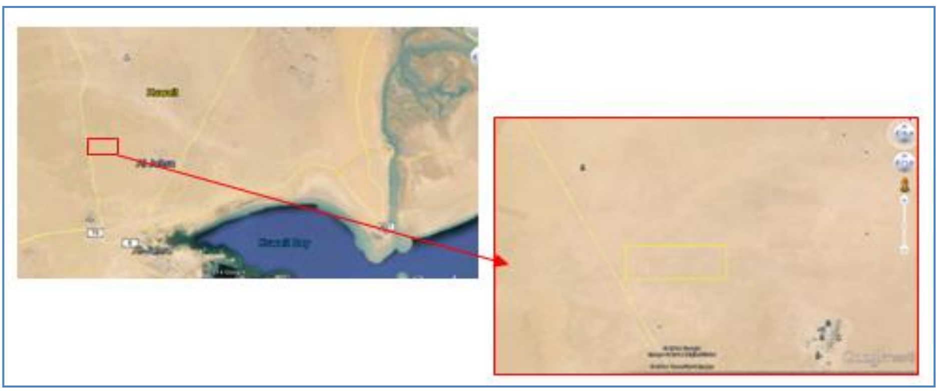

Figure 21: The different locations power

Furthermore, the power that can be created using wind turbine farm = 125 MWh. The needed wind turbines number (SWT-6.0-120) = 21 turbines. The third place position is illustrated in Figure 21. There is an extra characteristic could be taken in consideration when choosing the site of wind turbine, like; the wildlife. The chosen site was in 12 km^2.

The selected site is near the highway road to ease the transportation. Furthermore, this area should be separated to grids as shown in Figure 22. The wind turbines is dispersed beside three rows, the rotor diameter = 120 m. Therefore, the obtained distance between wind turbines is 600m vertically and horizontally. The free region is significant since supplies space for building the service buildings, such as; management, batteries, electrical transformers and maintenance buildings.

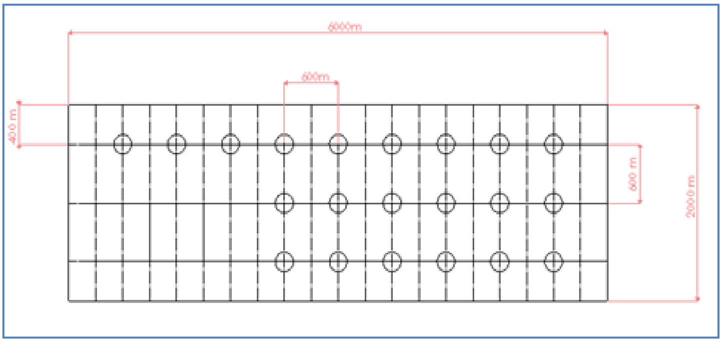

Figure 22 **:** the grid of wind turbine

Wind Turbine Description

There are several types of wind turbines, for this study, the chosen design is Endasa with diameter of rotor = 52m, rotor sweep 2123m^2, and rated output power = 800 kW. The rotor contains three rotor blades that made from GFRP with high quality. The producer of the rotor blades is LM Glasfieber, and the type is LM 25.1 P. At a wind speed = 3.5 m/s, the Made - Endesa AE-52 Prototype turbine connects the grid connection. The rated real output power is at a wind speed = 12 m/s. The nacelle is prepared with a gearbox of 3-stage spur/planetary with a ratio of 1:58. The producer of the Made - Endesa AE-52 Prototype gearbox is Flender.

The generator of the Made - Endesa AE-52 model is of a Synchronous type. The generator has been established by Siemens. The Made - Endesa AE-52 model has a Steel tube tower with an altitude =b50 meters. Made - Endesa is located at (48170) Zamudio (Vizcaya) Spain. The diameter of the rotor of the chosen model = 52 m, the model was drawn via solid works software, and exported later to ANSYS software as illustrated below in the next figure. In ANSYS software, a CFD simulation was employed and fluent solver was chosen. The geometry was then imported with surfaces freezing for creating one solid body.

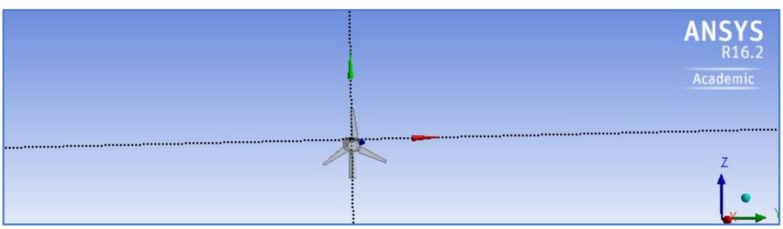

Figure 23: the model of the rotor using ANSYS software

A box enclosure is drawn in order to define the boundary conditions as shown in Figure 24, the inlet and outlet region were defined by renaming these surfaces in design modeler. So, two bodies were defined that are geometry and enclosure.

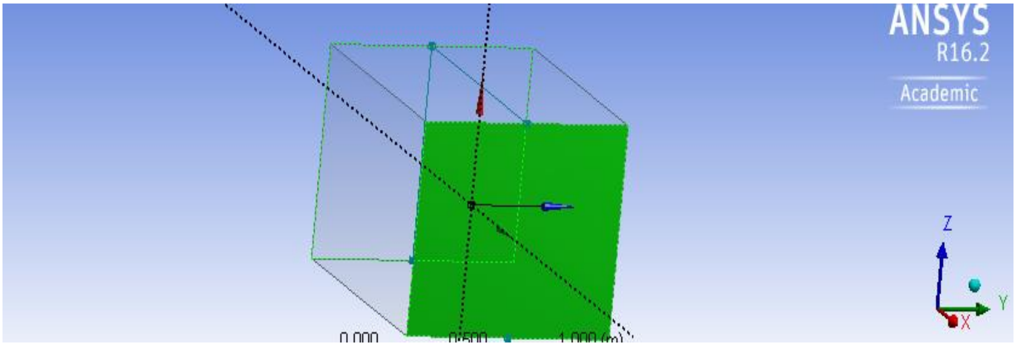

Figure 24: boundary conditions

Analysis of finite element is used to analyze the proposed system through meshing system using mesh toolbox, where the number of elements was 32K nodes as illustrated in Figure 25.

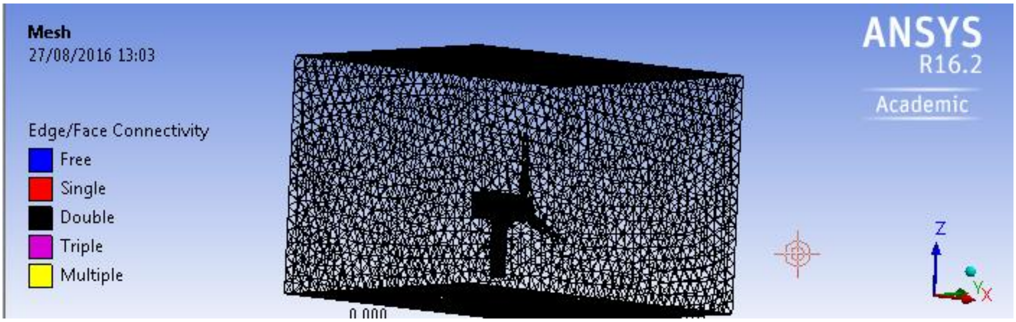

Figure 25: Mesh analysis for system

The results have been imported to the FLUENT solver in order to find the velocity distribution, where the model were defined as k-epslon model, and the materials were defined for both the solid and fluid.

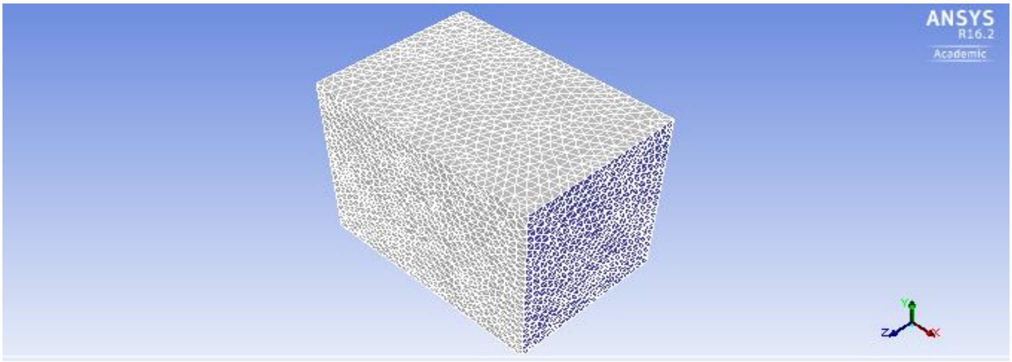

Figure 26: k-epslon model for system

The boundary condition for the inlet was defined as inlet velocity boundary condition and for the outlet was defined as outlet pressure. The inlet velocity is the average velocity of Jal Aliyah that is 11.21 m/s, the solution was initialized from the inlet velocity, where the initial number of iterations was 300 iterations, the results of the velocity distribution are shown in Figure 27.

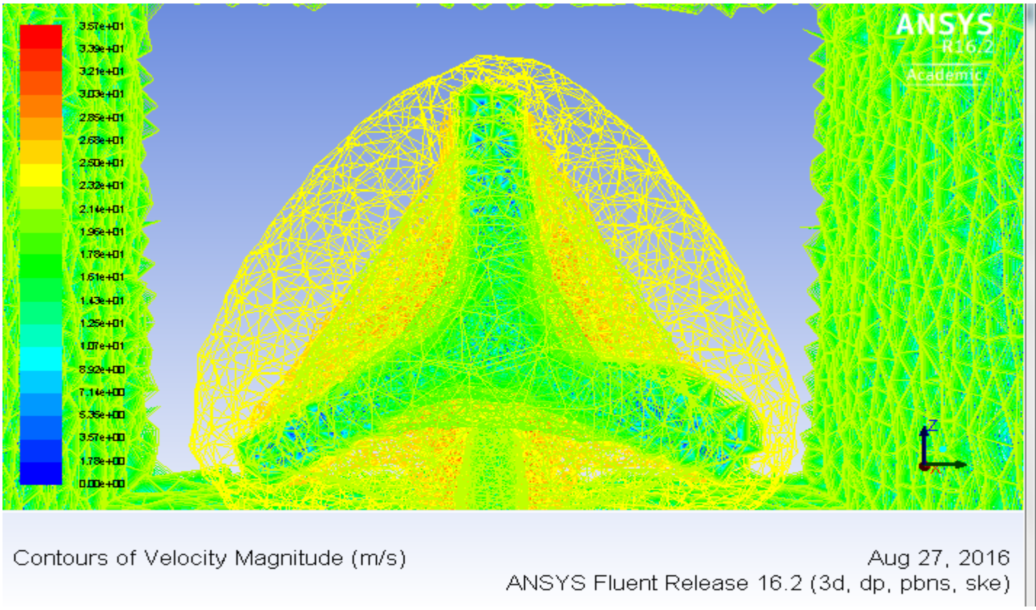

Figure 27: Velocity distribution

Also, the pressure distribution also was plotted as shown in Figure 28, where the pressure gradient is positive from the bottom to the top of the design, which means that this pressure will rotate the blades by making couple torque.

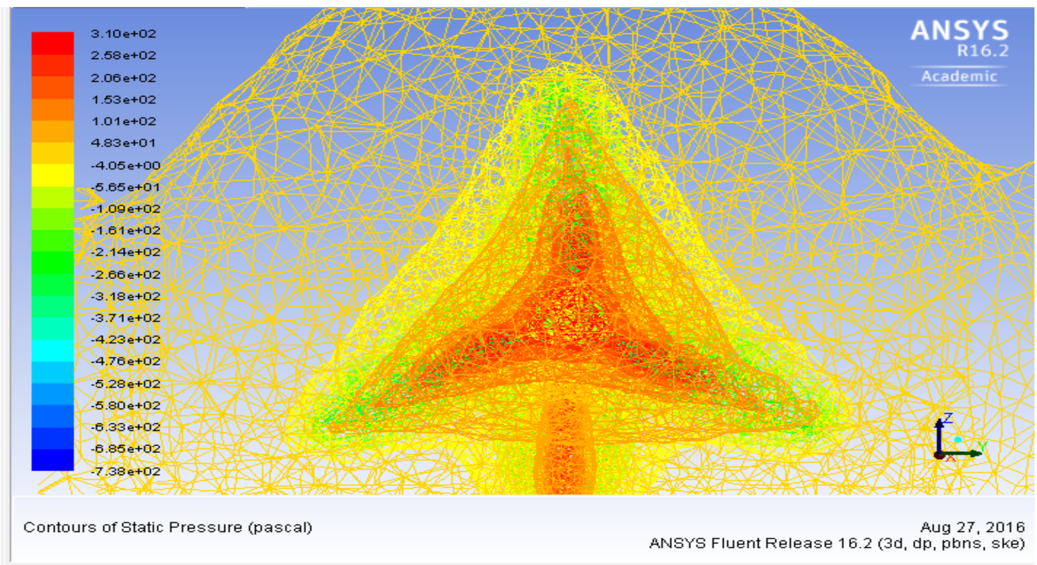

Figure 28: Pressure distribution

Figure 29 illustrates plot of velocity as function of distance at the tip of blade, the speed of tip will reach about 37 m/s when the speed of inlet is equal to 11.21 m/s. Thus, the TSR value is (3.3) and the power coefficient is (0.14).

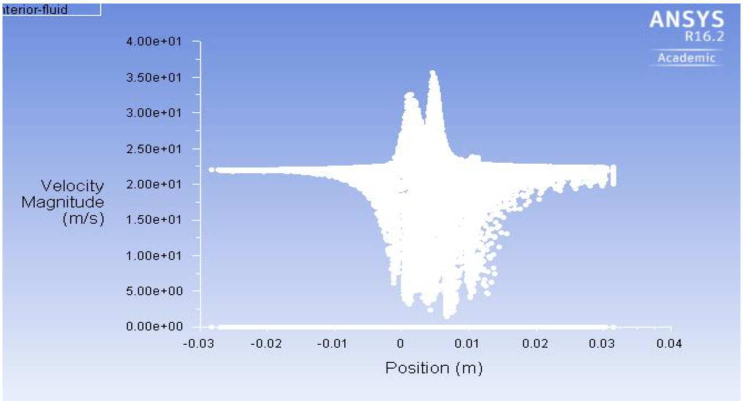

Figure 29: plot of velocity at the tip of blade

The pressure was plotted as shown in Figure 30, where a negative and positive pressure can be noticed that make the couple of torque

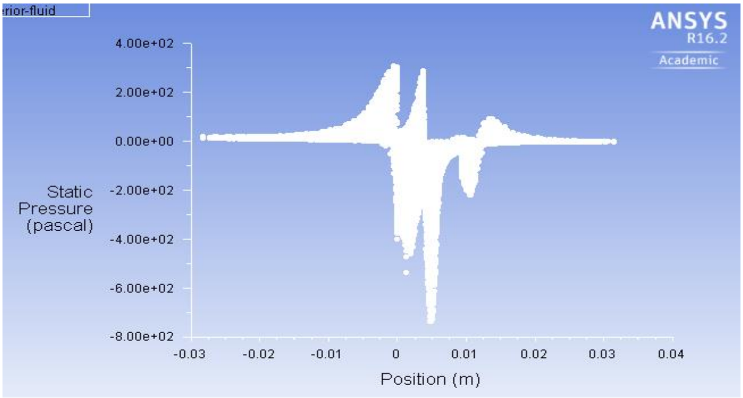

Figure 30: Plot of static pressure

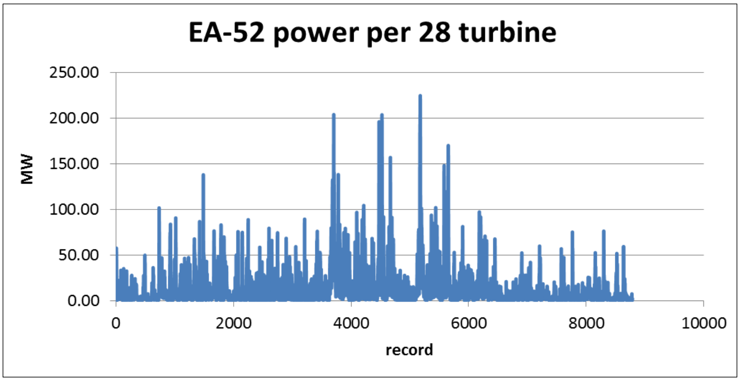

Figure 31: Hourly production of the proposed farm

Figure 31 shows the expected hourly production of the proposed farm, where the annual production is 105082 MW. According to (ministry of electricity and water of Kuwait, 2017) the price of the electrical power production per kWh is $0.13. But, $13.66 m is required to produce this amount of power using firing fuel.

Installing the wind turbines required $4000 per KW (irena, 2012). So, the cost of installing these turbines is $89.6, and the operating cost is $0.05/turbine thus the operating cost for 28 turbines is $ 5.2 Figure 32 illustrates the return rate for the proposed design, which is equal 12 years.

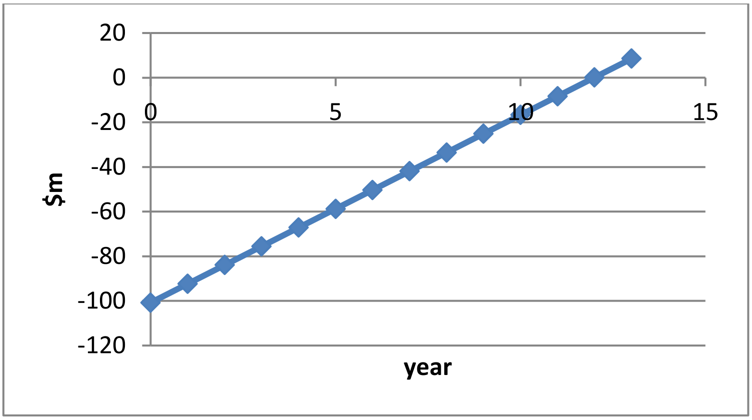

Figure 32: the rate of return for the proposed design

CONCLUSION

This paper is an evaluation for the renewable via using GCC. The composed meteorological data were employed in estimating the wind energy characteristics for the three considered situations in Kuwait city, which are; Jal Aliyah, RasSubiyah and Bubian Island. The wind standard characteristics are the standard deviation, wind density, highest amount of obtainable energy and the average of highest wind speed. Furthermore, a proposal for Jalaliyah location was provided to obtain the maximum amount of wind energy.

In general, the speed of the wind regularly increases with increasing the altitude, which consequences on the highest energy generated from the wind, which is applicable and true for any wind speed. Furthermore, the designers of the systems of wind turbine need a suitable evaluation of the power characteristics of wind turbines in to discover and select the most competent turbine system.

The analysis also included an evaluation for the wind energy characteristics when the increasing the heights of the turbine hub. The default calculations and measurements were performed at 10m altitude, and there are two extra cases which done in order to elevate and examine the additional characteristics parameters at 30m and 50m altitudes. It is observed that when increasing the height, the wind speed also increases. Consequently, essential recommendations are proposed for the designers create the suitable design and decide the wind power density throughout the selection procedure. The type of wind turbine (SWT-6.0-120) was selected with output power = 6MWh, the optimal selection for JalAliyah situation was wind turbine farm incluses 21 turbines with 126 MWh capacity. The location of the t farm location was specified using Google map while the effects of the environment on wind turbines are also considered.

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APPENDIX 1

Wind Turbine Characteristics suitable for Jal Aliyah station

Model name	Diameter of rotor in (m)	wind speed Cut-in (m/s)	Rated speed in (m/s)	wind speed Cut-out in (m/s)	Rated power (kW)	Available power in (kW)	Height of Hub in (m)	Efficiency of turbine	C_F
MWT-450	39	2.5	13	25	450	1607.213	50	0.279988	0.18
MWT62/1.0	61.4	3	12.5	25	1000	3541.448	50	0.28237	0.18
MWT-600	45	2.5	13	25	600	2139.78	50	0.280403	0.20
SWT-3.0-101	101	3	12.5	25	3000	9582.676	50	0.313065	0.19
CWT500	36.6	1.8	14.3	26.8	500	1884.015	50	0.265391	0.16
SWT-6.0-120	120	3	12	25	6000	11967.96	50	0.501338	0.18
GW 77	77	3	11.1	22	1500	3899.998	50	0.384616	0.19
MWT-500	40	2.5	13	25	500	1690.69	50	0.295737	0.17
GW 87	87	3	9.9	22	1500	3532.304	50	0.424652	0.18
N27/150	27	3	15.5	25	150	1305.68	50	0.114883	0.19
GW 70	70	3	11.8	22	1500	3872.185	50	0.387378	0.17
AN 600/41	41	4.5	14.5	25	600	2464.823	50	0.243425	0.16
N50/800	50	2.5	15	25	800	4058.147	50	0.197134	0.17
GW 82	82	3	10.3	22	1500	3533.893	50	0.424461	0.18
N29/250	29.7	3	15	25	250	1431.861	50	0.174598	0.17
G47	47	4	15	25	660	3585.779	50	0.18406	0.19
CWT300	30	1.8	13.4	26.8	300	1041.528	50	0.288038	0.17
GW 82	82	3	10.3	22	1500	3533.893	50	0.424461	0.18
AN 600/44 MK IV	44	5	15	25	600	3142.629	50	0.190923	0.16
AN 1000/54	54.2	3	15	25	1000	4768.551	50	0.209707	0.17
V 44	44	4	16	20	600	3813.988	50	0.157316	0.17
G52	52	4	13	24	850	2857.267	50	0.297487	0.18
V 42	42	4	16	25	600	3475.142	50	0.172655	0.16
G44	44	4	16	20	600	3813.988	50	0.157316	0.18
V 39	39	4	15	25	500	2468.977	50	0.202513	0.18
G42	42	4	16	25	600	3475.142	50	0.172655	0.18
W4500/750	45.4	2	12.5	25	750	1936.225	50	0.387352	0.13
G39	39	4	15	25	500	2468.977	50	0.202513	0.17
ECO 44/600	44	4	14.5	25	600	2838.725	50	0.211362	0.15
AE-52	52	3.5	12	25	800	2247.318	50	0.35598	0.16
V 47	47	4	15	25	660	3585.779	50	0.18406	0.15
AE-56	56	3.3	11.5	25	800	2293.948	50	0.348744	0.15
ECO 48/750	48	4	14.5	25	750	3378.318	50	0.222004	0.14
B41/600	41	4.5	14.5	25	600	2464.823	50	0.243425	0.15
W4100	40.1	2	15	25	500	2610.217	50	0.191555	0.13
V 29	29	3.5	14	25	225	1109.926	50	0.202716	0.14
600/41	41	3.5	14	25	600	2218.533	50	0.270449	0.12
HMZ WM 300	28	4	13	25	300	828.4383	50	0.362127	0.16
B44/600	44	3	15	25	600	3142.629	50	0.190923	0.16
LW 27/250	27	3	13	30	250	770.3208	50	0.32454	0.11
DT 2160	21.5	3	8.5	25	60	136.5362	50	0.439444	0.11
HMZ WM 750	43.4	4.5	13	26	750	1990.323	50	0.376823	0.14
62/1300	62	3	15	25	1300	6239.808	50	0.20834	0.15
DT 2169	21.5	3.2	8.5	25	60	136.5362	50	0.439444	0.12
E-47	48	3	12	34	800	1914.874	50	0.417782	0.13
W755/48	48	4	14	25	755	3040.749	50	0.248294	0.12
E-30	29.6	2.5	11	25	200	560.8872	50	0.356578	0.14
LW 52/750	51.5	2.5	13	25	750	2802.583	50	0.26761	0.14
LW 50/750	50.5	3	12	25	750	2119.535	50	0.353851	0.13
44/600	44	3	15	25	600	3142.629	50	0.190923	0.12
E-40/5.40	40.3	2.5	12	25	500	1349.795	50	0.370427	0.15
LW 30/250	30	3	13	25	250	951.0133	50	0.262877	0.11
E-40/6.44	43.7	2.5	12	28	600	1587.16	50	0.378034	0.15
E-44	44	3	12	34	900	1609.026	50	0.559345	0.14

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