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Parametric Investigation of Wind Energy for Jordanian Metrological Conditions

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ABSTRACT

The utilization of wind energy for power generation purposes is becoming increasingly attractive and gaining a great share in the electrical power production. Accordingly a lot of studies and projects were executed to meet these needs concentrating on sites that have wind speed exceeds 5 m/s. However Jordan has similar case for energy needs and electrical power generation which associated to lack of natural resources of oil and petroleum and high potential of wind energy at different sites and feasible wind speeds. Fundamentally, there are different parameters that are influencing wind energy and its potential for power generation. These include environmental conditions; wind turbines design restrictions and operation parameters. The operational parameters has a direct effect on the generated power which will lead the developers and researchers This study is designed to introduce a parametric analysis of wind energy and investigate the scaling ranges of each parameter for both general conditions and Jordanian environments to focus on the highest priority parameter that should be considered for manufacturing and optimizing of wind turbines. In this study, mathematical and computerized models were constructed to investigate wind turbine power generation under Jordanian metrological conditions. This enables for study and scaling up the effect of Jordanian environmental conditions on rate of power generation and determining the best operating ranges for optimal design, operation and control of wind turbine. The results show that the power change in the range from 314 to 363 (KW) when the high change from 55 to 70 m, while effect of rotor radius starts to be significant after 30m then increased dramatically after 40 m. Moreover, the recommended rotor radius may be not less than 40 m and turbine height not less the 70 m.

INTRODUCTION

Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of earth's terrain, bodies of water, and vegetative cover. This wind flow, or motion energy, can be used to generate electricity by wind turbines. This energy can be converted to electricity by using a wind turbine (http://science.howstuffworks.com).

In the united states, the electricity-generating capacity of wind power contributed about 1.3 percent of the total U.S. electricity supply in 2008 and 1.8 percent in 2009, (Wilburn, 2011)

Wind energy is clean source of energy, renewable and environmentally energy, relatively cost effectively and it has the advantage of being coupled on local basis for applications in rural areas and remote areas.

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On the other hand, the major disadvantage of wind energy is variability; speed of the wind is not constant and it varies from zero to maximum values depending on location and climate conditions. This means that wind turbines do not produce the same amount of electricity all the time.

Jordan has rich wind energy resources. Studies on the wind potential have been made for several years and the available wind resources were assessed and based on which a Wind Atlas has been prepared, which shows that there is a potential of several hundreds of Megawatts of wind power installations in the country. Wind Energy is one of the most promising sources for renewable energy in Jordan.

It has been revealed the several parameters which are affecting the wind projects in this study. It also gives an indication about the whole Jordanian situation regarding renewable energy, especially wind energy since wind energy is relatively one of the cheapest available renewable energy sources.

Many studies can be found in literature, e.g. (Al zou'bi M., 1995 and Halasa G., 1995). Al zou'bi showed that the pattern of wind energy variation is highly agreed with prevailing peak demands and corresponding peak hours. With the presence of high potential sites, from the renewable energy point of view, there is no excuse for those who oppose this type of energy to wait more time. Concerning wind energy resources in Jordan, there are tens of places known by their high wind speed and long windy times. The existing wind farms in Hofa and Ibrahimia are good examples of wind energy projects. These farms are connected to the national grid and characterized by a high availability and excellent capacity factors. The agreement between the power output of these farms and the annual load curve shows that these farms can significantly participate in reducing the burden on the national grid in summer, when the load reaches its peak. The preliminary research for new wind energy resources has revealed that tens of places have wind speed greater than 5m/s. Currently, there is a plan for three wind farms with Maximum capacity of 30MW each. These farms are distributed among three sites in the northern and southern regions of Jordan. The daily load curve of the Jordanian network has two peak periods, in midday and evening hours. The existing and planned projects for small and large wind farms are important for establishing a good alternative for existing conventional sources of energy.

Halasa G., (1995) presents in his paper the electrical power generation using solar- and wind-energy (hybrid power) for the country of Jordan. Sights are chosen to produce electricity using, the wind in the Mountains in Northern Jordan and the sun in the Eastern Desert. The paper also discusses different control methods to link with the national grid. This is very significant because developing countries, which depend on external sources to finance major energy projects, may be able to finance small scale solar and wind energies projects from their own resources and faster. The result is to install windmill farm in the mountainous area in the north, where wind speed proved to be viable, while the eastern desert is suitable to install solar power station.

In the recent international work, Benatiallah *et al*., (1995), presented the study of methodology for calculation the optimum size of a Wind system of a Long term data of wind speed for every hour of the day were used. These data were used to calculate the average power generated by a wind turbine for every hour of a typical day in a month. A load of a typical house in south of Algeria(desert area) was used as a load demand of the system. In their research, they investigated the genetic algorithm (GA) for optimally sizing a wind power system. A procedure for optimizing the size of a wind-energy system was presented.

Recent computational studies based on large eddy simulation have identified various mean velocity equilibrium layers and have led to parameterizations of the effective roughness height that allow the prediction of the wind velocity at hub height as a function of parameters such as wind turbine spacing and loading factors as explained by Meyers J., and C. Meneveau, (2012). In their paper, they employ this as a tool in making predictions of optimal wind turbine spacing as a function of these parameters, as well as in terms of the ratio of turbine costs to land surface costs. For realistic cost ratios, they find that the optimal average turbine spacing may be considerably higher than that conventionally used in current wind farm implementations.

Daryoush and Yiannis, (2014), described a new concept in wind power harnessing which significantly outperforms traditional wind turbines of the same diameter and aerodynamic characteristics under the same wind conditions and it delivers significantly higher output, at reduced cost. Their results led to the design of a demonstration facility which has provided actual data which verified the significantly increased power expectations., the system Called INVELOX, is that it captures wind flow through an omnidirectional intake and thereby there is no need for a passive or active yaw control. then, it accelerates the flow within a shrouded *Venturi* section which is subsequently expanded and released into the ambient environment through a diffuser

The aim of this study is to build up a mathematical and computerized model for parametric study, analysis and utilization of wind energy for the Jordanian situations and extract conclusions in order to be used by researchers and policies makers.

MERIALS AND METHODS

1. Energy Sector in Jordan:

Jordan is located in the Middle East. Situated between the longitudes 35^o and 39^o E and between the latitudes 29^o and 33^o N with a total area of 92,300 km^2. 90% of this area is classified as desert. “Considering the past ten years, i.e. 2000-2009, the population has increased from 4,900,000 up to 5,980,000 with an average annual growth rate of approximately2.5%” (Statistical indicators database, 2008-2013), from 2011 with start of Syrian crises the massive number of refugee come to Jordan and now the total number of refugee in Jordan about more than 1,000,000 capita.

Jordan is classified by the World Bank as a "lower middle income country". The nominal Gross Domestic Product (GDP) for 2009 was $22.929 billion ($3,828 per capita) achieving an annual growth rate of 3.2%. According to the Department of Statistics, almost 13% of the economically active Jordanian population residing in Jordan was unemployed in 2008. The currency has been stable with an exchange rate fixed to the U.S. dollar since 1995 at JD 0.708 to the dollar (Statistical indicators database, 2008-2013; Energy Statistics, 2010-2014; Statistics database, 2008).

Jordan has experienced an average growth rate of primary energy demands of 5.1% per year over the past ten years. The consumption has risen from 5114 up to 7739 million Ton Oil Equivalent (Figures and Facts (Energy Brochure) 2009). Jordan is among the highest in the world in dependency on foreign energy sources, with 97% of the country's energy needs coming from imported oil and natural gas from neighboring Arab countries. This complete reliance on foreign oil imports consumes a significant amount of Jordan's GDP, imported energy in 2011 cost 4019 million JD.

2. Wind Atlas for Jordan

The wind atlas for Jordan in figure (1) below provides the annual average wind speed all over the country. This atlas was established in 1987 using satellite measurements and has not been updated since. Therefore, and due to the lack of reliable wind data in Jordan, the National Energy Research Center has conducted a wind measuring campaign in the promising sites in Jordan as a first stage based on the availability of wind measuring systems at different heights (10, 30, 40, 50, and 60) meter above ground level. Generally, the most energetic wind is found at a distance of almost 400 km along the western border. At the same time, the lowest wind potential is found at the east, middle and southeast of Jordan. However, there are some areas in the northwest, middle, and southwest that have the best wind speed (Yearly report, 2008; (NERC); https://energypedia.info/index.php/Jordan_Energy_Situation#The_Electricity_Grid).

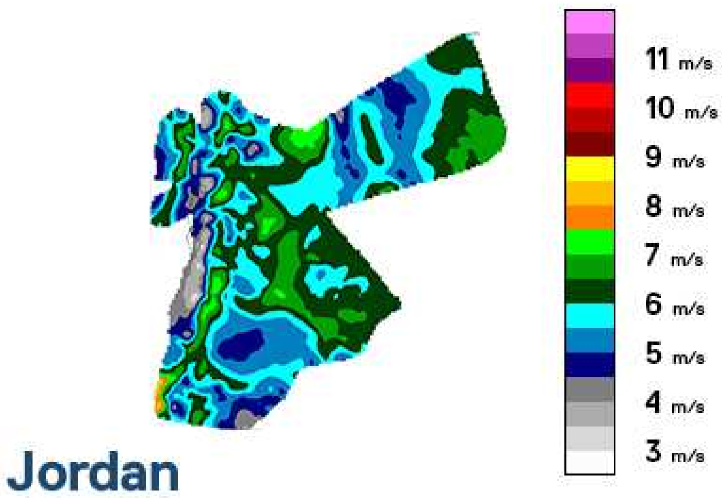

Fig. 1: the wind atlas of Jordan (Yearly report, 2008)

Modeling of wind energy- Effective parameters:

Wind energy can be affected by different parameters; these parameters are classified as in the following manner as shown by Manwell J. *et al*, (2008):

1. Operation parameters (e.g. wind speed (see Figure 2), blade angular speed)
2. Design parameters (e.g. effect of elevation, angle of attack, turbine rotor radius)
3. Surrounding parameters (e.g. air density, air temperature, pressure and humidity)

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Mathematical Model:

The initial capital investment in wind power goes to machine and the supporting infrastructure. Any factors that lead to decrease in cost of energy such as turbine design, construction and operation are a key to making wind power competitive as an alternative source of energy. A mathematical model of wind turbine is essential in the understanding of the behavior of the wind turbine over its region of operation because it allows for the development that aid in optimal operation of a wind turbine. There is a group of mathematical equations used for calculating the output power from wind energy turbine.

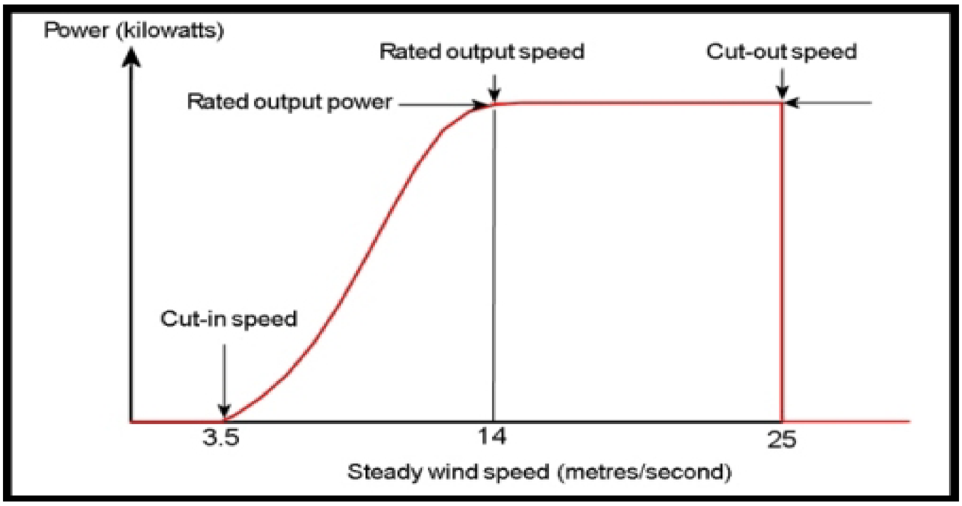

Fig. 2: Typical wind turbine power output with steady wind speed (http://www.wind-power-program.com/popups/powercurve.htm)

The moving molecules of air have kinetic energy, so locally the amount of air molecules moving across some area during some time period determines the power. This area is not the surface area of the earth, which was referred to in the estimation of extractable power and energy, but the area perpendicular to the wind flow. The mass, *m*, in the volume of the cylinder that will pass across the area, *A*, in time, *t*, can be determined from the density of the air and the volume of the cylinder, $\vee$ as elucidated by Cetin M. *et al*, (2005).

The power is the kinetic energy of the air molecules divided by the time:

$$P = \frac{Kinetic\ Energy}{Time} = \frac{K\,E}{t} = 0.5\ m\frac{v^2}{t} = 0.5\ \rho\ A\ v^3 \qquad (1)$$

$$\rho = m\,/\,Q$$
$$Q = VA$$

Where:
ρ is the air density in (kg/m^3),
m is the mass flow rate in (kg/s)
Q is volumetric discharge of air in (m^3/s)
V is wind velocity in (m/s)
A is the cross-sectional area of crossing flow path in (m^2)

And the volume ($\vee$) could be expressed as following:
$\vee$ = cross sectional area $\times$ length = $A \times L$
$m = \rho \times \vee = \rho \times A \times L$

The power (*P*) divided by the area (power/area) referred to as wind power potential or wind power density, which is:

$$\frac{P}{A} = 0.5\rho v^2 \qquad (2)$$

The coefficient of power of a wind turbine is a measurement of how efficiently the wind turbine converts the energy in the wind into useful power.The actual range of power coefficient C_p from 0.35 to 0.45 and the maximum value of C_p is 0.59 (The British Wind Energy Association 2003).

Wind energy is proportional to air density, according to Betz' law wind power is:

$$P = \frac{1}{2} C_p A \rho V_z^3 \qquad (3)$$

Air density ρ itself depends on pressure P and temperature T, according to formula:

$$\rho = 3.484 \frac{P}{T} \qquad (4)$$

And sweep area is calculated by this formula:

$$A = \pi R^2 \qquad (5)$$

Where, R is the radius of rotor.

The wind speed at elevation z can be calculated by the following equation as clarified by Bowdler D. *et al*, (2009):

$$V_z = V_{10} \left(\frac{Z}{10}\right)^{\alpha} \qquad (6)$$

Where, V_{10} = velocity of the wind at height, h_{10}= 10 meters

Computerized Model:

A careful study of the behavior of the wind turbines during their operation is of crucial importance in the planning phase and in the design stage of a wind farm, in order to minimize the risks deriving from a non-accurate prediction causing sensible faults of the system. To analyze the impact of the wind turbines in the system motivates the development of accurate yet simple models.

Computer codes developed the performance of the system by study the factors and the effect of these factors on the out power through analyzing aerodynamic, forces, and vibration have been modified for wind turbines as presented by Cetin M. *et al*, (2005) and Harrison, R. and G. Jenkins (1993).

Through computer programing we can study the effect of one factor and fixed the other factors and produced the relation between this factor and the out power of the wind turbine**.**

Chart (1) shows the flow chart that explains steps of calculating the power and how to apply the mathematical equation sequentially.

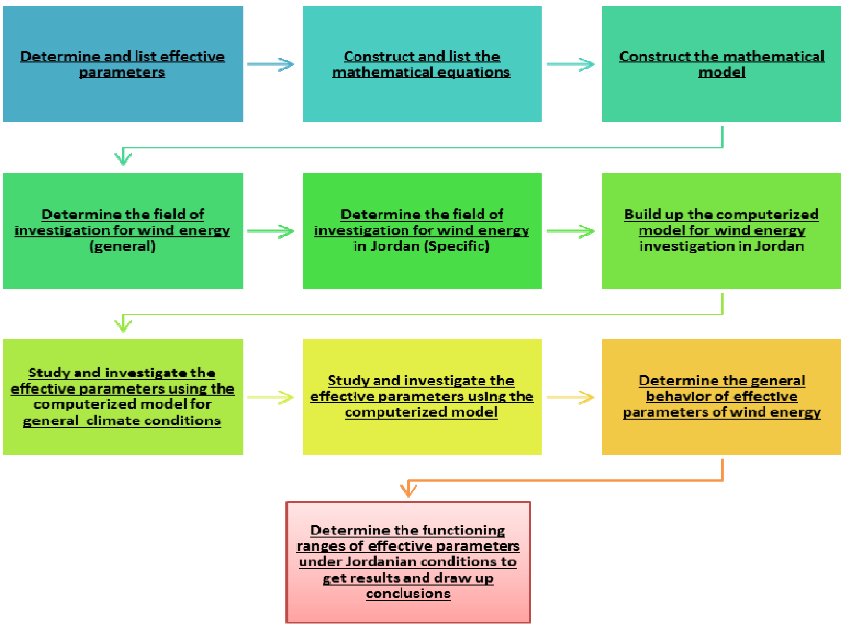

Chart 1: Process sequence for parameter generalization in computerized model.

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RESULTS AND DISCUSSIONS

The different parameters were investigated in this study to estimate the wind energy and effect of these parameters, the parameters were as following:

1. Temperature.
2. Atmospheric pressure.
3. Turbine elevation.
4. Rotor radius.

The result of modeling and analysis were as following:

1. General results:

1.1 Effect of temperature:

Figure 3 shows the output power as a function of temperature. The power decreases with the increase of the temperature.

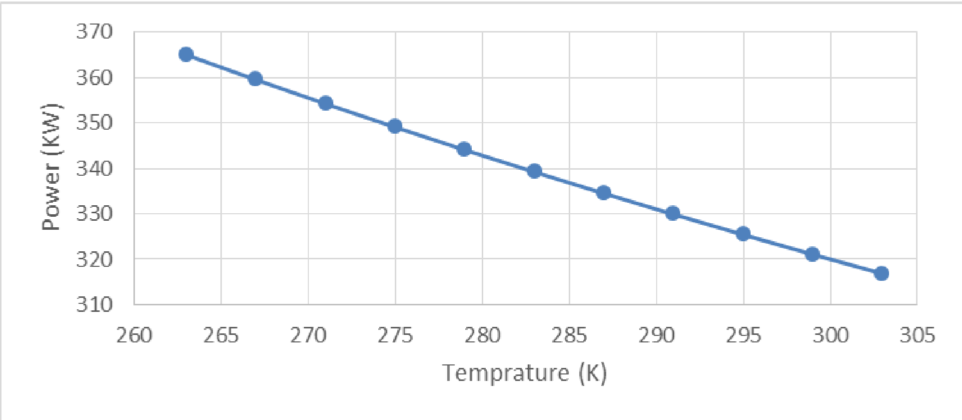

Fig. 3: the effect of temperature on the power

As shown in the fig.(3) the power is decreased by increase the temperature , this because the air density is decreased by increasing the temperature.

When air wormed, it expands and become less dense. As the air become less dense, its air pressure decreases. This occurs because molecules in warm conditions have grater kinetic energy than in cold conditions. As molecules move faster they spread out. In this condition the molecules move farther apart the volume of air increase and density decrease.

1.2 Effect of pressure:

Figure 4 shows the output power as a function of pressure. The figure indicates that power increase with the increase of the pressure.

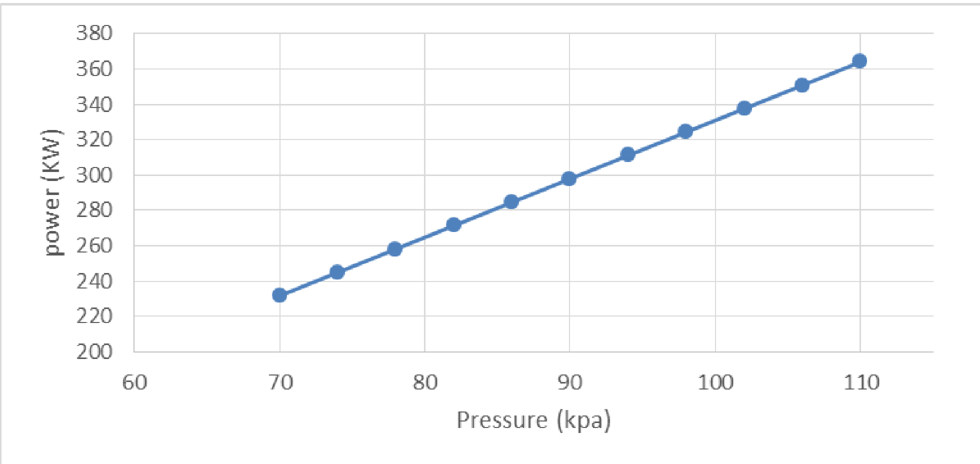

Fig. 4: pressure effect on out power

As shown in the fig.(4) the power is increased by increasing the pressure , this because the air density is increased by increasing the pressure; When air pressure increased the movement of air molecules decreased, this will cause decrease volume of air and increase the density of air.

1.3 Effect of elevation:

Figure 5 shows the effect of elevation on the power. The figure indicate the relation is direct proportional, that's because the wind speed increases with height above the ground,

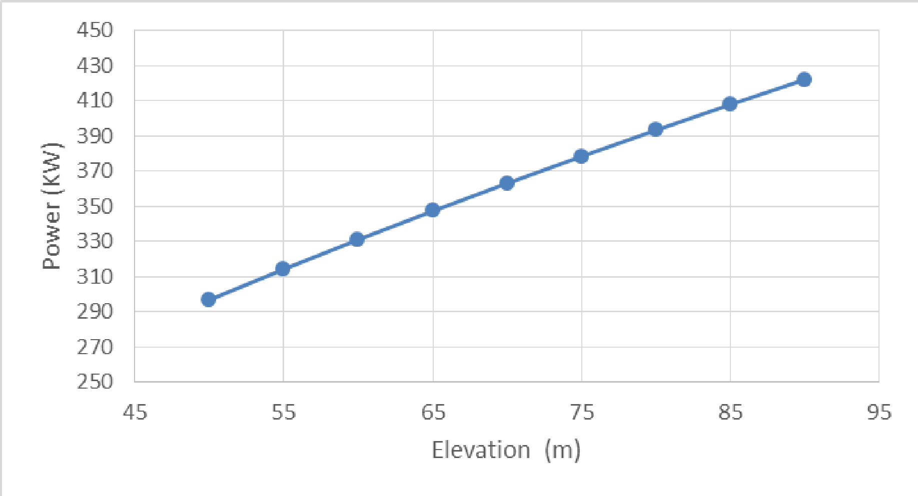

Fig. 5: output power Vs. turbine elevation

To maximize the performance of the turbine by exposing the system to higher wind speeds. As an example, a 5 kW residential wind turbine on a 35 ft tower in an open area might produce 1,200 kWh annually in a moderate wind regime. The same turbine on a 115 ft tower would generate 9,000 kWh per year. In other words, it would take eight turbines at 35 ft to equal the output of one properly sited turbine at 115 ft (Tower Height DWEA Briefing Paper, 2014) and Christine G. September (2015)

1.4 Effect of rotor radius:

The effect of the rotor radius on the power is shown in figure 6. This figure indicates that rotor radius is one of the most important parameter to producing wind energy, and the power change positively with rotor radius.

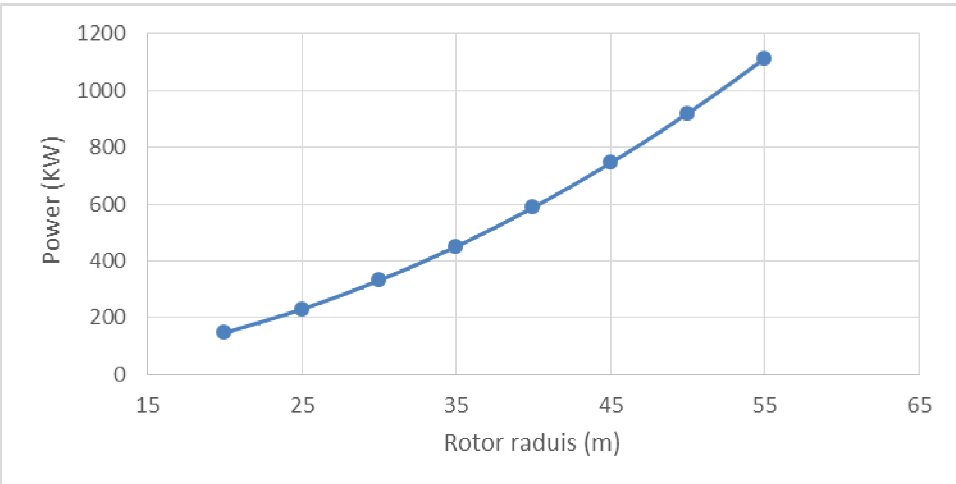

Fig. 6: relation between output power and rotor radius

The relation in the figure 6 shows squared power between rotor radius and power generation. The cross sectional area is increased with increasing of rotor radius and will increase power generation as per equation (1).

2. Specific results for Jordanian environmental conditions:

The model is then methodically used to study the wind power under environmental conditions of Jordan to determine the best operating range for each effective parameter. The results of this investigation are obviously presented through figure 7-10, while the parameters ranges for Jordanian metrological conditions are listed in table (1) below.

All of the previous figures have been repeated with the Jordanian condition and are presented in figure 7-10.

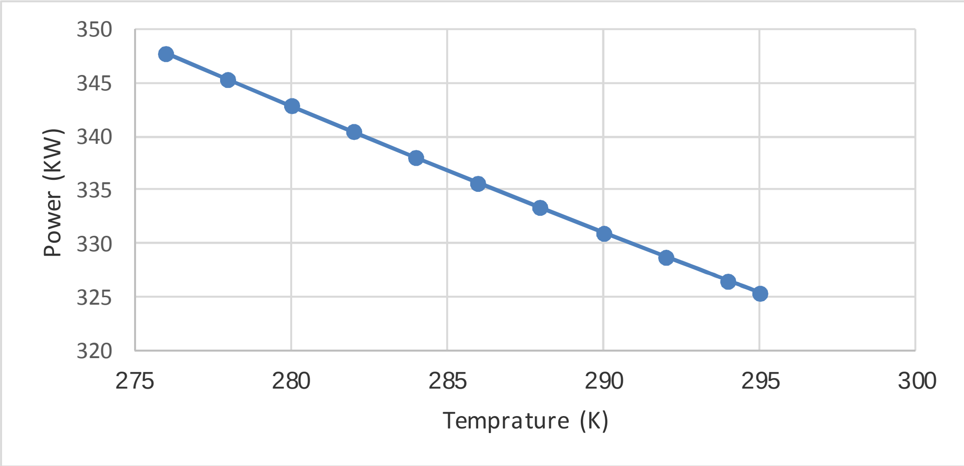

Fig. 7: relation between power an temperature in Jordan conditions

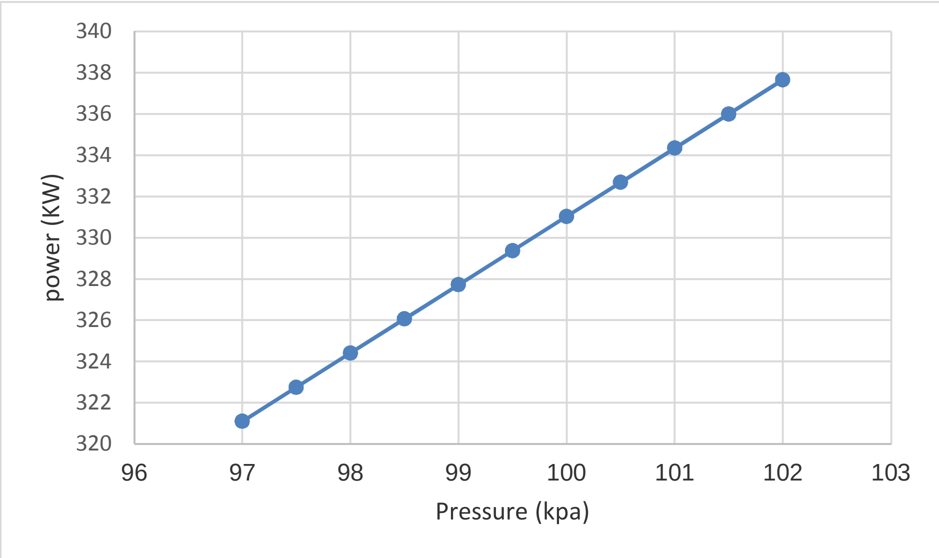

Fig. 8: relation between pressure and power in Jordan conditions

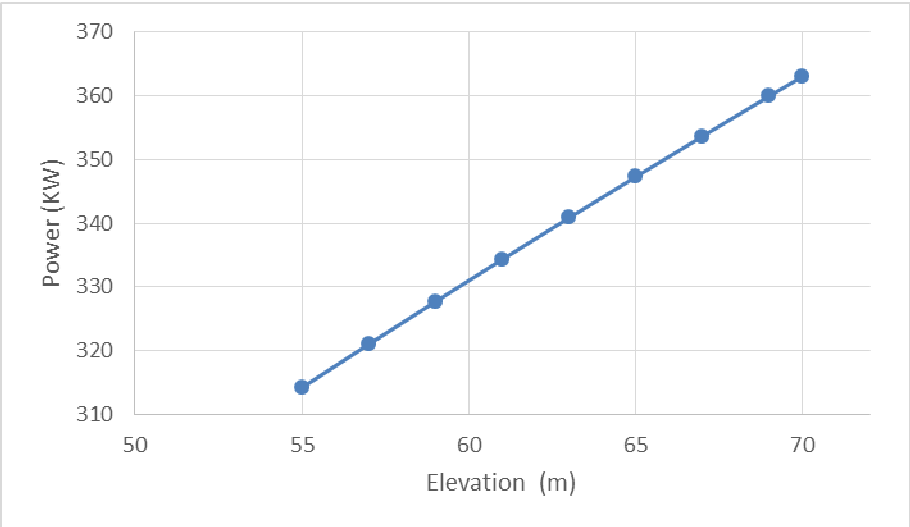

Fig. 9: relation between power and turbine elevation in Jordan conditions

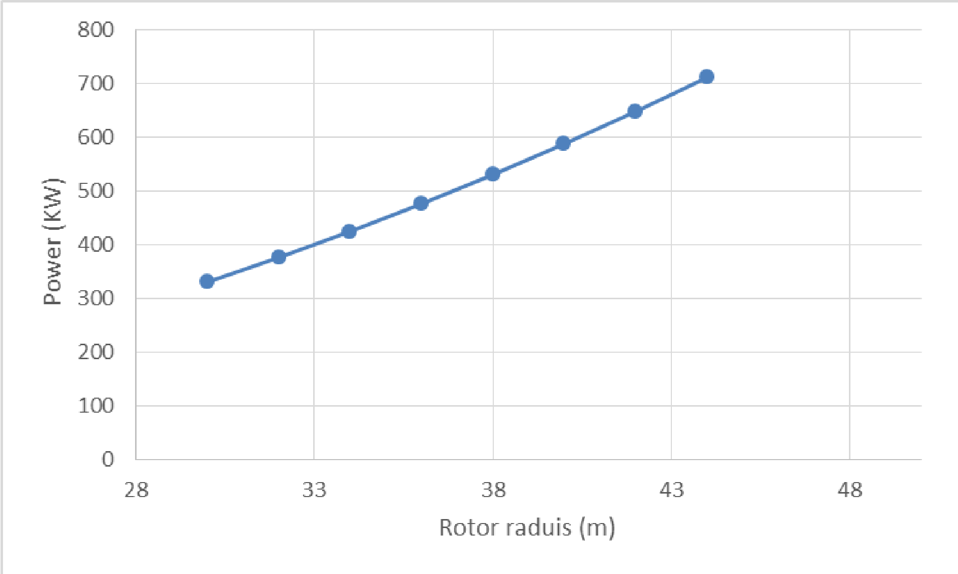

Fig. 10: relation between power and rotor radius in Jordan conditions

It could be noted that there was little change in the resulting power when change pressure at its range and fixed other parameters, as well as temperature as shown in figure 7 and 8, where 97 kPa is the minimum amount of pressure with 321 kW of power and 101 kPa is the maximum amount of pressure with 337.6 kW of power and the following figure explain this relation.

The wind speed depends mainly on the height of turbine which is directly proportional with the output power, where the power increase when the high increase, figure 9 shows the power change in the range from 314 to 363 (KW) when the high change from 55 to 70 (m).

The relation between the temperature and the elevation is reverse relation so that when the elevation increase the temperature will decrease and this effect on the power through the place of the wind turbine which has the best temperature and elevation to produce more power.

We conclude, the wind speed impact on the estimated power produced from the wind, and this premise must choose places of the wind turbine where the wind speed is higher than the other parameters to get the highest power. Where that the resulting power commensurate with the cubic wind speed, we conclude from this that the speed of the wind significant impact on the estimated power produced from the wind.

Figure 10 shows that the effect of rotor radius is insignificant up to radius 30m even in high wind speed, while the effect start to be significant after 30m and start increased dramatically after 40m.

Table 1 shows the best ranges of parameters which have directly influence on output power in the Jordanian satiations.

Table 1: the best ranges of parameters for Jordan metrological conditions

No.	The parameter	The range
1	Wind speed V_z (m/s)	5 – 9
2	Density ρ (kg/m^{3})	1.18 – 1.26
3	Rotor radius R (m)	30– 45
4	Elevation Z (m)	55 – 70
5	Temperature T (^{o}C)	3 – 22
6	Pressure P (kpa)	97 – 101

Conclusions:

Jordan imports most of the energy it consumes and there is a serious problem concerning the energy demand growth rate in the near future. It is important for Jordan to start focusing on its internal resources such as renewable energy since it provides Jordan with an independent energy source. Also it gives the Jordanians the opportunity to start a new energy market and to find new job opportunities for the local people.

According to the above analysis there are many parameters affecting the amount of energy generated from wind, as hosts of the wind power are affected by several factors including pressure, temperature, elevation, rotor radius and power coefficient. And they are many parameters which have indirect effect on output power.

Density have directly proportional effect with pressure inversely with temperature and density in turn is directly proportional to the power produced, it has been noticed that was little change in the resulting power when change pressure at its range and fixed other parameters, as well as temperature .

Because the only parameters can be controlled in wind power generation are turbine height and rotor radius; the recommended rotor radius not less than 40m and turbine height not less the 70m. While the best range of wind speed for optimal power output is 5 to 9 m/s, and air density range is 1.18 to 1.26 kg/m^3.

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