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Evaluating The Of Small Wind Turbines For Remote Area In Egypt

Sameh Fares, M.A. Abdelrahman, M.Moawed, and R.Y.Sakr

Department of Mechanical Engineering, Faculty of Engineering at Shoubra, Benha University, Egypt

ABSTRACT

Nowadays, wind energy is a promising solution to the energy problem, especially in remote areas. This paper provides an overview of the potential of small wind turbines in remote areas of Egypt, especially the Kharga region A further technical and economic assessment is conducted for the electricity generation with 20 different small wind turbines at different height at El-Kharga. The annual electricity generation from selected wind turbines is evaluated. The obtained data are presented and discussed investigating the net present value and the payback period analyzing the profitability of selected wind turbines. The dependence of the turbine profitability from the feed-in tariff is specifically addressed.

Keywords : Small wind turbines; wind profiles; wind energy; Egypt.

Nomenclature

E	Kinetic Energy (KW)	NPV	Net Present Value
P	Power (KW)	PVF	Present Value Factor
m	Mass of air (kg)	PBP	Payback period
u	Wind velocity (m/s)	IRR	Internal Rate of Return
ρ	Air density (Kg/m^3)	C	Cost ($)
A_T	Rotor cross section area (m^2)	B	Benefits ($)
C_p	Power coefficient	C	Yearly Net Cash Flow
CF	Capacity factor	I	Initial Investment Cost ($)
E_T	Energy out of turbine at period time (KW.h)	R	real rate of interest
P_R	Turbine Power Rated (KW)	I	Discount Rate
t	Period time (h)	N	Number Of Life Time Year
c	Scale Factor	S	Inflation Rate
K	Shape factor	u_m	Mean wind velocity (m/s)
α	Surface Roughness	N	Number of non-zero velocity
PDF	Probability Density Function	H	Elevation from sea level (m)
CPDF	Cumulative Probability Density Function	S.W.T	Small Wind Turbine

1 Introduction

Wind Energy is one of the promise sustainable technology for electricity generation and can be a proper replacement for conventional fossil fuel, Wind turbine are used in many fields such as electric generation, industrial, desalination, hydrogen production and wind pumping …. etc.

Recently, Egypt is witnessing a significant development in renewable energy investments, especially wind energy, after feeding new tariffs, rules and new policy set by the Egyptian government to increase investment in renewable energy. The total wind power production in Egypt in 2108 about 1125 MW and is expected to reach 1375 MW after the completion of the construction of a new large wind farm in the Gulf of oil with a capacity of 120 MW and another in the Gulf of Suez with a capacity of 250 MW [1].

Wind farms have traditionally been established in areas where climate, topography and the environment have allowed development, but turbine installation in rugged, complex terrain such as urban areas and suburban is a challenge as most of these regions have relatively low wind speeds but lack national grid electricity. This makes the installation of wind turbines in these areas as important as an energy solution.

Many studies have focused on large wind turbines that produce enormous energy and operate under good operating conditions, but there are limitations in studies of small turbines operating in complex locations and low wind speeds. Messineo and Culotta [1] studied the performance of six small wind turbines ranging from 0.5 to 25 kw in a suburb at south of Italy. They have confirmed that the choice of turbine is closely related to the wind conditions and to the type of terrain. also the prevalence of small turbines in remote areas depends mainly on government funding and incentives, given the high cost of small turbines compared to productivity.

Change in capacity factor will affect the overall profit and payback period of small wind turbine as said by S.Allardyce [2] when studied the integration of small scale wind into schools and communities especially in rural areas specially North Walls community school on Hoy in Orkney.

Large scale wind turbines alter the global climatic conditions and have adverse effects on the atmosphere A.Tummala and R.Kishore[3] said the small scale wind turbines offer a great scope for producing valuable power which can be sufficient for domestic needs without altering the climatic conditions.

On the other hand in Egypt S.Abdelhadya, D.Borelloc and S.Santoric[4] recommended small wind turbines with rated power more than 200kW, and A.Elzahaby and M.Khalil[5] recommended to use small vertical wind turbine 200 kw on top roofs in red sea area in Egypt.

This study aims to verify the feasibility of installing wind turbines in remote areas of Egypt. In order to achieve this, it was important to study the wind map of Egypt or known as the Atlas .The regional wind climates of Egypt determined by two methods, a traditional wind atlas based on observations from more than 30 stations all over Egypt, and a numerical wind atlas based on long-term reanalysis data and a mesoscale model (KAMM).[6]

The Global Wind Atlas provides a high-resolution wind climatology at 50, 100, 200m hub heights above the surface for the whole world (onshore and 30 km offshore). These layers have been produced using microscale modelling in the Wind Atlas Analysis and Application Program (WASP) and capture small scale spatial variability of winds speeds due to high resolution orography (terrain elevation), surface roughness and surface roughness change effects.[7]

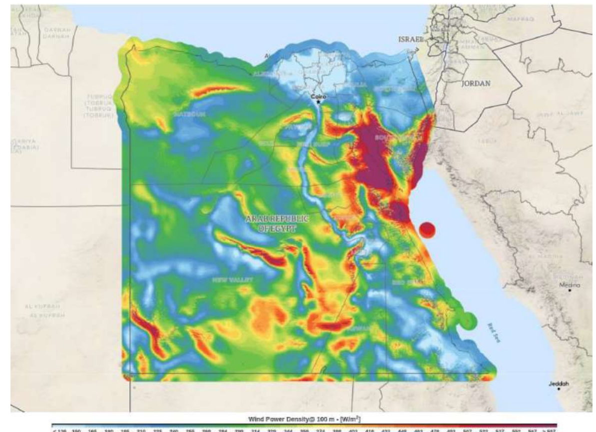


Figure 1: Mean Wind Power Density Map[8]

As shown in Fig.1 the power density available on Egypt ranges from 150 to >597 w/m^2 [8]. The areas surrounding Hurghada, Rafah and around Lake Nasser to Awainat are a promising place where wind farms can be established. Around El Arish, Luxor and Siwa wind energy may not be economical, with a value of less than 200 watt/m^2[9].

2 El Kharga Oasis as Case Study in Egypt

In the present study Al-Kharga Oasis was selected as a case study for the following reasons: Far from the main electricity grid, it has many fields and green farms that need electric power, and also depends in drinking and agriculture on water wells that need water pumping systems and can meet all these needs by installing turbines Small wind.

Figure 2 presented frequency of variably speed at El Kharga Oasis at large time period from year 2006 to 2010, the maximum probability of occurring velocity from 3m/s to 5 m/s as it represents more than 40% of the frequency of velocity and maximum velocity recorded in this area is 8-9 m/s Which are considered relatively low speeds.

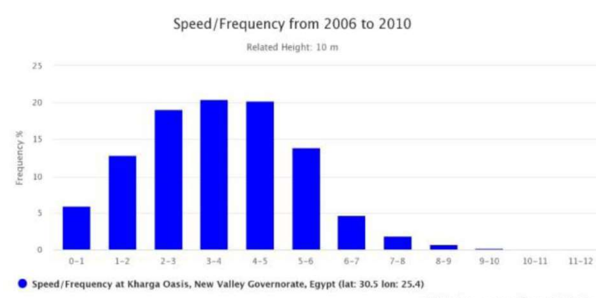


Figure 2 : Speed frequency at el Kharga oasis.

3 Small Wind Turbine on Market

To study the feasibility of the wind turbine of the oasis, it is necessary to know first the concept of small wind turbines and then make an inventory of the turbines available on the world markets so as to choose the sample to be studied. According to previous studies there are a lot of classifications of small wind turbines based on different parameters such as rotor areas, number of blades, axis of rotation, rated power, wind direction and type of generator.

There is still no world unified definition of small wind turbine. Originally, small wind turbine was defined by its characteristics to produce amount of electricity for house consumptions or to cover different household electricity demand[10].

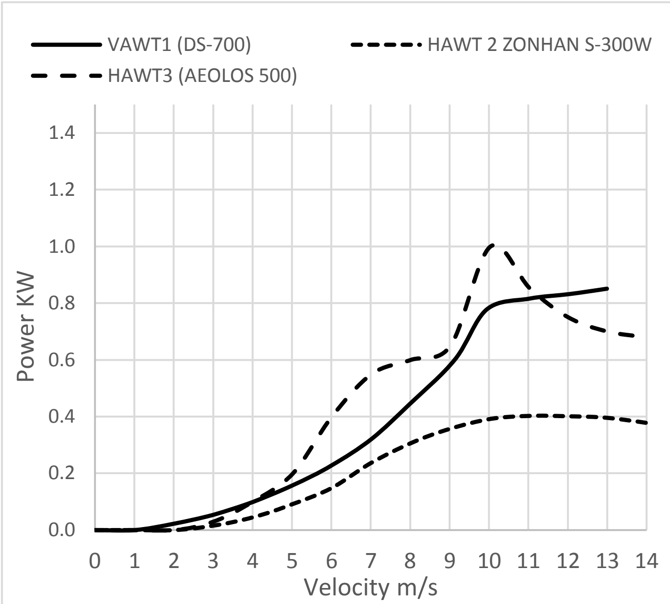
Technically, there are several definitions of small wind turbines. IEC classified the small wind turbines according to rotor swept area where all turbines smaller than or equal to 200 m^2 (which corresponds roughly to P<50 kW) can be considered as small wind turbines, in addition to IEC standard, several countries have defined small wind turbine with their own definition. Canadian Wind Energy Association (CanWEA) by Marbek Resource Consultants survey defined mini wind turbine from 0.3 KW to 1 KW and small wind turbine from 1KW to 300 KW, Germany by BWE defined Small wind turbine < 75 KW, China by Renewable Energy & Energy Efficiency Partnership (REEEP) & USA by American Wind Energy Association (AWEA) defined small wind turbine < 100 KW, But UK defined micro wind from 0 KW to 1.5KW and small wind from 1.5 KW to 15 KW and small –Medium wind from 15 KW to 100 KW and defined by Microgeneration Certification Scheme (MCS) that Micro & Small Wind Turbine < 50KW qualify for the MCS feed-in tariff program in UK[10].

In the present study, small wind turbines will be limited according to IEC standard As all turbines that produces less than 50 kw of power. About 200 different types of wind turbines are available on the market, with a production power ranging from 0.5 kw to 50 kw were analyzed. we found that the vertical axis wind turbine represented about 13% of market available data where the horizontal axis represents 87% of market available data. Available turbines were divided into five classifications according to rated power, considering the approximate number of turbines in each class. Class-I <1.5 KW, Class-II from 1.6 KW to 5 KW, Class-III from 5.5 KW to 10 KW, Class-IV from 11 KW to 20 KW and Class-V from 20 KW to 50 KW.

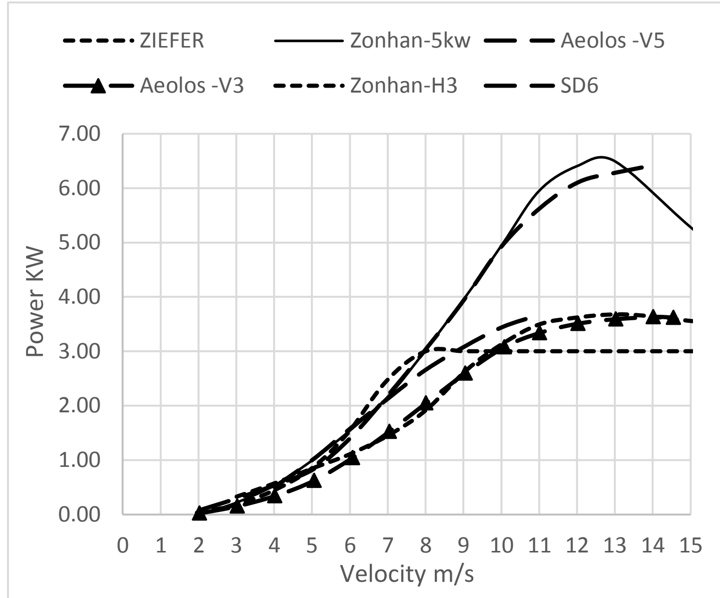
After survey and gathering data about small wind turbine (<50 KW) available on the world market and still produced, the survey included number of 20 model of wind turbine. The wind turbine selected based on model of vertical axis wind turbine with lower rated velocity included in the class segregation and other models of horizontal axis wind turbine one of them have lower rated velocity other model have higher rated velocity at same class. The technical specification of selected wind turbines is listed in table 1. where its power curve is presented in Fig 3.

Table 1: technical data for selected wind turbines.

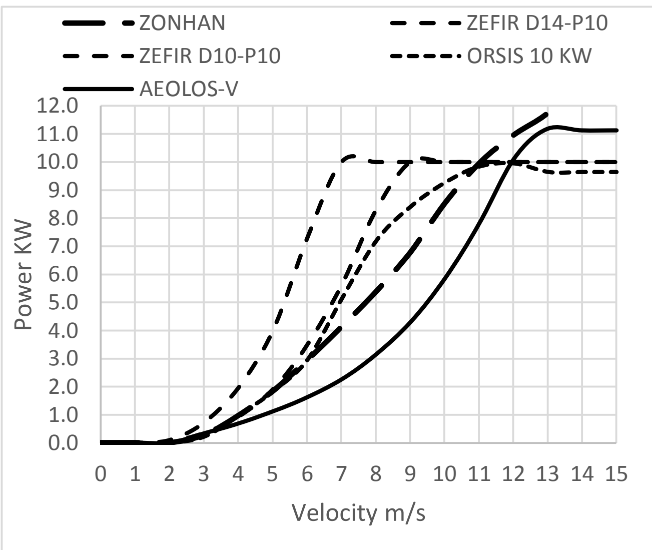
Model		TYPE	Power KW	Blades No.	Rotor Diameter m	Swept Area m2	V_I m/s	V_R m/s
DS-700	Class I	V	0.7	3	1.93	3.1	3	12
Aeolos-H 500W		H	0.5	3	2.7	5.72	2.5	12
Zonhan-S-300W		H	0.3	3	1.3	1.327	2	12.5
Zefir D7-P3	Class II	H	3	3	7	38.47	3	7
Zonhan-5KW		H	5	3	6	28.3	2.5	10
Aeolos -V5		V	5	3	4.5	21.6	1.5	10
Aeolos -V3		V	3	3	3	10.8	1.5	10
Zonhan-3KW		H	3	3	4	12.6	3	11
SD6		H	3	3	5.6	24.6	2.5	7.5
Aeolos-V-10 KW	Class III	V	10	3	5.5	33	2.5	11
Zonhan 10KW		H	10	3	7	38.5	2.5	11
Zefir D14-P10		H	10	3	14	153.86	3	7.2
Zefir D10-P10		H	10	3	10	78.5	3	8
Orsis 10 Kw		H	10	3	9.7	73.9	3	9
Victory 19-20	Class IV	H	19.9	3	19	283.39	2.5	6.6
Penta Wind		H	20	3	15	176.6	2.7	8
Eovent		V	20	3	10	120.0	2.5	9.3
Zonhan-H-30KW	Class V	H	30	3	12	113.0	2.5	11
T30proS		v	30	3	11	132.0	4	11
WES 50		H	50	3	20	314.0	3	9.5
ZIFR D14-P25		H	25	3	14	153.86	3	9.1



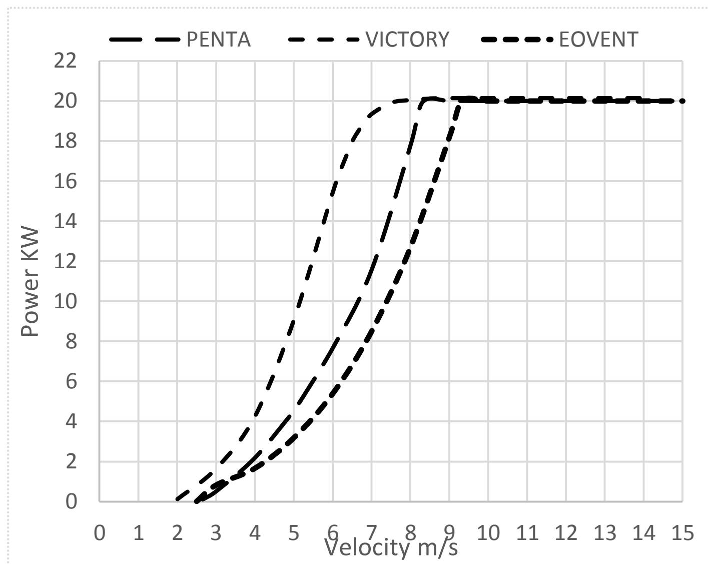
a) Class I



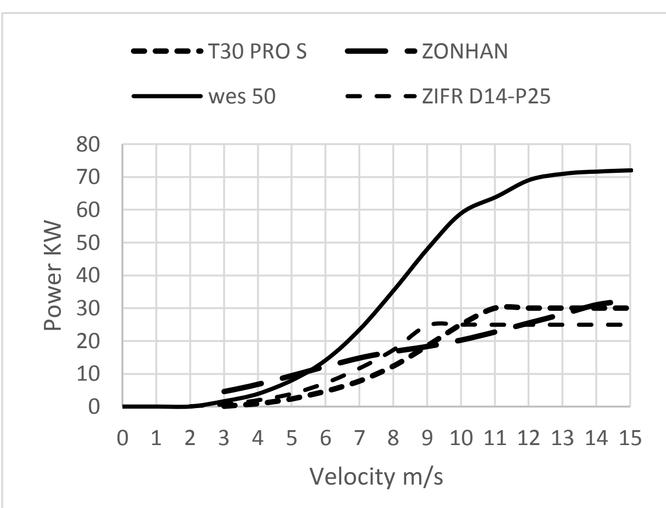
b) Class II



c) Class III



d) Class IV



e) Class V

Figure 3 : power curve for selected small wind classes; a) class I, b) class II , c)class III , d) class IV , e) class V

4 Energy Analysis

The energy available in the wind varies as the cube of the wind speed, so an understanding of the characteristics of the wind resource is critical to all aspects of wind energy exploitation, from the identification of suitable sites and predictions of the economic viability of wind farm projects through to the design of wind turbines themselves, and understanding their effect on electricity distribution networks and consumers.

4.1 Power available in the wind spectra.

The kinetic energy of a stream of air with mass m and moving with a velocity u is given by[11]:

$$E = \frac{1}{2} m\, u^2 \qquad 4\text{–}1$$

Consider a wind rotor of cross sectional area (A) exposed to this wind stream. The kinetic energy of the air stream available for the turbine can be expressed as[11]:

$$P = \frac{1}{2} \rho A\, u^3 \qquad 4\text{–}2$$

4.2 Wind turbine power

Theoretical power available in a wind stream is given by Eq (4-2). However, a turbine cannot extract this power completely from the wind. When the wind stream passes the turbine, a part of its kinetic energy is transferred to the rotor and the air leaving the turbine carries the rest away. Actual power produced by a rotor would thus be decided by the efficiency with which this energy transfer from wind to the rotor takes place. This efficiency is usually termed as the power coefficient (C_p).

Thus, the power coefficient of the rotor can be defined as the ratio of actual developed power by the rotor *(P_T)* to the theoretical power available in the wind hence[11],

$$C_p = \frac{2\, P_T}{\rho A_T u^3} \qquad 4\text{–}3$$

4.3 Capacity factor

Capacity factor is one of the important indices for assessing the field performance of a wind turbine. The capacity factor CF of a WECS at a given site is defined as the ratio of the energy actually produced by the system to the energy that could have been produced by it, if the machine would have operated at its rated power throughout the time period (t) Thus[11]:

$$CF = \frac{E_T}{t\, P_R} \qquad 4\text{–}4$$

The capacity factor reflects how effectively the turbine could harness the energy available in the wind spectra. Hence, CF is a function of the turbine as well as the wind regime characteristics. Usually the capacity factor is expressed on an annual basis. Capacity factor for a reasonably efficient turbine at a potential site may range from 0.25 to 0.4. A capacity factor of 0.4 or higher indicates that the system is interacting with the regime very efficiently.

4.4 Weibull Distribution curve:

A probability distribution of hourly mean wind speeds such as the Weibull distribution will yield estimates of the probability of exceeding any particular level of hourly mean wind speed. However, when used to estimate the probability of extreme winds, an accurate knowledge of the high wind speed tail of the distribution is required[12][1].

$$CPDF = F(\bar{u}) = 1 - exp\left(-\left(\frac{\bar{u}}{c}\right)^k\right) \qquad 4\text{–}5$$

Mean value of wind speed[12]:

$$u_m = C\Gamma(1 + \frac{1}{K}) \qquad 4\text{–}6$$

Where u is wind speed, c is a scale factor and k is a shape factor. To estimate Weibull parameters from speed data using the maximum likelihood method the following equations are used[13]:

$$k = \left(\frac{\sum_{j=1}^{N} u_j^k\, ln(u_j)}{\sum_{j=1}^{N} u_j^k} - \frac{\sum_{j=1}^{N} ln(u_j)}{N}\right)^{-1} \qquad 4\text{–}7$$

$$c = \left(\frac{1}{N}\sum_{j=1}^{N} u_j^k\right)^{\frac{1}{k}} \qquad 4\text{–}8$$

In the neutral atmosphere, the boundary-layer properties depend mainly on the surface roughness and the Coriolis effect. The surface roughness is characterized by the roughness length α [14][15]:

$$\bar{u}(h) \propto ln(h/\alpha) \qquad 4\text{–}9$$

Because each turbine can be installed on towers at different heights, it is necessary to calculate the wind speed *u* according to quota h (vertical velocity profile). This speed is usually expressed by the following relationship[1]:

$$u = u_o \left(\frac{h}{h_o}\right)^{\propto} \qquad 4\text{–}10$$

where *u* is the wind speed at the height to be extrapolated, u_o is the wind speed recorded by meteorological station and the power law exponent α is the wind shear exponent. This parameter is generally between 0.001 and 1.6 and depends on the surface roughness, atmospheric stability and height range. In particularly the are selected to study at EL Kharga Oasis villages, agricultural land with many or high hedges, forests and very rough so we built the our calculation depended on α is 0.4[16].

From the knowledge of the Weibull's parameters and of the wind speed profile at different height, different wind speed density distributions have been built for the probability of density curves based on scale and shape factor at 50 m height recorded by DTU wind atlas and calculated the wind speed numerically at different height as see on Fig3.10. The heights considered (10, 15, 20 and 30 meters) are those set out by producers themselves to the towers of the turbines considered.

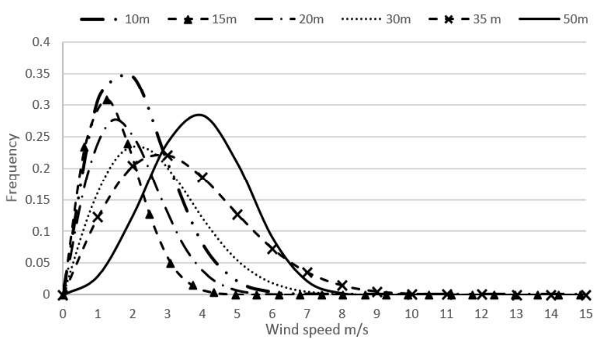


Figure 4: Weibull distribution curve for El Kharga at different height (10,15,20and 30 m)

5 Economic analysis

In general generation electricity, the cost of electricity is mainly affected by three components[17]:

1. Capital and investment cost
2. Operation and maintenance cost (O&M) cost
3. Fuel cost

The economic feasibility analysis of a plant, which requires high initial investments, plays a very important role in the assessment of the viability of a project. Three financial metrics, i.e., net present value (NPV), internal rate of return (IRR) and payback period (PBP), are used in this study.

5.1 Net Present Value, NPV

The net present value of project is the value of all project payments, discounted back to the beginning to the investment.

For Estimation, the real rate of interest "r" is defined as the summation of discount rate *(i)* and inflation rate *(s)* , this factor used to evaluate future incomes and expenditures[17].

$$r = i + s \qquad 5\text{–}1$$

$$Net\ Present\ Value = \frac{P_1}{(1+r)^1} + \frac{P_2}{(1+r)^2} + \cdots + \frac{P_n}{(1+r)^n} \qquad 5\text{–}2$$

Where the present value factor (PVE) is[17]:

$$PVE = \frac{1}{(1+i)^t} \qquad 5\text{–}3$$

If NPV >0 Investment is worthwhile

NPV<0 Investment is not worthwhile

NPV=0 Neutral case

5.2 Payback period, PBP

Payback period is the simplest of the techniques for evaluating an investment proposal. It is defined as the time required to recover the total investments by profit gaining. In other words, this is the length of time between the starting of the project and the time when the initial investment is return in the form of yearly benefits.

This indicator is obtained via the following equation[18]:

$$\text{PBP} = \frac{\text{I}}{\text{c}} \qquad 5\text{–}4$$

Where *I* is the initial investment, c is yearly net cash flow.

Initial investment also called the "capital cost" this group of costs reflect all cost elements that occur only once at the beginning of the project. Investment cost includes cost of purchase and installation of equipment, site preparation, acquisition of necessary licenses or permissions, planning and professional advice necessary to connect the wind farm system facilities or construction of public grids.

Costs of wind and other renewable, have been developed over the last decade, many supported on Strategic Energy Review assist to reduction impact on renewable energies cost. This shows that the capital cost of wind power will drop to around 826€/kW in 2020, 788 €/kW in 2030 and 762 €/kW in 2050.[19]

5.3 Internal Rate of Return (IRR)

The IRR is the value of the discount rated for which the value of NPV becomes equal to zero. It is calculated according to[20]

$$\sum[B/(1+r)^n] = \sum[C/(1+r)^n] \qquad 5\text{–}5$$

Where B is the benefits or total income in the year and the C is the cost expenditure at year or total investment cost of project at year

5.4 Egypt Feed in Tariff

Egypt faces a major challenge in providing a sufficient amount of electrical from its primary energy resources, especially oil and natural gas that contributes to 95% of the total energy resources needed for generating electricity in Egypt, Therefore, there has to be diversification of the energy resources to maximize the benefits of using local resources which are characterized by continuous and stable prices such as investing in generation electricity from renewable resources that are rich in Egypt.

The electricity transmission company (EETC) or distribution companies are committed to purchase the produced electricity from RE power plants at the prices announced by the Cabinet of Ministers through Power Purchase Agreements (PPA) for 25 years for the PV projects, and 20 years for the wind projects.

Wind Projects' Feed-in Tariffs depending on the full operating hour for every project if the FOH from 2500 up to 3000, Feed-in Tariff for first segment (5 year period) 11.48 $. Cent/KW.h and Feed-in Tariff for second segment (15 year-period) 7.51 to 11.48 $. Cent/KW.h[21].

6 Results and Discussion

According to the analysis of wind speed probabilities in EL-Kharga Oasis during the year at different altitudes, the annual energy output of the selected turbines can be predicted when installed at Kharga Oasis as shown in Figure 5. As the turbine is installed at higher altitudes, the wind speed increases and the energy produced increases. At the lowest altitude of 10 m, the maximum amount of energy can be obtained is 275 kwh for Class-I and 2086 kwh for class-II, while the other classes cannot be installed at that low altitude due to longer blade. At the highest altitude, the largest energy can be obtained as follows; 13000 kwh , 28000 kwh , 36000 kwh for class-III, class-IV and class-V respectively.

To compare the performance of the selected turbines at different altitudes, the number of hours that the turbine operates during the year to produce the turbine rated power can be estimated and thus calculate the capacity factor as shown in Fig 6. The capacity factor ranges from 1 % to 19 % These are relatively low values due to the low wind speeds of EL kharga Oasis compared to the larger rated wind speed for available small wind turbines .

Variable costs of production in wind energy projects are directly related to the cost of annual operations and maintenance (O&M) that are relatively high, accounting for 5-8% of initial investment (capital cost).[19], As per reviewing of different analysis for O&M cost and other variable costs in number of association such as National Renewable Energy Laboratory[22], IEA wind energy [23], Economics of Wind Energy EWEA[24], A prudent level of variable costs would be between 1-2 c€/kWh over the life span of the wind turbine. Which would mean 10 to 20% of total costs (about 10% in O&M activities).[19] and by M. Ragheb[17] Economics Of Wind Energy it’s calculated by 1.5 percent of turbine price $/year.

Table 2: Calculation Model assumptions for turbine classes.

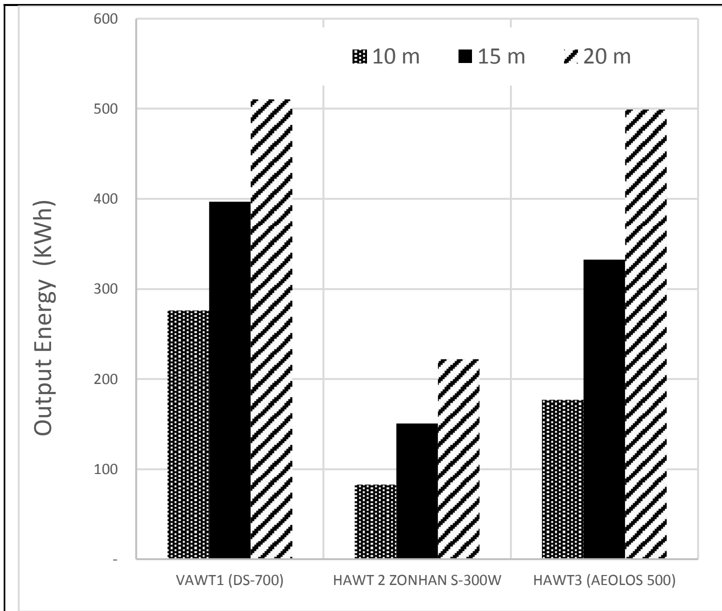
Investment Cost	**908.51 $/kW**
Expected life time	**20 years**
O&M cost	**2 cent $/kWh**
Real rate of interest	**5%/year**

Figure 7 shows the payback period for selected turbine classes at selected location. The Payback period (PBP) have been evaluated for each turbine based on the annual energy production by the turbines and the number of hours corresponding to the wind rated power, hence the length of time which could recover initial investment for the wind turbines has been shown. Considering that the life time of all selected turbines is 20 years, all turbines in the classes I, II and IV are acceptable while turbines in class III are acceptable except Aeolos-V-10kw and turbines in class V are acceptable except T30-Pro VAWT. The best economical turbines are as follows: Victory-20kw with a payback period of 6.4 years, followed by Zonhan-30 kw with a payback period of 8 years and Zefir D14-P10 with a payback period of 8.5 years. The results show that variability and low price of Feed-in Tariff in Egypt is a major factor for this case.

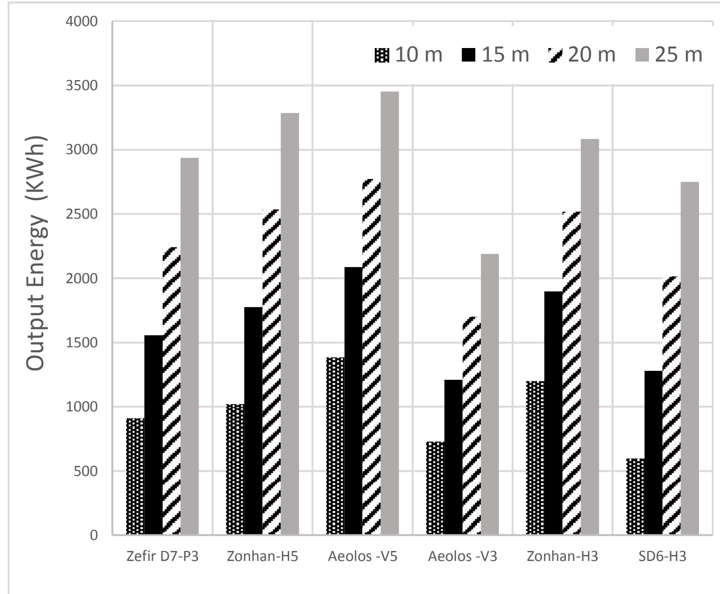
Figure 8 shows that change in capacity factor will affect the overall profit and payback period of small wind turbine. The PBP period decrease with higher CF , Capacity factor lower than 6.8% increase the PBP more than the life time cycle of turbine.

Table 3: Results Of Economic Study For Turbines

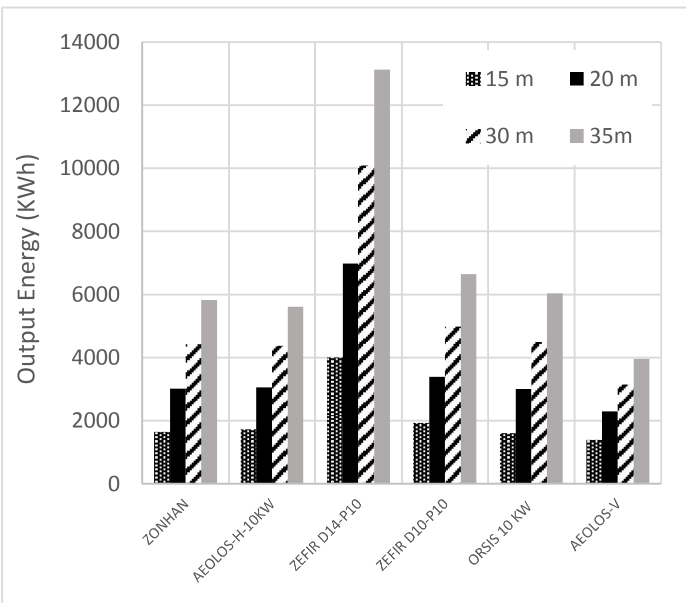
Model	Class	Power KW	Capacity Factor (CF)	PBP	Project NPV $	Income NPV $
DS-700	Class I	0.7	0.083	12.7	-12	624
Aeolos-H 500W		0.5	0.113	9.3	153	607
Zonhan-S-300W		0.3	0.085	12.4	1.4	274
Zefir D7-P3	Class II	3	0.112	9.4	884	3,609
Zonhan-5KW		5	0.075	14	-514	4,028
Aeolos -V5		5	0.079	13.34	-299	4,243
Aeolos -V3		3	0.083	12.7	-51	2,675
Zonhan-3KW		3	0.117	9	1,054	3,771
SD6		3	0.105	10	658	3,384
Aeolos-V-10 KW	Class III	10	0.045	23.4	-4,241	4,834
Zonhan 10KW		10	0.066	15.97	-1,995	7,090
Zefir D14-P10		10	0.150	7	7,028	16,113
Zefir D10-P10		10	0.076	13.9	-921	8,164
Orsis 10 Kw		10	0.069	15.2	-1,673	7,412
Victory 19-20	Class IV	19.9	0.194	5.4	23,392	41,471
Penta Wind		20	0.087	12	521	15,242
Eovent		20	0.080	13.17	-982.6	17,188
Zonhan-H-30KW	Class V	30	0.157	6.7	23,341	50,596
T30proS		30	0.038	27.7	-15,009	12,246
WES 50		50	0.081	13	-1,920	43,506
ZIFR D14-P25		25	0.080	13.17	-1,228	21,484



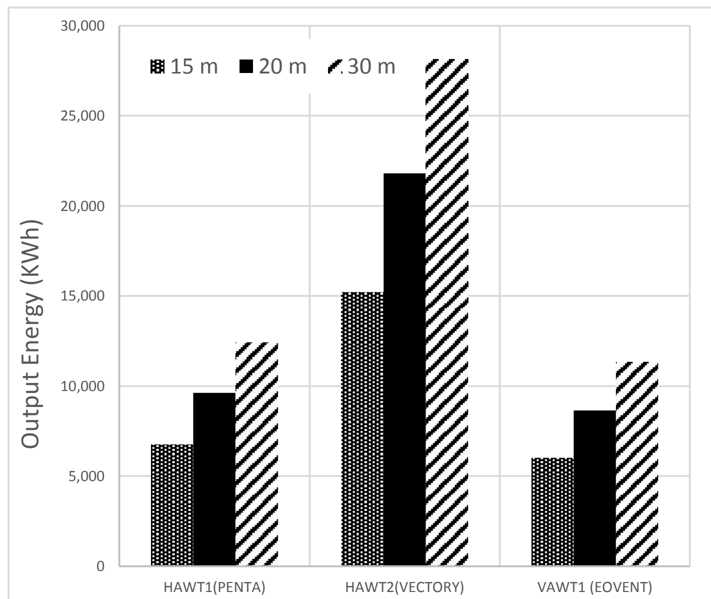
a) Class I



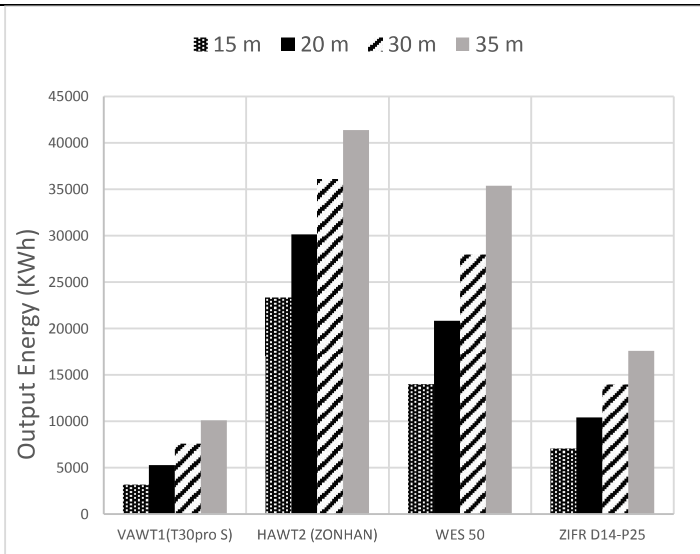
b) Class II



c) class III

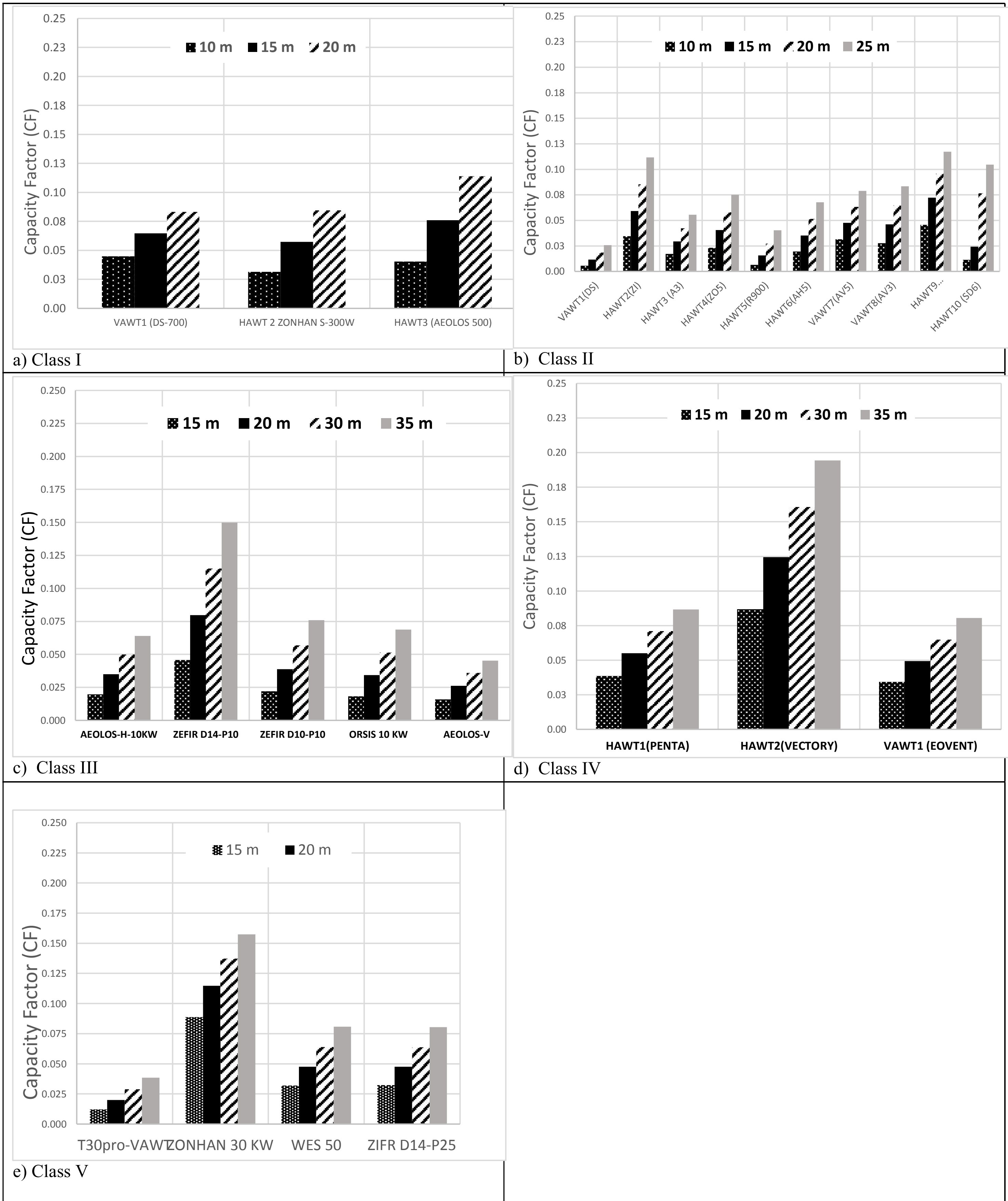


d) class IV



e) class V

Figure 5 : Annual energy output at different height for selected small wind classes ; a) class I, b) class II , c)class III , d) class IV , e) class V.



a) Class I

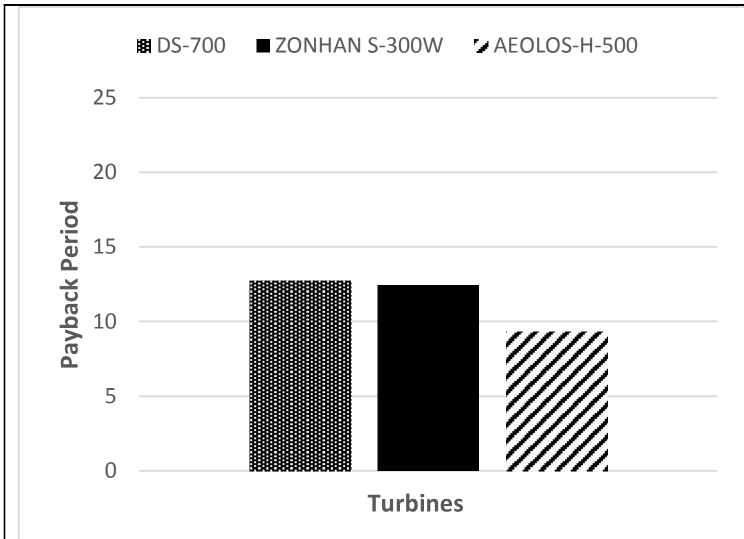
b) Class II

c) Class III

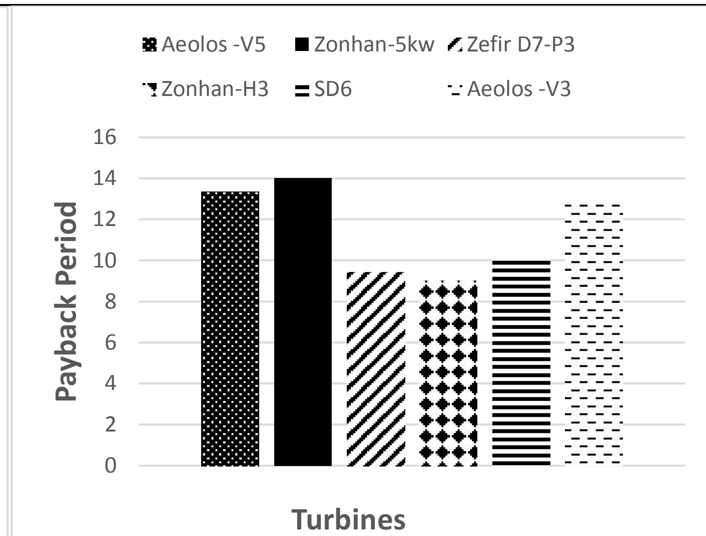
d) Class IV

e) Class V

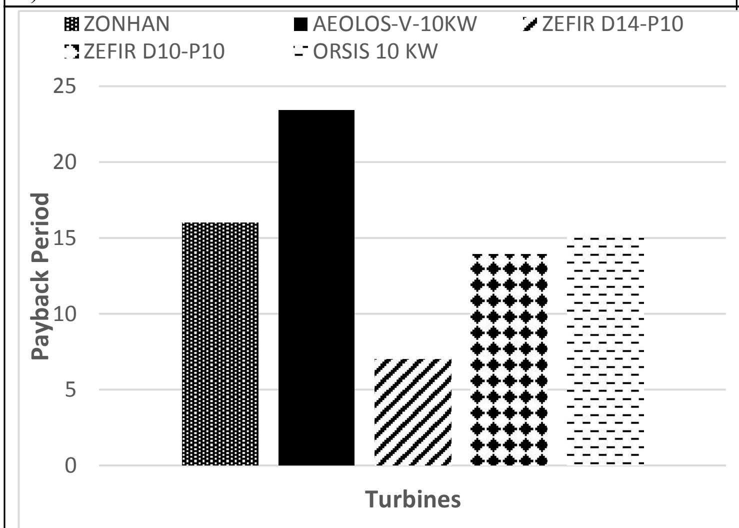
Figure 6 : capacity factor for selected small wind turbines at different height ; a) class I, b) class II , c)class III , d) class IV , e) class V.



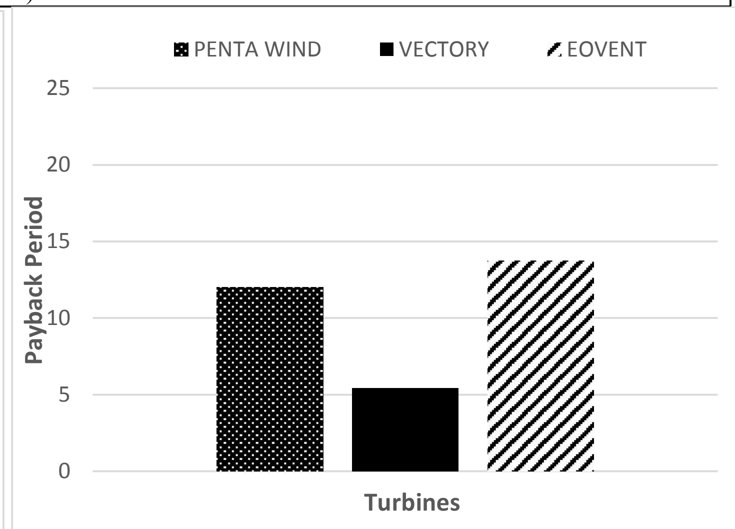
a) Class I at 20m



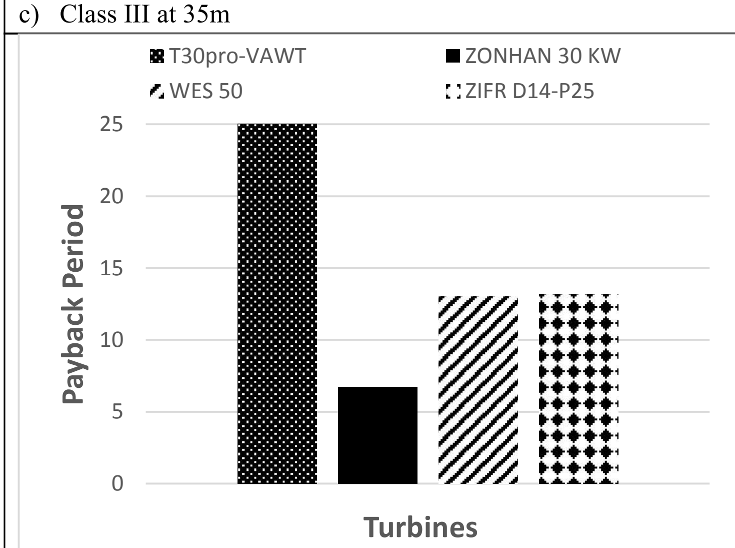
b) Class II at 25m



c) Class III at 35m



d) Class IV at 35m



e) Class V at 35m

Figure 7 : Payback period of selected small wind turbines at different classes; a) class I, b) class II , c)class III , d) class IV , e) class V.

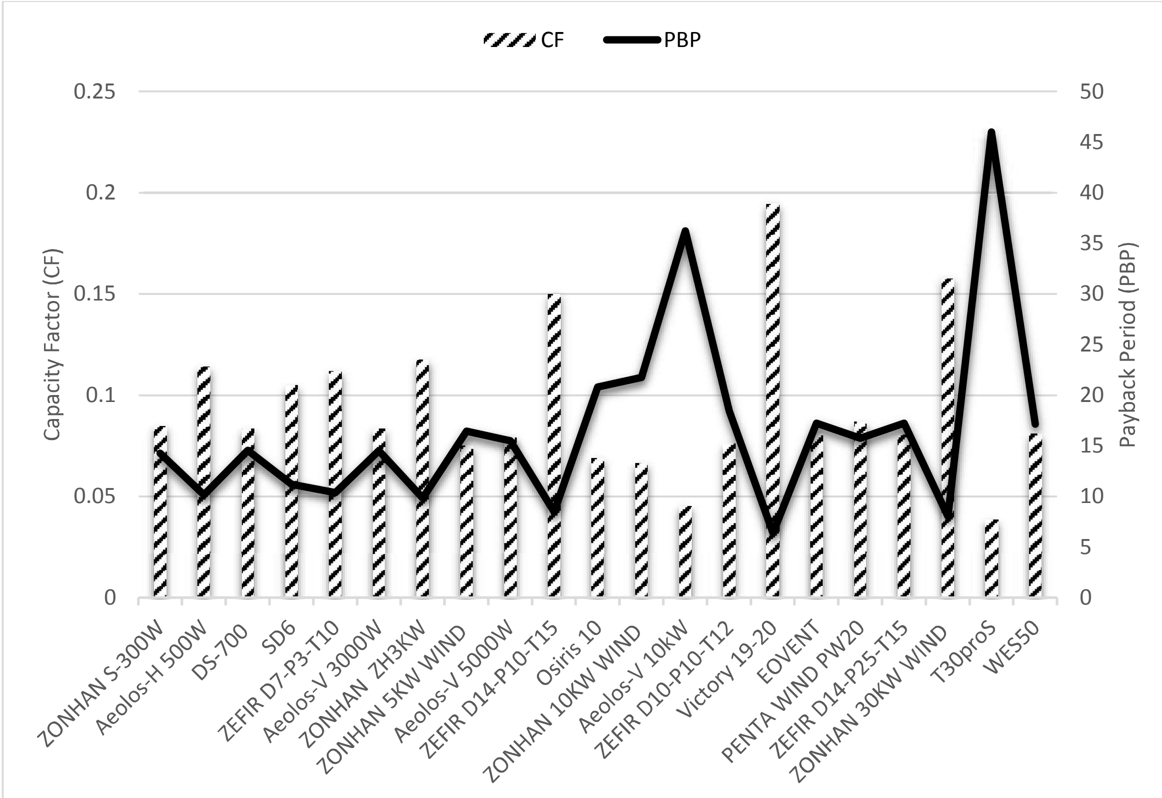


Figure 8 : PBP & CF Graph For Turbines

7 Conclusion

In this paper, wind speed of AL-Kharga area was studied to explore the economic feasibility of small wind turbines. The most important results of the present study can be summarized as follows:

- Adoption of wind turbines with rated power more than 10kW is recommended.
- HAWT can operate at the chosen location, achieving economic feasibility.
- VAWT is not economically feasible. Special for turbine rated power more than 20 KW.
- Victory19-20, Zonhan 30 kw and Zefir D14-P10 are the most economic feasible wind turbines.
- Due to the low wind speed in AL-Kharga region, a small number of small wind turbines are economically viable while most require relatively higher wind speeds.
- As capacity factor of wind turbine improved the turbine be more effective economically.

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