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Technical Note

Development and Economical Evaluation for Wind Power Plant in –Chabahar in Sistan and Baluchestan Province-Iran

P. Raeisi Mahdi Abadi[a], S. Vahdati Daneshmand[b]*, R. Sharifi[c]
a Department of Electrical Engineering, Zahedan Branch, Islamic Azad university, Zahedan, Iran
[b]*Department of R&D, MAPNA group, Tehran, Iran*
[c]*Department of Electrical Engineering, Islamic Azad university, West branch Tehran, Iran*

P A P E R I N F O

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High costs, unreliable resources for long term use and extensive negative impact on our environment are such problems associated with traditional sources of energy and fossil fuels which make us move toward implementation of renewable sources of energy. Fossil fuel pollution and reserve depletion in oil producing countries caused by increasing demands, make wind energy an attractive source of energy in the future. Renewable energy sources are expected to have an important role in many countries as well as Iran and would be flourished in near future. In this study we aim to offer economic evaluation of wind turbine installation for chabahar in southeastern part of Iran. This study evaluates the economic feasibility of electricity generation using wind turbines in Chabahar - Iran situated in the Southeast part of Iran. All analyzes were performed by Homer software and local weather information and software provided by NASA Weather Homer is used. In this study 5 MW wind turbine with INVELOX technology is used .The analysis results show that Annual average of wind speed is 4.11 m/s at a Height of 10 m and 905 Gwh is the average of annual energy production, the cost of energy is calculated of 2.3 cents/kwh.

A B S T R A C T

1. INTRODUCTION

Nowadays, scientists and publics are more concerned and sensitive about the need for environmental friendly energy sources. The energy demand is increasing continuously and the only way to fulfill this demand is to start using renewable energy sources. Wind is one of those major free, clean and inexhaustible renewable energy sources (Karsli et al., 2003). It is an abundant resource available in nature that could be used in mechanically converting wind power to electricity using wind turbines (Ahmed and Hanitsch., 2008). The extraction of power from wind technology, with modern turbines, is one of the well-established industries, at present. Parameters such as improvement of wind farm efficiency as well as reducing wind turbine component costs, make wind power generation competitive to the conventional sources. Furthermore, the wind power has an additional advantage of being a non-polluting source of energy (Ozerdem et al., 2006). Preparing technical and economical feasibility study is a vital step before investing in a wind farm project. This study gives an outlook to investors about costs and economical aspects of a wind farm project. Accurate and proper information on a project conditions (such as site and wind characteristics) play a key role in wind farm feasibility studies. So, inappropriate information may lead to disinvestment and waste of money. In contrast, choosing a suitable site for a wind turbine regarding to the parameters such as: turbine size, blade shape, capacity, etc. result in high efficiency of a wind farm. It is quite important to know several fundamental properties of the site such as wind behavior, availability, continuity, and probability in the proposed region. To make decisions with those properties, statistical and dynamic wind characteristics of the site should be found out using wind observations and statistical wind data (Karsli et al., 2003). In this paper design and economic evaluation of wind power in Chabahar is studied.

2. SITE DESCRIPTION

There is no doubt that any interruption in consistent supply of energy in a country can cause disastrous catastrophes in industrial and economic sectors. To

*Corresponding Author's Email: Vahdati_S@mapnagroup.com (S.V. Daneshmand)

avoid this, relying on a single source of energy should be stopped and diversification of resources is advised. Renewable energies are well-known alternative resources with a great advantage of local accessibility. Wind energy can play a significant role in this case; considering that there was 40 GW increase in wind power generation in 2011 which is higher than any other renewable power sources. This increased the global wind power generation by 20% (compared to 2010) to 238 GW. By the end of June 2012, the global wind power generation reached 254 GW in China and USA to be the largest producers by 67.77 and 49.80 GW respectively (Ali Mostafaeipour., 2013). Studies have demonstrated a reduction of 5.6 million tons of CO2 production when a 1.5 MW wind turbine is implemented to generate 4 million KWh of electricity per annum (Shaahid et al., 2013) & (Hansen, 1998). An accurate evaluation of the wind potentials and its economy measure at any specific place is the key for its future development. Extensive research and studies have been done in Iran in this regard (Alsaad, 2013), (Al Sayedgh et al., 2010), (Ayodele et al., 2012), (Mpholo et al., 2012), (Adaramola et al., 2011), (Fyrippis et al., 2010) & (Fazelpour et al., 2014). Fazelpour and his colleagues analyzed and evaluated the development of a hybrid power generation system consisting of wind turbines, Solar cells, Diesel generators and batteries in a hotel in Kish- Iran (Fazelpour et al., 2014). Hosseini et al. investigated green energies including the wind energy in Iran (Hosseini et al., 2013). Mostafaeipour studied the feasibility of power generation from wind turbines in province of Yazd- Iran. In another work Mostafaeipour and his colleagues studied the wind energy potential and its economy in Zahedan- Iran. Sistan and Baluchestan Province is one of the 31 provinces of Iran. The province is subject to seasonal winds from different directions, the most important of which are the 120-day wind of Sistan known as Levar, the Qousse wind, the seventh (Gav-kosh) wind, the Nambi or south wind, the Hooshak wind, the humid and seasonal winds of the Indian Ocean, the North or (Gurich) wind and the western (Gard) wind (Tizpar et al., 2014). Considering the large windy areas along the shoreline in Iran, wind power plant can be a convenient source of renewable energy. In the current work, the wind data is taken from NASA to evaluate the economic feasibility of a wind farm in Chabahar- Iran. The average monthly wind speed for this period is illustrated in Table 1. (<https://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi?+s01#s01>).

2.1. Primary Data

Iran is a 1,648,195 Km^2 large country. While half of the country is mountainous and the other half is desert; it has a very diverse climate with enormous windy areas. According to the country's wind atlas in different regions which is presented in Figure 1. (Mostafaeipour, 2011), the overall nominal capacity of wind power generation is around 60000 MW. Based on current estimates, the feasible wind power generation can reach up to 18000 MW which shows the high potential and the economic significance of investing in wind power generation industry.

TABLE 1. Average Monthly Wind Speed in m/s at a Height of 10 m in Chabahar.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
3.59	4.16	3.91	4.01	4.53	4.65	4.8	4.8	4.56	3.61	3.09	3.56

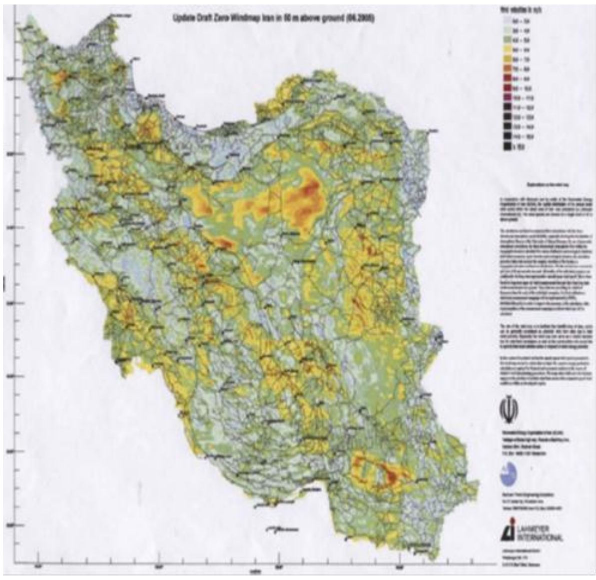

Figure 1. Wind atlas of Iran for elevation of 80 m above the ground [18,22].

2.2. Wind Data

Wind source data are necessary information to define the wind conditions that a wind turbine would experience in a typical year .The most important wind source data is the wind speed which should be provided from its average in per month. Another necessary parameter to design the wind system is known as "Weibull shape factor". This parameter is a measure of the distribution of wind speeds over the year. In fact, this factor shows how windy a location is. The third parameter is called "autocorrelation factor". This measure shows how strongly the wind speed in 1 h tends to be depends on the wind speed in the preceding hour. The fourth factor is defined as "diurnal pattern strength". This factor shows how strongly the wind speed tends to be depends on the time of the day. The other factor, hour of peak, is the hour of the day that tends to be windiest. Elevation of the site above the sea is also another parameter required for calculating the density of the air needed in wind turbine output power calculations. The last necessary parameter is anemometer height, showing the heights above the ground where the wind speed data are measured. The wind data for the studied region of Chabahar is presented in Table 2. The annual average wind speed at a height of 10 m is 4.11 m/s. The turbine's hub height is 84 m which has the advantage of higher speed and less turbulence compared to the wind at 10 m height. When turbulence happens a portion of the wind kinematics energy is wasted by conversion to heat and also by formation and elimination of small eddy currents. Turbulence may follow a consistent pattern over a long time but in small time periods it is completely inconsistent. Turbulence in a flow can reduce its capacity to generate power and can cause fatigue in turbines as well (Burton et al., 2001).

TABLE 2. Data of the Studied Region.

Region	Northern Latitude	Eastern Longitude	Height, m
Chabahar	25° 20'	60° 27'	10

Figure 2. is a Cumulative Frequency Diagram (CFD) for the wind speed and Figure 3. illustrates the monthly average of wind speed in Chabahar which are used as tools for evaluation of the power of a specific site. Figures 4. & 5. illustrate the hourly variations of wind speeds at height of 10 m for Chabahar (Mohammadi et al., 2014).

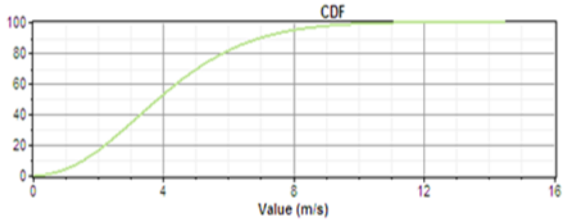

Figure 2. Cumulative Frequency Diagram (CFD) of Wind Speed in Chabahar.

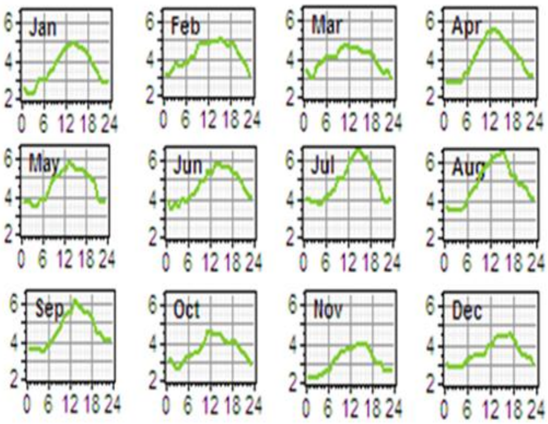

Figure 3. Monthly Wind Speed Diagrams

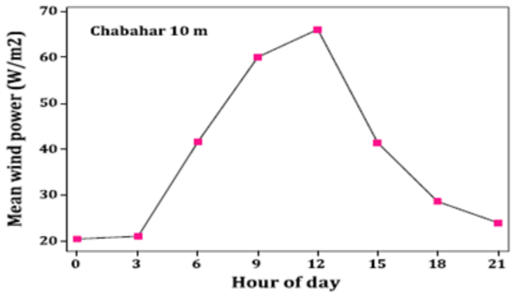

Figure 4. Hourly variation of wind power (W/m^2) for Chabahar.

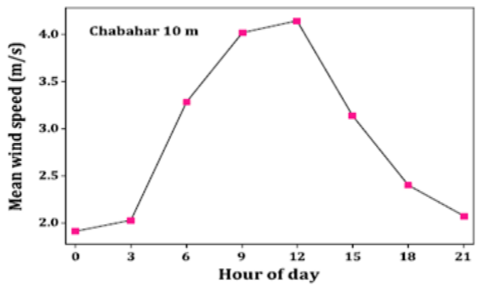

Figure 5. Hourly variation of wind speed (m/s) for Chabahar.

To calculate the wind speed at any desired height the following correlation can be used:

$$\frac{v}{v_0} = \left(\frac{h}{h_0}\right)^n \qquad (1)$$

Where; v_0 is the wind speed at reference height, h_0 is the reference height, h is the desired height and v is the wind speed with respect to h. n is the surface roughness coefficient which varies from 0.08 to 0.39 and can be obtained from Table 3. (Jain P, 2011).

TABLE 3. Typical Surface Roughness Value. (Jain P, 2011).

Type of terrain	**Coefficient (n)**
Open seas	0.08
Open terrain with a smooth surface, like concrete runway, mowed grass	0.11
Open agricultural area without fences and hedgerows and very scattered buildings. Only softly rounded hills	0.15
Agricultural land with some houses and 8-m-tall sheltering hedgerows with a distance of approx. 1250 m	0.17
Agricultural land with some houses and 8-m-tall sheltering hedgerows with a distance of approx. 500 m	0.19
Agricultural land with many houses, shrubs and plants, or 8-m tall sheltering hedgerows with a distance of approx. 250 m	0.21
Villages, small towns, agricultural land with many or tall sheltering hedgerows, forests, and very rough and uneven terrain	0.25
Larger cities with tall buildings	0.31
Very large cities with tall buildings and skyscrapers	0.39

2.3. Electrical load data

The consumption of electric charge data in Chabahar, Sistan and Baluchestan regional electricity company were collected and presented in Figure 6.

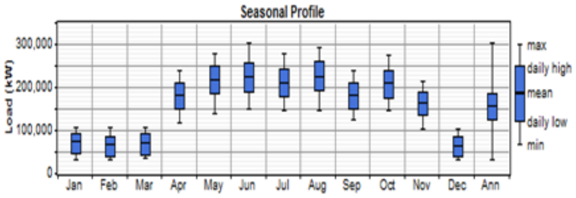

Figure 6. Monthly average load for Chabahar and Konarak site.

3. WIND TURBINES

In the current study, wind energy is calculated by using Homer software considering the long term wind speed and the height of turbine hub (</ http://www.homerenergy.com). Technical data for INVELOX Turbine (5MW) is presented in Table 4. and its output power versus wind speed diagram is illustrated in Figure 7. A recently developed technology (Allaei, 2013), (Allaei and Schwartz, 2013), (Allaei and Andreopoulos, 2013), (Allaei and Schwartz, 2013), (Allaei et al., 2013), (Allaei, March 2013), (Allaei, 2012), (Allaei,October 2012), (Allaei , August 2012)& (Allaei, September 2012). INVELOX (increased velocity), has shown promise. The patented INVELOX is simply a wind capturing and delivery system that allows more engineering control than ever before (Allaei, 2010: 7,811,048) & (Allaei, 2010: 7,812,472). While conventional wind turbines use massive turbine-generator systems mounted on top of a tower, INVELOX funnels wind energy to ground based generators. Instead of snatching bits of energy from the wind as it passes through the blades of a rotor, the INVELOX technology captures wind with a funnel and directs it through a tapering passageway that passively and naturally accelerates its flow. This stream of wind energy then drives a generator that is installed safely and economically at ground or sub-ground levels. The five key parts of INVELOX are shown in Figure 8.

These key parts are (1) intake, (2) pipe carrying and accelerating wind, (3) boosting wind speed by a Venturi, (4) wind energy conversions system, and (5) a diffuser. Installation, operation and maintenance costs are given in Table 5. Along with all new technologies come strong skeptics with opposite views on their viability. A reason to be skeptical about INVELOX is the fact that in the past-ducted turbines have not made any significant headway in the industry due to questions related to technical implementation and financial viability, even though positive performance was in general demonstrated. One technical issue, for instance, which has been insurmountable to address is the implementation of a mechanism design which will allow for self alignment of large-scale ducted turbines with the wind direction. In addition, ducted turbines still need to be placed at a certain height which increases the technical complexity as well as the cost. INVELOX eliminates the need for self-alignment with the wind because its intake is omnidirectional and all rotating parts are on the ground which simplifies the operation and maintenance. It is also reasonable to question whether, once a turbine is placed inside an INVELOX system, the increase in resistance will reduce the output making the promise of superior performance no longer valid. It should be noted, however, that the same is true for traditional open-flow systems. The free stream wind reduces its speed as it approaches the blades due to the induced velocity field by the vortex system shed in the wake of the turbine; this reduction could be up to half or to two-thirds, depending on the environmental and blade profile factors. In the case of ducted turbines like the present one inside INVELOX, mass conservation requires that the area-averaged velocity remains constant upstream and down stream of the turbine along a constant cross-section duct. It appears that the vortex sheets shed by the rotating blades are mostly affecting the wake flow more than the upstream flow. There is a small decrease in the incoming velocity in some parts of the upstream flow as it approaches stagnation particularly directly upstream of the blades, but at the same time other parts of the flow are accelerating to satisfy mass conservation. (Allaei and Andreopoulos, 2014), Also, for the first time, INVELOX's capability accommodates up to three turbines without any substantial change in the infrastructure. This was accomplished by carrying out field measurements of direct electrical power obtained in a prototype facility built in the Chaska industrial park. This capability provides a significant advantage over classical wind turbines which require additional infrastructure without any significant improvement in the cost per output power. This advantage comes as a direct result of its omni directionality, which decouples the intake from the wind turbine. The intake can capture wind flowing from any direction while the turbine is stationary, mounted on a near ground position. In addition, the system eliminates the need for costly control mechanisms, such as:

a. Pitch control for the blades is not required because wind speed can be controlled once the turbine reaches its maximum output.

b. Yaw control is not required because intake is designed to capture wind from 360°.

c. Gearbox is not required because the turbine turns at higher (Allaei et al., 2015)

speeds due to its small size. The number of wind turbines based on the peak load of 61 wind turbines in Chabahar and Konarak is considered.

According to Tables 1. and 4. and Figures 1. to 4. it can be concluded that wind power generation is feasible throughout the year in this region.

TABLE 4. INVELOX Turbine (5MW) Data.

Nominal capacity	5000 KW
Life span	25 years
Temperature range	-20 ºC to 45 ºc
Minimum wind speed	1 m/s
Maximum nominal wind speed	6.5 m/s
Maximum wind speed	-
Hub height	124 m

TABLE 5. Initial, Operation and Maintenance Costs.

Turbine model	**Initial cost (US$)**	**Operation and maintenance cost (US$)**
One INVELOX Turbine (5MW)	3,750,000	44,550
61 INVELOX Turbine (5MW)	228,750,000	2,717,550

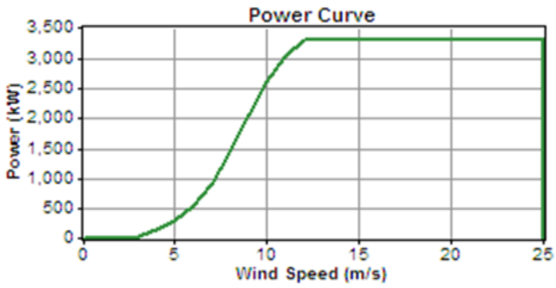

Figure 7. Output Power versus Wind Speed Diagram.

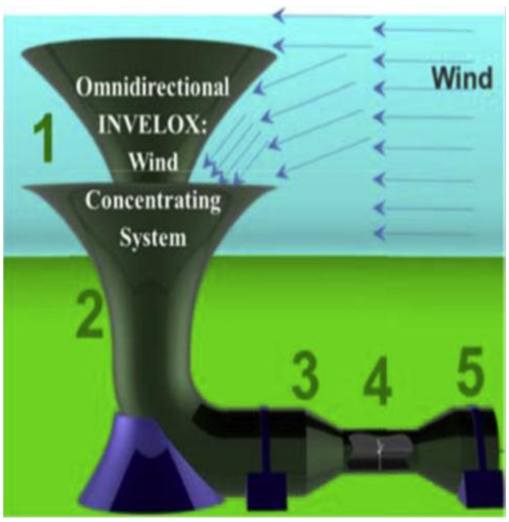

Figure 8. Schematic of the INVELOX wind delivery system with its key components, (1) intake, (2) channeling wind, (3) wind concentrator, (4) Venturi plus wind power conversion system, (5) diffuser returning wind to nature.

4. GRID

The grid is an auxiliary source whereby it acts as a backup to the renewable energy system in case there is deficit energy. The grid also acts like a storage system when the renewable energy system produces excess energy. Therefore, there is grid power price which is the price of electricity bought from the grid and the price of electricity sold to the grid, also known as feed-in-tariff (FiT) (Mukhtaruddin, 2013).

5. ASSESSMENT CRITERIA

The analysis on the grid-connected wind system in terms of economic viability is based on net present cost (NPC) and payback period. HOMER assesses the technical feasibility of the hybrid system by determining whether the system can serve the load adequately. Then, it estimates the NPC of the system and ranks all the system according to total NPC (Mukhtaruddin, 2013).

5.1. Net Present Cost (NPC) The total NPC assesses all costs that incurs within the project lifetime. The costs include initial costs, replacement costs, operating and maintenance costs, fuel costs and cost of electricity from the grid. Total NPC is calculated as in equation (2).

$$NPC=\frac{TAC}{CRF} \quad (2)$$

where TAC is the total annualized cost, and

$$CRF=\frac{i\,(1+i)^N}{(1+i)^N-1} \quad (3)$$

where N is the number of years and i is the annual interest rate. Annual interest rate can be calculated using equation (4).

$$\text{Annual real interest rate, } I=\frac{i'-f}{1+f} \quad (4)$$

where i’ is the nominal interest rate and f is the annual inflation rate. For this study is intended to i= 6%.

5.2. Payback period The payback period is an indication of how long it would take to recover the difference in investment costs between the current system and the base case system. In this case, the current system would be the grid connected wind energy system. The purchase price per kilowatt hour of electricity in the Iran is about 14 cents.

5.3. Calculation of Generated Power for Installed Turbines For this study the Homer software which is developed by National Renewable Energy Lab is used. Wind speed, initial purchasing cost of the wind turbine, operational and maintenance costs, turbine’s lifetime and its hub height are the inputs of the software. Figures 5. and 6. are demonstrating the daily and monthly generated power in the area which are calculated by Homer. According to our simulation on the software, the annual generated power of the turbine is estimated to be 905 GWh. The monthly average energy production in Chabahar and Konarak is presented in Figure 3. This can reduce the greenhouse gas generation compared to traditional mediums of power generation as detailed in Table 6. below.

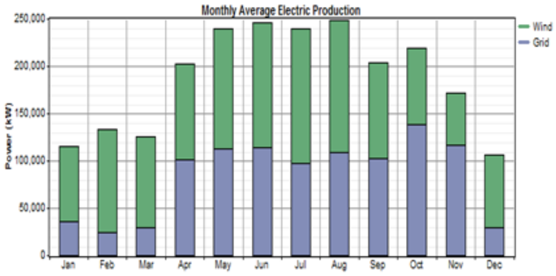

Figure 6. Monthly Generated Power Diagram.

TABLE 6. Level of greenhouse gas emissions per unit of electricity generated by wind power in Chabahar and Konarak.

Pollutant	Emissions (kg/yr)
Carbon dioxide	-569,082,624
Carbon monoxide	0
Unburned hydrocarbons	0
Particulate matter	0
Sulfur dioxide	-2,467,226
Nitrogen oxides	-1,206,599

5.4. Capacity Factor Capacity factor for wind turbines is defined as the ratio of generated power to the nominal capacity of the turbine and it is an important parameter to find the efficiency of the turbine. The capacity factor would equal to 1 if the turbine is working at its maximum nominal capacity throughout the year. Achieving a capacity factor of 1 is practically impossible due to the changes in wind speed. Equation 2 can be used to find the capacity factor of a turbine: (Gary and Johnson, 2001) & (Thom, 2001).

Capacity factor percentage = (Nominal capacity * 8760) / (Power output) * 100 (5)

Table 7. presents the calculated capacity factor by Homer software for INVELOX 5MW turbine.

TABLE 7. Calculated capacity factor by Homer software for INVELOX 5MW turbine.

Quantity	Value	Units
Total rated capacity	305,000	kW
Mean output	103,408	kW
Capacity factor	33.9	%
Total production	905,849,984	kWh/yr

5.5. Installation and Maintenance Costs and Investment Return Although a wind farm requires a considerable capital investment, in long term, its revenues are far more than traditional fossil fuel power plants. The capital investment for a wind farm breaks down to the installment, operational and maintenance costs which are paid by the system annually. The overall cost of power generation per KW can be decreased by increasing the capacity of the wind farm. Generally, commercially available wind turbines are designed with higher efficiency and lower costs (Jiwoong, 2010). The operational and maintenance costs can be three dollars per megawatt hour of electricity generated considered (Shaahid et al., 2013).

The annual cost of a wind farm can be calculated from equation (6):

Annual cost = (initial investment / lifetime) + operational and maintenance costs (6)

The cost of each KWh of power can be achieved from equation (7):

Cost of each KWh = (Annual cost / Annual power output) (7)

Considering the annual cost of 20,611,912 US$ and annual power output of 905 GWh - which is achieved from Homer simulation; for the given turbine under local condition in Chabahar, the cost of each KWh of power would be 0.023 US$. By having 905 GWh of generated power with a cost of 0.023 US$/KWh; and the sales price of each KWh which is 0.14 US$ in Iran, the annual revenue of a wind turbine can be as high as 105,885,000 US$. This will result in capital investment return period of less than 2.5 years.

6. CONCLUSION

Due to the finite non-renewable energy resources and the environmental impact of fossil fuels, renewable energy, particularly wind and solar energy are coming from the most basic issues of human beings. The design and construction of renewable energy in addition to energy needs, there by maintaining oil supplies will.

The annual average wind speed for Chabahar is 4/11 m and the second hearing with respect to the peak load of 305 kW turbines in Chabahar and Konarak 61 INVELOX 5 megawatt is used. According to the results of the annual energy production, the cost per kilowatt hour of energy, reduce emissions and eliminate the environmental impact The use of wind energy and wind power plant connected to the electricity grid in Chabahar and Konarak was quite profitable and the release of large amounts of greenhouse gases, one of the fundamental problems of human use of fossil fuels, is prevented. To raise the percentage contribution of renewable energy, the number of wind turbines should be increased. Fortunately, the wind turbine equipped with INVELOX technology enables up to three wind turbines at its venturi channel and productivity 2/3 which makes the need to build new towers destroyed and electricity prices further will be decreased. To reduce greenhouse gas production the number of wind turbines should be increased, effectively with the problems listed only need to add a new turbine is no need to build a tower.

7. ACKNOEWLEDGMENT

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