

Wind Energy Generation Potential in Union Hidalgo, Mexico: A Preliminary Study

J.R. Dorrego¹, O. Lastres¹, A. Núñez¹, G. Hernández², U. Miranda³ and R. Saldaña³

1. Instituto de Estudio de la Energía de la Universidad del ISTMO, Tehuantepec, Oaxaca, México

2. Centro de Investigación en Energía, UNAM, Temixco, Morelos, México

3. Gerencia de Energías No Convencionales, Instituto de Investigaciones Eléctricas, Reforma 113, Col. Palmira, Cuernavaca, Morelos, C. P. 62490

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Abstract: Union Hidalgo municipality in Oaxaca State, Mexico, is located in an area with attractive wind potential. For this reason, this paper presents a preliminary study of the technical feasibility of wind power generation in Union Hidalgo, by a micro-study with a higher resolution than that used in *Wind Resource Atlas of Oaxaca*, published in April 2004. In this work, the wind map of Union Hidalgo was generated using the micro-scale model WAsP 9.1, with a resolution of 50 meters. Wind speed and direction data recorded at 15 m and 32 m agl (above ground level) over four years and seven months in a surface anemometer station were used. With Class 7 wind patterns, the results show values that justify the installation of wind turbines to produce electricity in the area. Estimated capacity factors (55% on average) are comparable with those obtained in wind power plants already operating in areas near Union Hidalgo and sites with high wind potential in other parts of the world. The topography of the study area is predominantly flat, and together with the directional behavior of the wind, which comes from the NNW 44% of the time, this favors the introduction of wind power plants in the area.

Key words: Wind resources, wind map, wind power plants, wind turbine, micro-scale model, technical feasibility.

1. Introduction

Given its strategic and economic importance, the national energy sector constitutes a key sector in the country's development that requires careful and responsible planning. Efforts within the sector should be aligned to common goals that result in the security of the supply, quality and coverage of national energy, and they should be realized with full respect for the environment. To achieve this goal, a long-term vision is required where strategies and resources are channeled towards proper development of the sector by means of plans, programs and well-defined goals that contribute to a balanced market and environmental sustainability, together with economic development

and the welfare of the population. A good performance on the part of the industry is fundamental in achieving this objective [1].

The National Climate Change Strategy Mexico, 2007 [2], prepared by the Inter-ministerial Commission on Climate Change, specified possibilities and ranges of emission reduction of greenhouse gases (GHGs), proposed necessary studies to define specific mitigation goals, and outlined the needs of the country to move forward in building adaptive capacity. The energy generation and use sector presents several areas of opportunity for mitigation of GHG emissions, both on the supply side and the demand side. Mexico is joining the efforts of several countries that promote sustainable development to preserve the global environment.

Wind energy is a major source of power in over 70 countries across the world. The world's wind power

Corresponding author: J.R. Dorrego, research professor, research fields: design and manufacturing of small wind turbines, wind resource assessment and design of wind farms. E-mail: rdorrego63@yahoo.es.

capacity grew by 31% in 2009, adding 37.5 GW to bring total installations up to 157.9 GW. A third of these additions were made in China, which experienced yet another year of over 100% growth.

Wind energy is now an important player in the world's energy markets. The global wind market for turbine installations in 2009 was worth about 45 bn EUR or 63 bn US\$. The Global Wind Energy Council (GWEC) estimates that around half a million people are now employed by the wind industry around the world. The main markets driving this significant growth continue to be Asia, North America and Europe, each of which installed more than 10 GW of new wind capacity in 2009. China was the world's largest market in 2009, nearly doubling its wind generation capacity from 12.1 GW in 2008 to 25.1 GW at the end of 2009 with new capacity additions of 13 GW (see top ten cumulative capacity in Fig. 1) [3].

In Mexico, there exist regions with significant wind resources that also require productive activities that contribute to improving economic conditions and the quality of life of its population. Among these is the Isthmus de Tehuantepec in the state of Oaxaca. According to the Wind Resource Atlas of Oaxaca [4], published in April 2004 in this state there is an approximate area of 6,600.00 km² with potential wind resources between good and excellent.

It is believed that approximately 67% of the 6,600.00 km² of land with wind has excellent wind resource

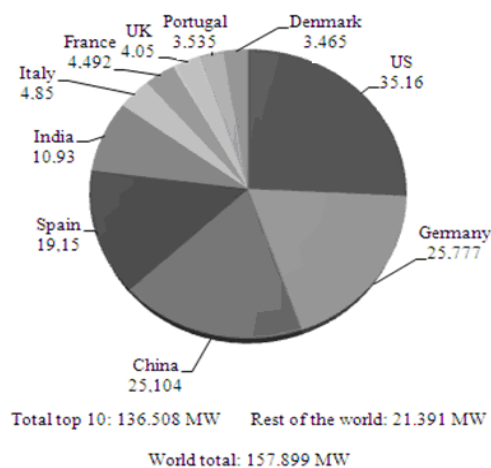


Fig. 1 Top 10 cumulative capacity in December 2009.

potential. Using a conservative estimate of 5 MW per km², this windy land could host more than 33,000 MW of potential installed capacity. If the authors consider additional areas with moderate wind resource potential (or areas which are good for rural electrification applications), the surface wind increases the estimated total to more than 8,800.00 km², or almost 10% of the total land area of Oaxaca. This amount of windy land could accommodate more than 44,000.00 MW of potential installed capacity.

In the wind corridor of the Isthmus 509.08 MW of wind capacity is currently being installed and 334.05 MW is in operation, representing an improvement of 12.96% on the target of 2,577.00 MW by 2012. There are large areas within the region attractive for their wind potential where technical and economic pre-feasibility studies for installing wind farms have not yet been completed. One of these regions is called Union Hidalgo municipality, which is located in an area with excellent wind potential, as referenced in [4] with "Class 6" (600 W/m²-800 W/m², 7.7 m/s-8.5 m/s) and "Class 7" (up to 800 W/m²; exceeding 8.5 m/s) winds, estimated at 50 m in height. For this reason, it is necessary to perform a micro-study in Union Hidalgo municipality, with a higher resolution than that used in calculating the map in Ref. [4]. This would make it possible to assess the exploitable wind potential and technical feasibility of the installation of wind farms in said area. To this end, this work carries out a wind mapping of the municipality from data sets measured at a nearby airspeed station and energy production is estimated at five wind farms, using Acciona AW70-1.5, Gamesa G83-2.0 and MTorres TWT82-1.65 wind turbines.

2. Methodology

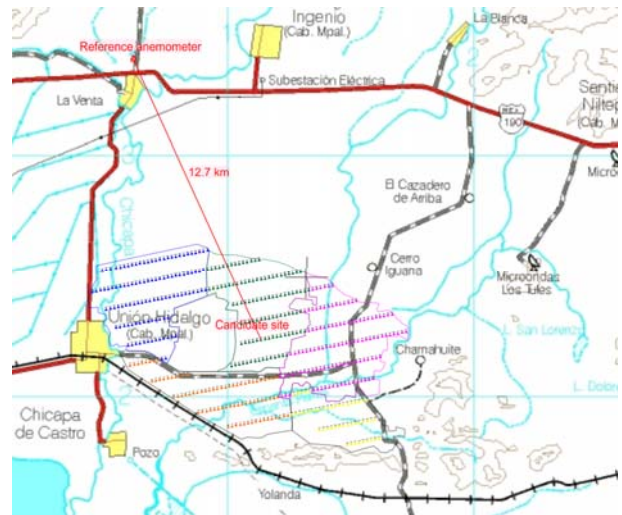
For the study of wind potential in Union Hidalgo, wind speed and direction data were used, recorded over four years and seven months in a surface anemometer station, located in La Venta, at a distance of 12.7 km to the NW (Table 1, Fig. 2). The data were recorded at 15 m and 32 m agl with NRG systems whose characteristics are shown in Table 1. This site was

Table 1 Features of the site and measuring instruments.

Measurement site	
Latitude	N 16°34'47" (1833939.5 m UTM zone 15)
Length	W 94°48'59" (306204.6 m UTM zone 15)
Height above sea level	40 m
Anemometer height	15 m, 32 m
Length of measurement period	4 years 7 months
Average range	10 minutes
NRG #40C Anemometer, calibrated	
Sensor type	3-cup anemometer
Sensor range	1 m/s to 96 m/s (2.2 mph to 214 mph) (highest recorded)
Transfer function	m/s = (Hz x 0.765)+0.35, mph = (Hz x 1.711)+0.78
Calibration	Each anemometer individually calibrated, calibration reports provided via electronic download
Output signal range	0 Hz to 125 Hz (highest recorded)
Threshold	0.78 m/s (1.75 mph)
Distance constant (63% recovery)	3.0 m (10 feet)
Moment of inertia	68x10-6 S-ft ²
Swept diameter of rotor	190 mm (7.5 inches)
Operating temperature range	-55 °C to 60 °C (-67 °F to 140 °F)
Operating humidity range	0 to 100% RH
NRG #200P Wind Direction Vane, 10K	
Sensor type	Continuous rotation potentiometric wind direction vane
Sensor range	360° mechanical, continuous rotation
Transfer function	Output signal is a ratiometric voltage
Accuracy	Potentiometer linearity within 1%
Dead band	8° Maximum, 4° Typical
Threshold	1 m/s (2.2 mph)
Operating temperature range	-55 °C to 60 °C (-67 °F to 140 °F)
Operating humidity range	0 to 100% RH

selected for its proximity to the candidate site and its climatic similarity. The WASP model generates reliable estimates up to a radius of 50 km in non complex terrain with similar topography and climate.

The wind map of Union Hidalgo was generated using the micro-scale model WASP 9.1, with a resolution of 50 meters. This model was also used to estimate the energy production of Acciona AW70-1.5 (1.5 MW, rotor shaft height 70 m), Gamesa G83-2.0

**Fig. 2** Location of reference sites (La Venta) and candidate site (Union Hidalgo).

(2.0 MW, rotor shaft height 83 m), and MTorres TWT82-1.65 (1.65 MW, rotor shaft height 82 m) wind turbines, constituting five wind farms: Iguana 1 (117 turbines), Iguana 2 (106 turbines), Esquipulas (49 turbines), Estero (82 turbines) and Zapotal (111 turbines).

Because the three models of wind turbines have similar diameters, the wind turbines' locations were not altered. Three models of wind turbines were used for the purposes of comparison, responding to the current presence and/or interest of manufacturers in the wind energy market of the Isthmus of Tehuantepec and their optimum fit with the characteristics of wind resources in Union Hidalgo. The turbines' ideal design speeds were calculated following the procedure described in Refs. [5, 6].

3. Results and Discussion

Below are preliminary results obtained with the WASP 9.1 model for Union Hidalgo, at a distance of 12.7 km from La Venta and with a similar topography.

Fig. 3 shows the map of average wind power density (kW/m^2) of the study area, estimated at an altitude of 50 meters. The authors can see that most of the power density area is located between $1,000.00 \text{ W/m}^2$ and $1,500.00 \text{ W/m}^2$, with an average value of $1,167.00 \text{ W/m}^2$ (average speed of 9.6 m/s), corresponding to a site with excellent wind potential, Class 7. These

results are encouraging and exceed the values reported in Ref. [4], making it more attractive to develop wind prospecting campaigns in this area, in order to specify the estimated results with WASP.

To estimate the energy production through wind power plants, the area was divided into five wind farms, namely Ejidos Iguana 1, Iguana 2, El Zapotal, Esquipulas and El Estero (Fig. 4). Three wind turbine models were selected: Acciona AW70-1.5, Gamesa G83-2.0 and MTorres TWT82-1.65. Wind turbines were located at ten diameters to the NNW-SSE and at two diameters perpendicular to this. Some of their features are shown in Table 2.

The three manufacturers of the selected wind turbine models already have a presence, or a particular interest in the wind energy market of the Isthmus of Tehuantepec. Production estimates were repeated in the five plants for

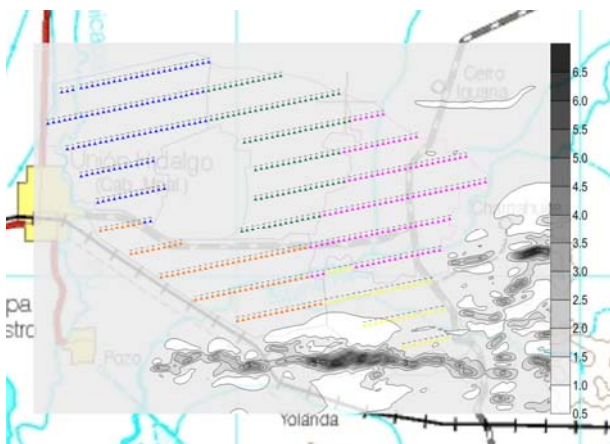


Fig. 3 Spatial distribution of average wind power density in the study area.

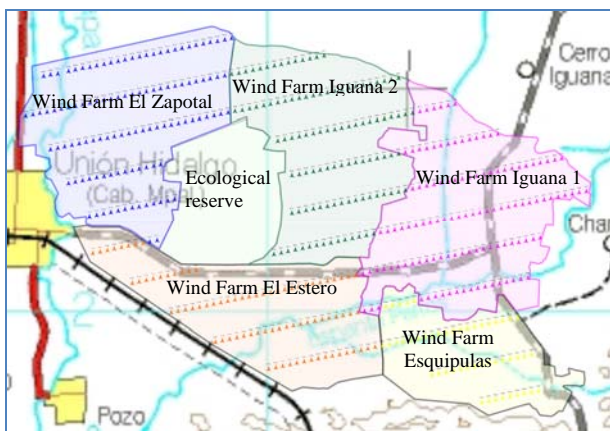


Fig. 4 Location of the five wind power plants in different "Ejidos" (cooperatives) of Union Hidalgo.

each of these models, assessing the impact of the power curve in the annual production of energy and the total capacity factor of wind power at each plant (optimal selection of the appropriate wind turbine for the distribution of speed frequencies at the site).

The calculation of the optimum operating speeds that wind turbines should have to be best suited for the site was based on the Weibull parameters estimated by WASP for Union Hidalgo ($k = 1.84$ and $c = 11.5$ m/s). Given the value of k , The authors use the following equation to determine the optimal value of V_r , derived from the results published in Ref. [6]:

$$V_r = 1.3c \quad 1.8 \leq k \leq 2 \quad (1)$$

Eqs. (2) and (3) were used to determine the values of V_s and V_o [5]:

$$V_s = 0.275 * V_r \quad (2)$$

$$V_o = 1.85 * V_r \quad (3)$$

The values calculated by the above procedure correspond to the values shown in Table 3 for $r = 1$. Also included are the calculations for values equal to $0.98 V_r$, $0.95 V_r$ and $0.90 V_r$, to search for commercial wind turbines operating at speeds close to the calculated optimum.

In Tables 2 and 3 the authors can observe that the turbine which best approximates the ideal design speeds is MTorres TWT82 - 1.65, which reaches its

Table 2 Operating speeds of the three models of wind turbines.

Wind turbine models	Wind turbine classes	V_s^a (m/s)	V_r^b (m/s)	V_o^c (m/s)	Rotor diameter (m)	Specific power (W/m^2)
Acciona AW70-1.5	I	3.5	14	25	70	390
Gamesa G83-2.0	IIa	4.0	16	25	83	370
M Torres TWT82-1.65	IIIa	3.0	15	25	82	313

(a) start-up wind speed; (b) rated wind speed; (c) cut-out wind speed.

Table 3 Calculation of optimum operating speed of the wind turbines for Unión Hidalgo.

V (m/s)	$r^* = 1$	$r = 0.98$	$r = 0.95$	$r = 0.90$
V_s	4.1	4.0	3.9	3.7
V_r	15	14.7	14.2	13.5
V_o	27.7	27.14	26.3	24.9

*Coefficient which varies between 0.9 and 1 in the calculations.

Table 4 Estimated production of five wind farms in Union Hidalgo.

Names of the wind farms	Wind Turbine Model					
	Acciona AW70-1.5		Gamesa G83-2.0		MTorres TWT82-1.65	
	AEP _{net} (GWh)	Mean capacity factor (%)	AEP _{net} (GWh)	Mean capacity factor (%)	AEP _{net} (GWh)	Mean capacity factor (%)
Iguana 1	787	51	1037	51	889	53
Iguana 2	718	52	948	51	811	53
Esquipulas	317	49	413	48	363	51
El Estero	547	51	719	50	624	53
Zapotal	757	52	1,002	52	857	53
Total	3,126	51	4,119	51	3,544	53

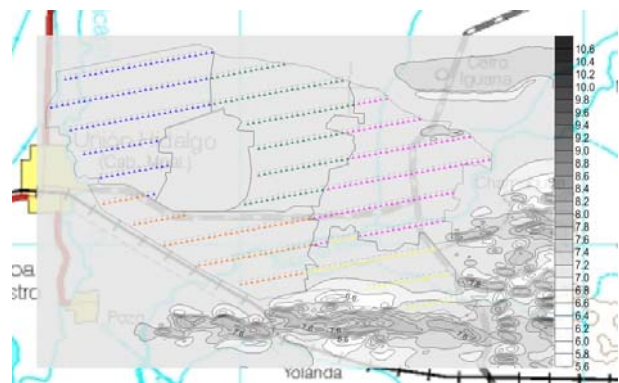
rated power at 15 m/s.

This wind turbine starts its generation at 3 m/s and stops generating at 25 m/s, taking advantage of low wind speed better than the other two turbines. However, the authors note that it is a Class IIIa wind turbine designed to work in places with 7.5 m/s average annual speed [IEC 61400-1]. Union Hidalgo is a Class 7 site, with average speed approximately 10 m/s at an altitude of 50 m and 10.2 m/s at 71 m, which is the height of the TWT82-1.65 tower. This suggests that the wind turbines installed on the site should be Class I or S (Special), capable of withstanding a Class 7 wind pattern.

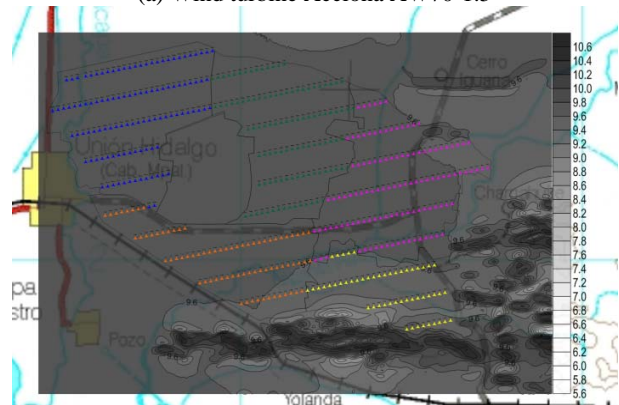
Table 4 shows the annual net energy values of wind energy produced at each plant for each of the selected wind turbines as well as the estimated average capacity factor. The MTorres TWT82-1.65 turbine is the one that shows an increased capacity factor at each plant. This is due to its being a better match to the observed frequency distribution in Union Hidalgo.

In most cases capacity factors exceeding 50% are estimated, with a maximum of 53% with the MTorres TWT82-1.65 MW. The average of the five wind farms is 51%, 51% and 53% for Acciona AW70-1.5, Gamesa G83-2.0 and MTorres TWT82-1.65 wind turbines, respectively.

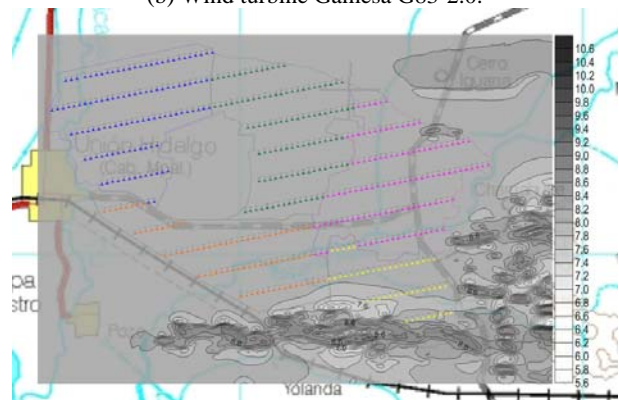
In Fig. 5 the maps show the spatial distribution of net annual energy produced by the five wind farms for the three models of wind turbines. The turbines that produce more energy are the Gamesa G83-2.0 model, but they do so at lower capacity factors than the other two models. It can be observed that the average annual



(a) Wind turbine Acciona AW70-1.5



(b) Wind turbine Gamesa G83-2.0.



(c) Wind turbine MTorres TWT82-1.65

Fig. 5 Annual energy production (GWh) in the five wind farms for each turbine selected.

energy production of the Acciona wind turbine is in the range of 6.6-7.0 GWh, while for the Gamesa it is between 8.8-9.2 GWh and for the MTorres 7.4-7.8 GWh. The final decision regarding which wind turbines models should be used in Union Hidalgo, should be taken on the basis of a technical-economic feasibility study, which fully covers all the stages that such studies require.

4. Conclusions

The results of the wind resource assessment in Union Hidalgo show values that justify the installation of wind turbines to produce electricity in the area, with a Class 7 wind pattern (average power density equal to 1,167 W/m² at an altitude of 50 m). Estimated capacity factors (53% on average) were comparable with those obtained by the power plants already operating in areas near Union Hidalgo, and sites with high wind potential in other parts of the world. The attractiveness of the area for the installation of wind power plants is increased by the existence of a predominantly flat terrain and the directional behavior of the wind (coming from the NNW 44% of the time). These factors favor the installation of wind turbines.

Given these facts, it is advisable to undertake a technical and economic feasibility study of wind energy production in Unión Hidalgo using wind farms. The results obtained in the preliminary study presented here, should be specified from measurements to be realized on site over a minimum period of one year. The study should include an assessment of the

restrictions of existing power networks, the analysis of potential environmental constraints, and a selection of wind turbine technology most appropriate to the site, defined by the IEC 61400-1 standard.

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