International Journal of Applied Research in Mechanical Engineering

Volume 1 | Issue 2 Article 13

October 2011

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Recommended Citation
Sajid, M. Z. I.; Chandra Reddy, K. Hema; and Nagesh, E. L (2011) "New Method to Harness More Wind Energy," *International Journal of Applied Research in Mechanical Engineering*: Vol. 1 : Iss. 2 , Article 13.
DOI: 10.47893/IJARME.2011.1026
Available at: https://www.interscience.in/ijarme/vol1/iss2/13

New Method to Harness More Wind Energy

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Abstract - A new and novel method to harness more wind energy has been designed Details of the experimental results and theoretical explanation is presented in the paper. The simplicity and economic viability of the method is expected to be a boon in converting poor windy sites to usable ones and to harness more energy at the existing windmill sites.

I. INTRODUCTION

Wind energy is rapidly emerging as one of the most cost effective and neat form of renewable energy. In the Annual Conference of the World Wind Energy Association, held on 06th November 2006 at New Delhi with the theme "Vision for Wind Energy", His Excellency, the then President of India Dr**.** A P J Abdul Kalam said that "Energy Independence is the lifeline of a nation". The main constraint for wider use of windmills for irrigation and wind turbines wind speeds prevailing in any parts of the world. Let is consider the example of India. The pattern of wind speeds prevailing in India based on Indian Meteorological Department (IMD) wind data (1,2) are presented in Figure 1. From this Figure it can be easily seen that in over half of the area of India the wind speeds are in the range 5-10 Km/hr, most parts of which are not suitable to tap wind energy (the windmills available in India is around 9 Km/hr). If by some means we could increase wind speeds by about 30% we can cover more areas with windmills and also increase windmill output at the existing sites.

It is a known fact wind speeds above hills are much larger than those at equivalent heights above flat ground. Moreover power is cube of velocity. With these two facts in mind an attempt is made to design a method to convert poor windy sites to usable ones.

II. EXPERIMENTS

Some experiments were conducted on models simulating dams or escarpments in a slow speed wind runnel. A 60X15 cm and 5 cm high rectangular model with longer side perpendicular to the air stream was mounted on the working table of the wind tunnel. This enables it to have an almost two-dimensional wind flow over the central portion of the model. For a 30^0 slope wind velocities were recorded at various heights in a vertical plane above the centre of the model. Simultaneously, measurements of the velocities was made at equal heights on plain surface. A micro-mini vane anemometer was used for wind power measurements.

Wind velocities at different heights above the dam were expressed in terms of the corresponding available velocities at equal heights over a horizontal terrain. The variation of this ratio with height expressed as a fraction of the height of the model is shown in Figure 2. The results show that wind speed increases over the escarpment starting with 1.35 times at the top of the dam and increasing gradually upwards. The maximum increase is noticeable at about half of the escarpment height. Therefore, the windmill if it were to extract the increased wind velocities should have its axis at this height.

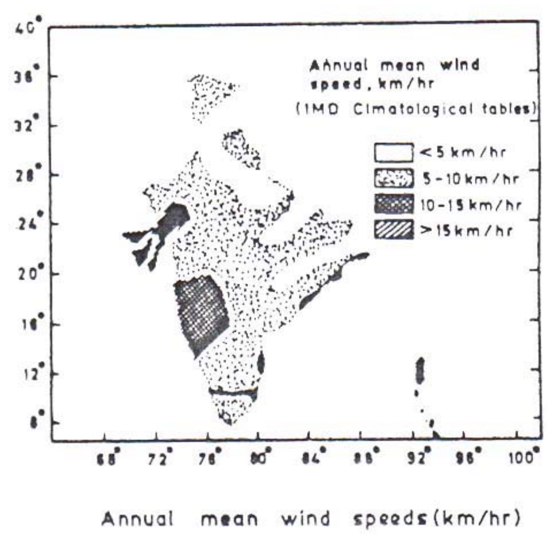
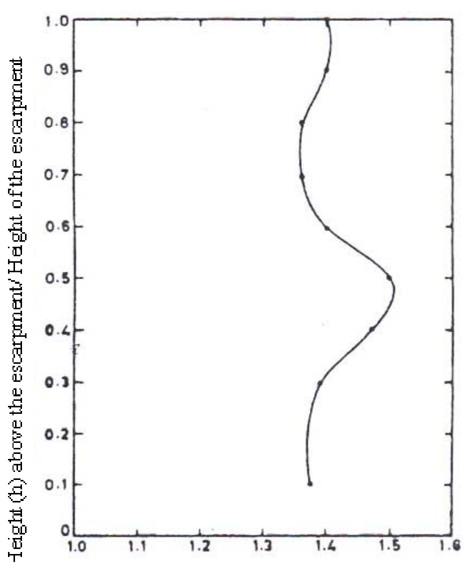


Fig. 1 : Annual Mean Wind Speeds

In general, the value of wind speed mentioned in meteorological data is its this is taken height about 12.2 meters and this is taken into consideration while calculating the possible wind power that may be tapped. To know the real gain in field, wind speed has to be found with respect to the above value. The calculated values are plotted in Figure 3, along with a wind profile over a plain terrain. From the graph it can be seen that the maximum gain is about 1.5 and hence the power $(1.5)^3 = 3.38$.

Let us take a small village in which we need about 50 windmills to meet irrigation and drinking water needs and also for small power generation. the above results indicate, if we construct an earthen dam of typical 10 meter height, 30^0 slope and 10 meter length since the power is increased by 3.38 times, we may need only 15 windmills to obtain the same amount of power with escarpments. The earthen dams are feasible to construct in rural areas in a country like India which has huge man power.

To find an answer for frequent directional changes in wind, further experiments were carried out an curved (concave shaped)



Wind speed at a height (h) above the escarpment
Wind speed at the same level on a horizontal terrain

Fig. 2 : Wind Speed At Different Heights Over The Escarpment

30^0 model and symmetrical triangular 30^0 model. In the curved model wind velocities were measured at the extreme ends and the middle, the increase was found to be almost sane (about 1.5 times) at about half of the height . the triangular model gave an increase in wind speed of about 1.4 times at half of the height. These results show that in coastal areas where wind direction changes in the day and night, symmetrical 30^0 escarpments (10 m height) can be utilized. In areas where frequent changes in wind direction occur, curved escarpments will be useful. In further experiments a 30^0 slope model with partial slant portion (equal in scale to 10m) gave an increase in wind speed of about 1.3 times. The latter experimental results may be useful to increase wind speed at the existing windmill sites. In a bid to find a cheap cheap material to make sloping structures and which are mobile, bamboo has been chosen. Bamboo screens of typical size (5 X 4m) can be made and the upper portion plastered with a thin and uniform layer of clay and animal dung. Over the coating a polythene sheet is covered. The polythene covering will help to give smoothness and also prevent it from rain (In open grain storage, large polythene covers are widely used in India which last for about 2 years).

In choosing bamboo for the sloping structure the following advantages were taken into consideration. bamboo is abundantly available in any developing countries. Bamboos as well as blades for windmills in Thailand. Some studies by researchers reveal, bamboo tested have been found to have half the yield strength of mild steel (3.4). Also some work on bamboo reinforced slabs, bamboo-create wall panels and roofing elements was already carried out. (3,4,5). It was found that carried reinforced slab can be designed like steel reinforced concrete taking permissible tensile strength and bond strength as 24,000 KN/m^2 and 350 $KN/\ m^2$ respectively. Also some studies have been conducted on bamboo-mortar composite wall panels and roofing elements. The performance of these types of structures have been claimed to be satisfactory under various researchers (4-120 also confirm the versatility of this low cost construction materials.

The cost of a typical bamboo screen (5 x 4m) with clay coating and polythene covering may be about Rs.1000/- (about 25 US). The bamboo screen can be made locally. Eucalyptus or casuarinas poles can be used in the supporting structure. The hollow space beneath the bamboo structure can be used for storage.

In areas where wind speeds are very high and where one wants to save ground space, one can install a 10m structure (inclined at 30^0) made of asbestos sheet before the windmill. The supporting structure can be wooden or steel. The Supporting structure can be wooden or steel. The asbestos withstands rain and heat and has been in wide use as roofing material for a long time.

Practical And Economic Feasibility

To see the effect of 30^0 slope on wind speed, experiments were carried out by placing slopes of different roughness before a model windmill and increase in wind speed has been found to be substantial. Though full scale field tests are yet to be conducted, the results of Bowen and Lindley (13) show that there is good agreement between full scale field measurements and wind tunnel. Bowen and Lindley conducted field tests on a 13 m high and 26^0 sloping escarpment. Hence, it is felt that variation in increase in wind speed as was found on a sloping model in wind tunnel.

The earthen dams are quite strong. There are some earthen embankments around water storage tanks in villages in India which are quite old.

III. THEORETICAL EXPLANATION OF FLOW OVER ESCARPMENTS

To predict the change in wind distribution connected with changes in surface topography, a method has to be evolved which will help in the design of structures. Usually the existing codes of practice suggest rules for modifying the design wind profile above hills, but some measurements have shown such hills, but some measurements have shown such empirical formula are unreliable (14,15). Hence, the need for simple theoretical solutions to boundary-layer flow over surface obstacles.

A theory which explains the general features of the effect of a two dimensional surface hump on a turbulent boundary subsequently by Jackson (16) and subsequently by Jackson and Hunt (17). In further studies (18) Jackson modified the above theories to be applicable to carious escarpment shapes. According to Jackson, as the vorticity in the outer part of the boundary layer is small, one can expect the disturbance to the flow there to be approximately irrational. This implies perturbation caused by a change in surface topography has exactly the same distribution as the perturbation to a uniform, in viscid flow caused by the same surface shape. Then the surface can be found using ordinary irrotational theory. Near the surface, changes in viscous and Reynolds stresses are also to be taken into account. It can be shown that the thickness of the layer in which stress changes are important is much less than that of the boundary layer, so that close to the boundary layer in which stress changes are important is much less than that of the boundary layer, so the problem of an inner boundary layer being driven by an inner boundary layer being driven by an externally generated pressure gradient (19). Methods to deal with the above problem are available. (20)

If the flow field can be divided into two layers as suggested above, the problem can be solved with existing techniques. Before attempting the same, the following points have to be resolved:

i) The magnitude of the irrotational disturbance in the outer layer must be found,

ii) One should find uniform velocity of the corresponding inviscid flow,

iii) How to improve on the initial assumption that the disturbance is irrotational

iv) The thickness of the inner layer in which stress changes are important must be found.

The flow field over escarpment is shown in Figure.

Here the surface is given as : $y = hf(\frac{x}{L})$,

Where h is the height is the height of the hill and L is representative length. L may be taken as the horizontal distance from the peak in which the hill falls half its maximum height.

Near the hill

$$\tilde{x} = \frac{x}{L} = O(1),$$

the irrotational layer is assumed as having thickness of the same order, viz.,

$$\tilde{Y} = (\frac{(y-hf)}{L}) = O(1)$$

we can write an expression for the horizontal velocity with the limits $\tilde{Y} \to o$ as:

$$U(Y) = U_0(Y) + hf\frac{x}{L} U_o^1(Y) + \frac{h}{L} U_0(L)\tilde{U} \quad (1)$$

Here U (Y) is the incident velocity profile, and the first term is chosen to match the solution in the inner layer near the wall where to lowest order the velocity is assumed to be a simple displacement of U. the second term is chosen for conditions at infinity, we have

$$U \to U_o(Y) + h^2 f^2 U_o(Y) + \frac{h}{L} U_o^{'}(L)\, U$$

$$U \to U_o(Y) \text{ if } \tilde{U} \to o \text{ as } \tilde{Y} \to \infty \quad (2)$$

To satisfy the continuity equation, the vertical velocity is written as

$$\mathbf{V} = \frac{h}{L} f^1(x)(U - U_0(\tilde{Y}L) + \frac{h}{L} U_o(L)\tilde{V} \quad (3)$$

Where

$$\frac{\partial \widetilde{U}}{\partial \widetilde{x}} + \frac{\partial \widetilde{V}}{\partial \widetilde{Y}} = o$$

Equation (1) can be rewritten as

$$U(Y) = U_o(Y) + hf(x/L)U_o^{1}(Y) + \frac{h}{L} U_o(L)\tilde{U}$$

Where

$$\tilde{U} = \frac{\Delta U}{Uo} \text{ (in outer layer)}$$

$$= \frac{-U(Y) + Uo(Y)}{Uo(Y)} / Y \sim L$$

$$= 1 - \frac{U(Y)}{Uo(Y)} / Y = L$$

$$= 1 - \frac{U(L)}{Uo(L)} = - \frac{U(L)}{Uo(L)} = - \frac{U(L)}{Uo(L)} + 1$$

$$U(Y) = U_o(Y) + \frac{h}{L} U_o(L) - \frac{h}{L} U(L) + hf \frac{x}{L} U_o^{1}(Y)$$

$$\delta = -\frac{U(Y) - Uo(Y)}{Uo(Y)} = \frac{\Delta U(Y)}{Uo(Y)}$$

$$= \frac{h}{L} \frac{U(L)}{Uo(Y)} - \frac{h}{L} \frac{Uo(L)}{Uo(Y)}$$

$$+ hf \frac{x}{L} - \frac{Uo'(Y)}{Uo(Y)}$$

Where δ is increment factor

at $Y = L$, $U_o^{1}(Y) \to o$

$$\therefore \delta \to o$$

For the condition

h⌡ Y ⌡ ∞

we have

$f\frac{x}{L} = o$ o ⌡ x⌡ L

$\frac{h}{2L} x$ L ⌡ x ⌡ 2L

h 2L ⌡ x ⌡ ∞

we have Y = mx

$m = \tan\theta$

$$= \frac{h}{2L}$$

$$\frac{h}{2L} \tan\theta$$

$$\frac{h}{L} = 2 \tan\theta$$

U(Y) can be found by either Reed's formula or 1/7th law.

REED'S FORMULA

Reed (21) using tower observations derived an empirical formula for the wind speed at a height (z_2) other than the observation height (z_1), for well exposed sites on flat open ground

$$V(z_2) = V(z_1) [c V(z_1)]^a (z_{2/z}1)^b$$

Where

$a = 0.0977 \ \ell_n{}^z{}_1 - (0.0386 = 0.0627 \ \ell_n{}^z{}_2$

$+0.00642 \ \ell_n{}^z{}_1 - \ell_n{}^z{}_2)$

$b = 0.318 + 0.327 \ \ell_n{}^z{}_{1/}$

c = 2.24 (m/s or mph)

We have

$$\delta = 2 \tan\theta \left[\frac{Uo(L)}{Uo(Y)} - \frac{U(L)}{Uo(Y)}\right]$$

The theoretical calculations for finding δ are carried out as follows:

1) Assume $U_o(10) = 1$

   All velocities have to be multiplied by $U_o(10)$

2) H, □ are chosen such that
   h = 10m □ =30^0
   than L is calculated as follows :

(a) For the given values of h, □ and L

   Taking $f\frac{x}{L}$ = o so long as

   o ⌡ x⌡ L

(b) L ⌡ x⌡ 2L, Y / x tan□ but ⌡ h

   For the same values of h, □ and L taking

$$f\frac{x}{L} = \frac{h}{2L} x$$

(c) 2L ⌡ x⌡∞ for the same values of h, □ and

$L f\frac{x}{L}$ =h, y / h

The theoretically calculated values of δ at various heights are plotted in the graph (Figure 3) along with experimental values.

There is fairly good agreement at height (between 19 and 22m) and at other heights some variation is noticeable. A satisfactory explanation for the variation in theoretical and experimental results is difficult for the simple reason that some factors were left out in the calculations of experimental results for lack of sophisticated instruments. Nevertheless the theory gives a broad picture of the prediction technique of wind over escarpments. There is still scope prediction

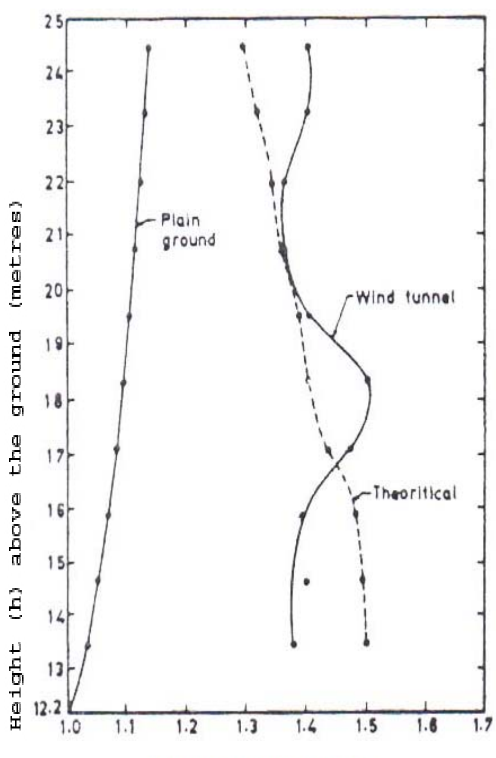
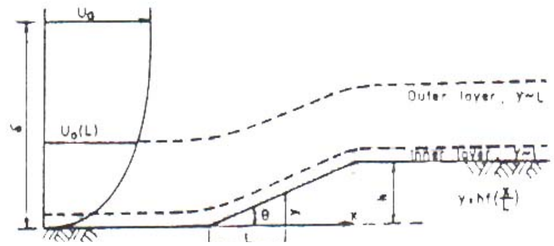


Fig. 3 : Wind velocities at different elevation

(i) Over plain ground (ii) over earth mound



x ,y	Horizontal and vertical co-ordinates
u	Horizontal and vertical velocities
h, L	Height and width of the escarpment
f(x/L)	Shape of escarpment
U_0 (y)	Incident velocity profile
U_0	Geo strophic wind
Δ	Boundary- layer thickness
K	Von Karman's constant
Y_0	Surface roughness length
l	Thickness of inner Reynolds stress layer
Ũ,Ǔ	Perturbation in outer and inner layers

Fig. 4 : A sketch of the flow field

Technique of wind over escarpments. There is still scope to improve upon the existing theory.

IV. CONCLUSION

The experimental and theoretical results show that there is a definite increase in wind speed over a 10m high, 30^0 sloping escarpment. The earthen dams and bamboo screens are expected to be a boon to cover more areas with windmills and to harness more energy at the existing to harness more energy at the existing windmill sites. The cost of earthen dams, bamboo screens and asbestos sheets is expected to be economic in view of the locally available resources and huge man power a available in rural areas in a country like India. Moreover the construction of earthen dams and bamboo screens generates employment in rural areas and are a clear case of appropriate technology.

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