Harnessing wind power for rural development

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There is considerable scope of harnessing wind power to meet part of the growing energy need of rural communities. However, much remains to be done for development of appropriate windmills suited to wind conditions obtaining in different parts of India before large scale utilization of wind energy could become possible.

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■ In India today, human and animal muscle power still supplies the bulk of the energy needed to maintain various activities in our villages and to sustain agricultural production. Villages form the core of India and if this core is to progress, it will need supplementary inputs of energy obtained either in the form of centrally produced electricity and imported fuel oils or, preferably, from within its own environment through the utilization of renewable local energy resources like sunlight, human, animal and agricultural wastes, and wind.

In spite of steady progress in the implementation of rural electrification schemes, over 2,50,000 villages will still remain in darkness in 1980. Erratic monsoons, inadequate transportation facilities for bulk movement of coal for thermal power stations, high electricity transmission losses (up to 35%), and very low load factors (1-14%) contribute to the unfavourable economics of electricity distribution to backward and remote areas of the country.

Wind : a natural resource

It has been estimated that roughly 10 million megawatts of energy are continuously available in the Earth's winds. The utilization of some of this energy through various mechanical conversion devices has played a decisive role in the economic development of many countries where winds are strong and steady.

In India, unfortunately, the wind is neither strong nor steady. However, wind data collected over 30 years by the India Meteorological Department indicate the existence of predictable wind patterns in various regions of the country. The wind curves in Fig. 1 show that Madhya Pradesh, West Bengal, Bihar, Uttar Pradesh and Punjab have an aggregate annual average wind velocity of 6.3 km/hour; Kerala, Tamilnadu, Karnataka, Andhra Pradesh, Maharashtra, Rajasthan and Orissa, 9.7 km/hour; and Gujarat, 12.2 km/hour. The national average is 9.4 km/hour.

Since the energy that can be extracted from the wind is proportional to the cube of the wind velocity, the success of any scheme to tap this energy is dependent

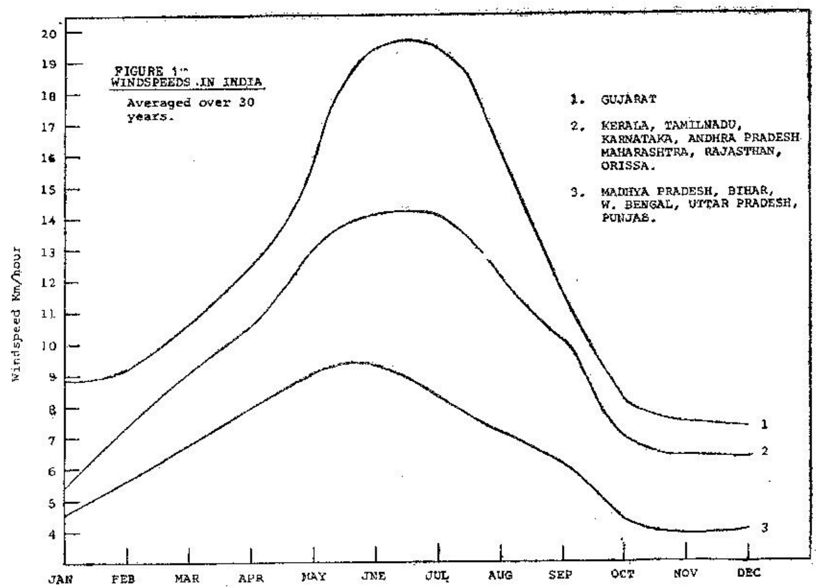


FIGURE 1 WINDSPEEDS IN INDIA

Table 1—Economics of a windmill costing Rs 10,000 operating in areas covered by the curves in Fig. 1

Curve no.	Average annual wind velocity (km/hr)	Annual windmill output at 75% duty cycle (kwh)	Recurring annual cost (Rs)	Cost/unit (kwh) energy produced (Rs)
1	12.2	2,227	1,950	0.88
2	9.7	1,059	1,950	1.84
3	6.3	329	1,950	5.93
Hypothetical	20.0	9,702	1,950	0.20

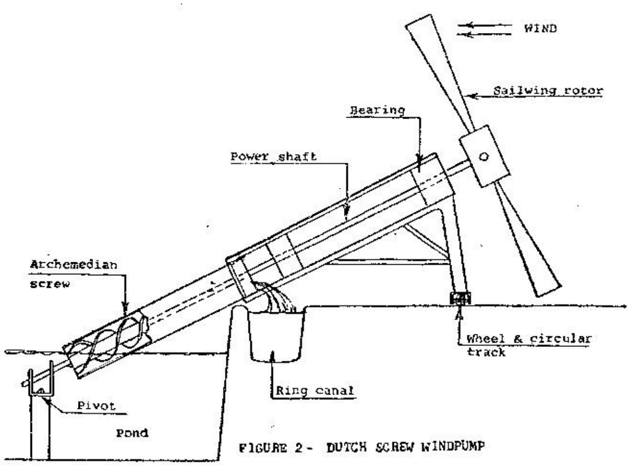


FIGURE 2 - DUTCH SCREW WINDPUMP

on the availability of adequate wind velocity over a period of time sufficient to justify the investment in and maintenance of the energy conversion device. To illustrate, consider a windmill costing Rs 10,000 on which the recurring annual expenditure in terms of interest on capital invested (12%), depreciation (5%) and maintenance (2.5%) is Rs 1,950. The economics of this windmill operating in areas covered by the curves in Fig. 1 can be broadly summarized as shown in Table 1.

The table indicates that the economics of the windmill are favourable for such areas of the country as are indicated in curves 1 and 2, if the cost per unit energy produced by the windmill is compared with the cost of commercial energy, which is about Rs 1.18 per unit (obtained by averaging the relative costs of agricultural electric power, kerosene and diesel oil).

Windmills and their uses

Windmills had been widely used in Persia, China, Europe and the USA for pumping water and grinding grains. Efficient wind electric generators were later developed in the USA, thousands of which produced electricity for farms and homesteads before the advent of rural electrification.

A windmill converts the energy of a moving mass of air into mechanical motion that can be used to either work a machine directly or to turn a generator to produce electricity. The mechanical type windmill and the wind electric generator (aerogenerator) are compared in Table 2.

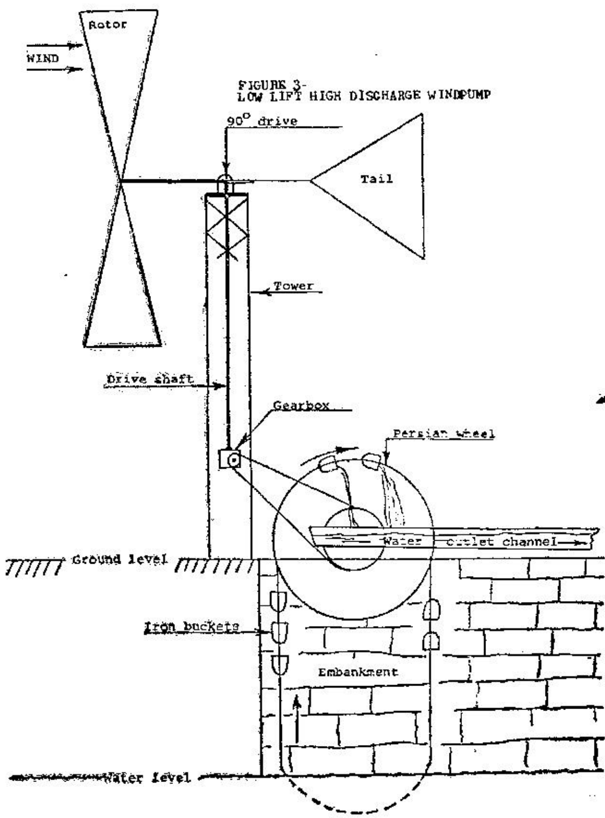


FIGURE 3- LOW LIFT HIGH DISCHARGE WINDPUMP

Windpumps

The windpump is the simplest type of windmill to manufacture and maintain, and is therefore the most relevant to rural India.

Windpumps can be classified into low-lift high-discharge and high-lift low-discharge types. The first type, illustrated in Fig. 2 & 3, can be coupled to Archemedian screw pumps, low speed centrifugal pumps with wooden or metal paddles, pallet pumps, chain washer pumps, double acting reciprocating pumps or Persian wheels similar to the "Halt" used by farmers in Punjab, Haryana and around Udaipur. Such devices can discharge up to 40 litres per second (500 gallons/minute) in a 15 km/hour wind. They can be constructed with local expertize and materials. They have potential for lift irrigation from canals, rivers lakes, tanks and open wells where the water table is 3 metres or less, and for pumping sea water for the manufacture of salt.

The high-lift low-discharge windpump is widely used in the USA, Europe, South America and Australia to pump water from deep wells when the water table is between 12 and 90 metres. The water yielded by tubewells is biologically pure and can normally be safely used for drinking purposes.

Table 2—Comparison between mechanical type windmill and wind electric generator (aerogenerator)

Sr. No.	Factors determining choice of windmill type	Mechanical type windmill	Aerogenerator
1.	Applications :	Limited to water pumping and some mechanical functions like grinding of grains, oil expelling, fodder chopping, and operation of simple machinery when operating frequency and rpm are not critical.	Very wide, particularly if stored power is converted to 220 volts 50 hz ac before distribution.
2.	Cost of construction :	Low to moderate, depending on design and choice of materials, ranging between Rs 3,500 and Rs 15,000.	High, usually exceeding Rs 22,000 (excluding electrical storage and distribution systems) according to rated output.
3.	Maintenance :	Simple sailwing windmills need regular attention because of crude construction and choice of materials; commercially manufactured windmills, if properly installed, can work unattended for a year or more.	Limited mechanical maintenance is required, but a technician is needed to regularly attend to the electrical storage and distribution system.
4.	Level of construction technology :	Low : it is possible to construct simple windmills using facilities available at district and *tehsil* towns.	High : efficient aerogenerators operate at high speed and require sophisticated techniques for manufacturing wind rotors, mechanical transmission and generating equipment.
5.	Wind velocity required :	Relatively low : specially designed mills can pump water at a wind velocity of 4 km/hr.	High : aerogenerators operate efficiently at wind velocities of 20 km/hr and higher.
6.	Energy conversion efficiency :	Generally low : efficiency falls and transmission losses increase with increasing wind velocity.	High at optimum windspeed, often approaching 70% of the theoretical maximum conversion efficiency of 59.26%.
7.	Possibility of energy storage for use during calm spells :	Limited : the only feasible method of storage at present is pumping water into overhead tanks; future possibilities are use of large flywheels and operation of compressors for storage of compressed air.	Electrical energy is easily stored in accumulators; another possibility is production and storage of hydrogen and oxygen by electrolysis of water.
8.	Spatial distribution of energy produced :	Scope limited to water pumping windmills (wind-pumps), when water stored in tanks can be distributed through pipelines and channels.	Distribution of electricity over reasonable distances is easily possible through cables and overhead transmission lines.

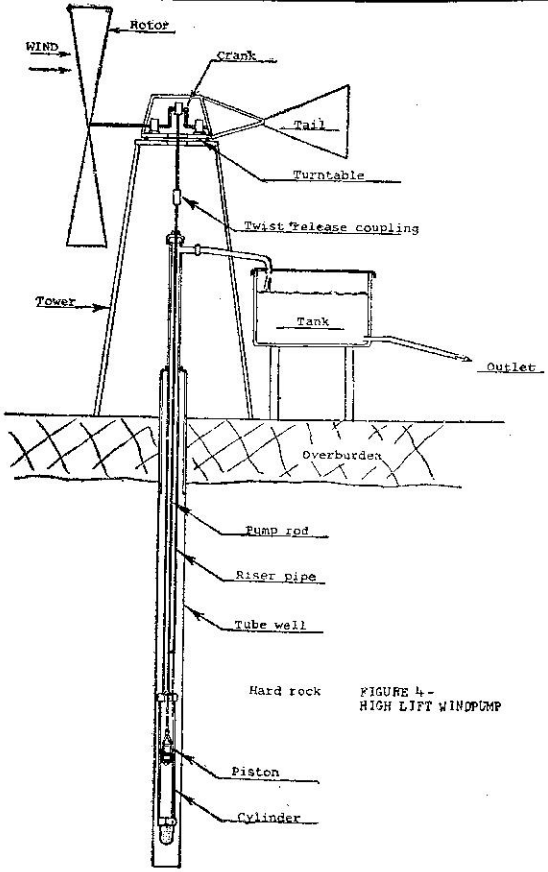


Fig. 5. Type WP-II deep well windpump developed by the National Aeronautical Laboratory, Bangalore.

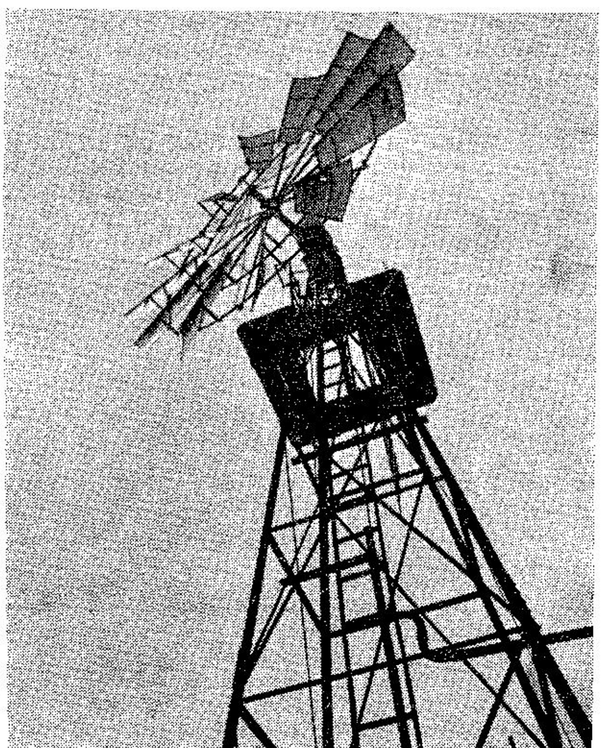


Fig. 6. Deep well windpump built by village artisans, designed by Marcus Sherman.

Fig. 7. Gearbox and crank mechanism of commercially manufactured deep well windpump.

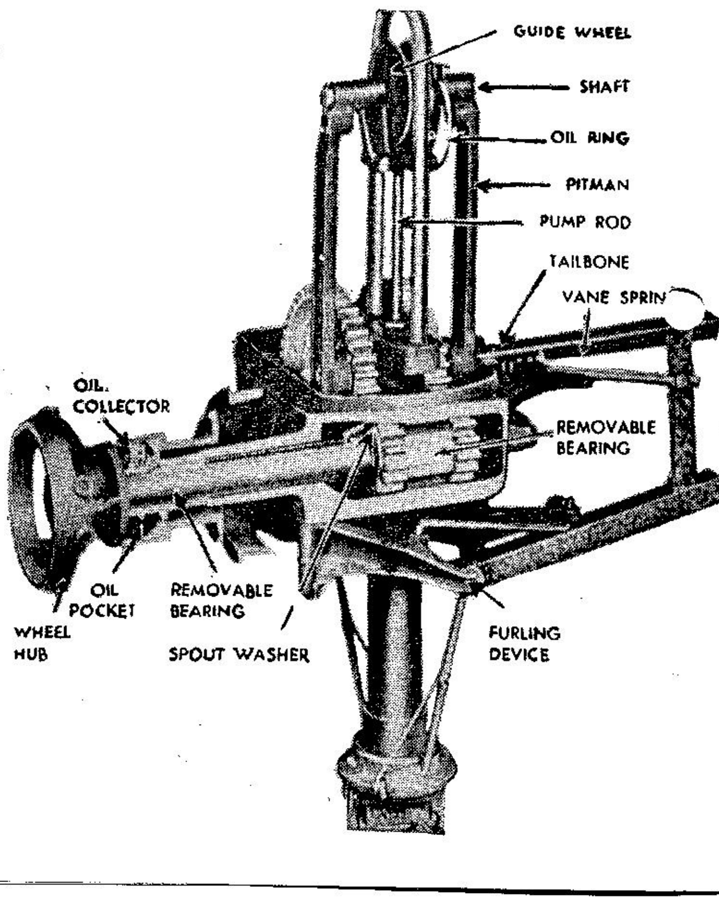


Table 3—Wind velocity and windmill output

Wind velocity (km/hr)	Power output, 5 m dia. rotor (hp)	Pump strokes with 2:1 crank reduction drive (strokes/min.)	Pump discharge (7.5 cm cylinder, 15 cm stroke) (litres/hr)	Power for pump (hp)	Excess power available (hp)
10	0.07	30	1,250	0.07	—
15	0.22	45	1,875	0.105	0.115
20	0.53	60	2,450	0.14	0.39
25	1.00	75	3,125	0.175	0.825

Reciprocating piston pumps with an operating stroke of 12.5 to 25 to cm lend themselves well to windmill operation. Pumps of this type are commercially available in India and are extensively used as deep well handpumps in village water supply schemes.

In the windpump, reciprocating motion is transferred from a crank attached to the rotor shaft via a plunger rod which goes down the water riser pipe, through the top of the pump cylinder located near the bottom of the tubewell, and thence to the piston yoke and bucket-washer assembly. Valves located in the piston yoke and the foot of the cylinder assure positive lift to the column of water at each upward stroke of the plunger. A high-lift windpump system is schematically illustrated in Fig. 4.

Deep well reciprocating pumps have an efficiency of up to 80% and can operate at any stroke frequency up to 50 strokes per minute.

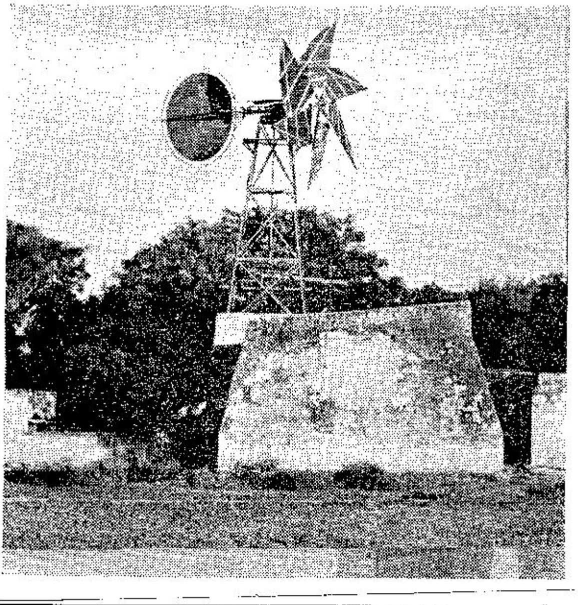
Deep well windpumps have been developed at the National Aeronautical Laboratory, Bangalore, and a number of these along with some imported units are operating in various places in India for supply of protected drinking water to rural communities (Fig. 5, 6 & 7).

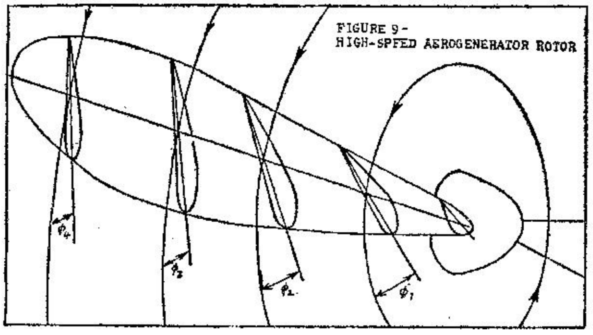
Multi-purpose windmills

As wind velocity increases, an increasing amount of power can be extracted from it. At windspeeds above 10 km/hour, more power can be produced than is actually needed for the operation of a deep well pump. Since the windmill output is roughly proportional to the cube of the wind velocity, whereas the shaft horsepower of the pump increases linearly with the pump discharge. The Table 3 enumerates this characteristic.

The wind velocity often exceeds 10 km/hour in many parts of the country (see Fig. 1), particularly between March and September. In such cases, windmills with rotary rather than reciprocating outputs may prove to be more cost effective since they could pump water and, during the windy season, simultaneously operate a variety of agricultural machines and implements used for community services, such as grain grinders, fodder choppers, and oil expellers. A multipurpose windmill of this type, developed by the author, is shown in Fig. 8.

Fig. 8. Multi-purpose windmill to pump water and operate agricultural implements, located at the S.W.R.C., Tilonia, Rajasthan.





Aerogenerators

Aerogenerators are designed to operate at high rotor-speeds and utilize propeller type rotors shaped to follow conventional aerofoil designs of known aerodynamic characteristics.

In high-speed aerogenerator-rotors (Fig. 9) the aerodynamic lift force, for a given relative wind speed, increases with the angle of attack (ϕ) until it reaches the stalling value of about 15°, after which the lift decreases. For high efficiency, the blade sections must be shaped to have the greatest possible lift and the smallest possible drag. To extract maximum power at each succeeding section along the blade, it is necessary that both its shape and the blade angle, which its principal axis makes with

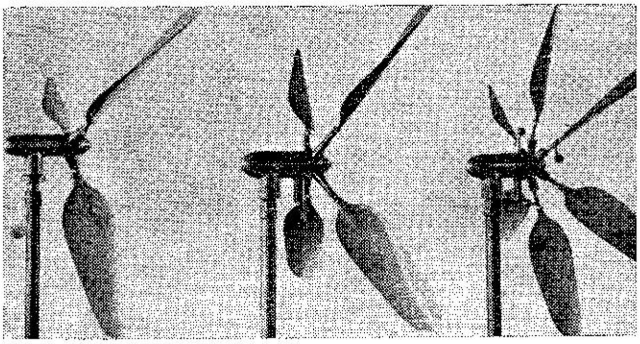


Fig. 10. Aerogenerators with automatic centrifugal rotor pitch control (Rotor blades are made of fibreglass reinforced plastic).

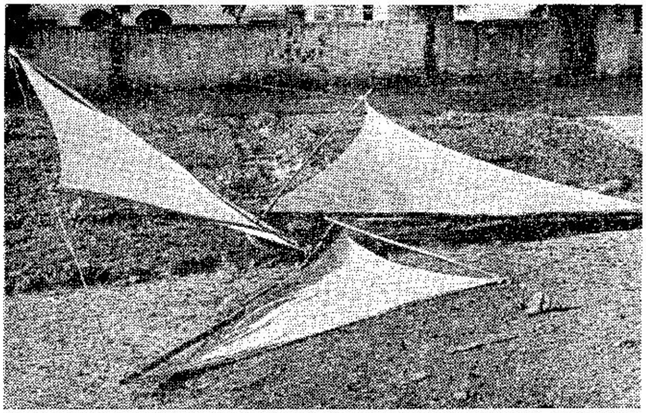


Fig. 11. Bullock-cart wheel, canvas and bamboo windpump rotor.

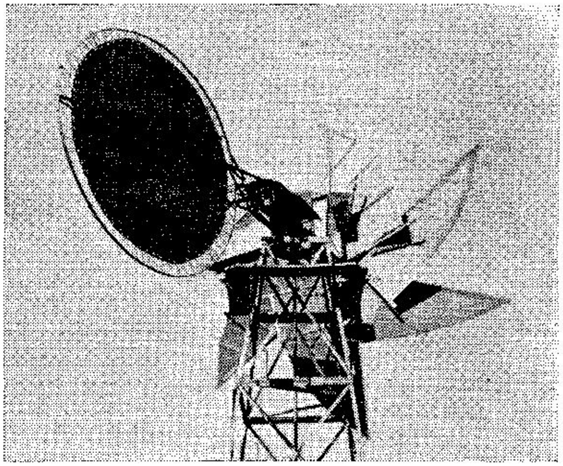


Fig. 12. Sailwing rotor of multi-purpose windmill.

the plane of rotation, vary to suit the changing magnitude and direction of the relative wind. The smaller the peripheral speed (2π rN) the greater the angle which, for any given wind speed, the relative wind will make with the plane of rotation.

It follows, therefore, that to maintain the best angle of attack, the blade angle should vary continuously along the blade and should be greatest at the root and least at the tip.

$$\phi = \tan^{-1}\left[\frac{R \tan A}{r}\right]$$

where A is the tip angle of attack, R the tip radius, and ϕ the angle of attack for radius r.

The development of the propeller for aircraft in the 1920s, and the commercial availability of storage batteries, catalyzed the development of 'low solidity' windmills for generation of electric power (solidity = ratio of total blade chord to circumference of swept circle at any given radius). Low solidity rotors are not restricted by the actual wind velocity, and can exceed it by 6-10 times.

Either dc generators or ac alternators can be used : dc generators can charge a bank of storage batteries through a voltage regulator similar to the automobile cutout relay, while ac alternators need to operate at constant speed for a constant output frequency. Some aerogenerators have centrifugally operated automatic rotor pitch control which varies the angle of attack of the blades so as to maintain near constant rotor speed despite variations in wind velocity (Fig. 10).

The power stored in batteries can be used directly if dc machinery is available for the load. Alternatively, rotary dc to ac converters, or electronic inverters, are employed to produce alternating current of 220 volts, 50 hz.

The major disadvantage of aerogenerators is their high relative cost and high cost of storage batteries and electricity distribution network. The estimated cost of wind electricity generation, storage and distribution systems is over Rs one lakh, which may be considered beyond the means of most Indian villages. On the other hand, there is considerable potential for widespread use of much smaller aerogenerators producing about 0.2 kw, which is sufficient to power a radio or a television set. When developed, such devices could be made available at a price that might be considered reasonable in terms of the cost of television set or radio receiver.

Windmill components

The rotor, also called the windwheel, consists of a number of blades or sails disposed radially around a shaft to which they are attached, and which is oriented prallel to the wind direction so that the blades rotate in a plane approximately normal to this direction. The blades may vary in number from one to eighteen or more, may be tapered or of same chord-width throughout, and may be plane or twisted. Their pitch may be fixed or variable and they may either be rigidly mounted or allowed to 'cone' or 'drag' to relieve the stresses set up by rapidly changing windspeeds.

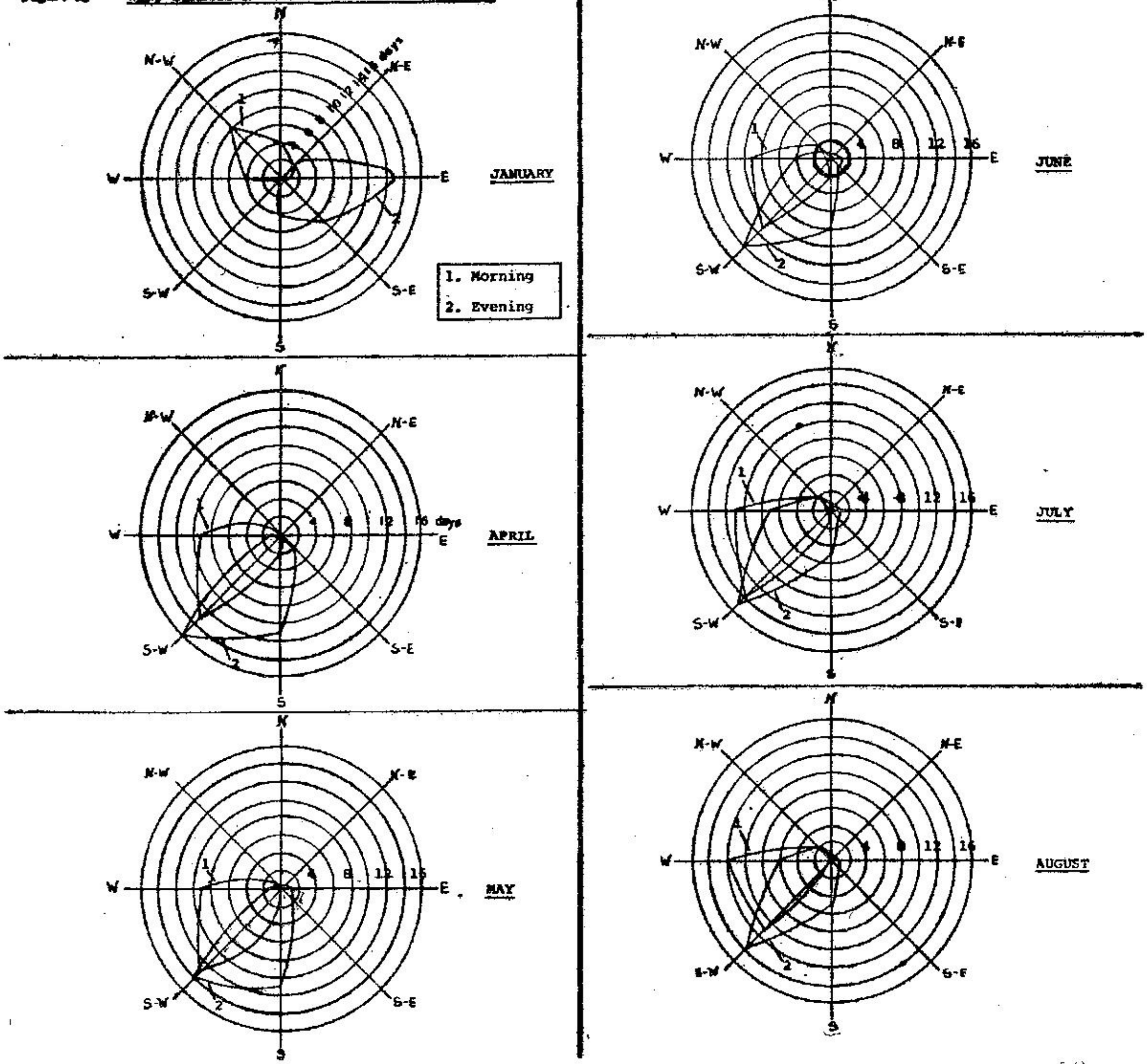
Windpump rotors can be made with strips of sheet steel or aluminium held in position by circular steel frames (Fig.5) or can be fashioned from waterproof cloth stretched between radial poles (Fig. 11 & 12).

Materials for aerogenerator rotors are wood, aluminium or fibreglass reinforced plastics (Fig. 10).

The turntable, usually mounted on a race and resembling a thrust bearing, permits the rotor and power transmission system to 'yaw' or rotate around a central vertical axis to keep the rotor facing up-wind.

It is useful to study the wind direction pattern of a proposed windmill site before the windmill is designed. Locations with marked wind turbulence require windmills fitted with freely-moving turntables, but there are many places in India, particularly along the coastline, where the wind direction does not change more than two or three times a day. Fig. 13 shows the wind direction patterns at Vishakhapatnam during the months of January, April, May, June, July and August. Such uniform patterns indicate that the windmill need not necessarily have provision for automatic 'into-the-wind' orientation,

Figure 13 WIND DIRECTION PATTERNS AT VISHAKHAPATNAM



and could instead be designed for manual orientation with considerable saving in cost.

The tail is designed to use wind pressure to rotate the turntable as wind direction changes in order to hold the rotor approximately perpendicular to the air-stream. It can be spring loaded to allow the rotor to face the wind-stream at an angle other than 90 degrees when the wind velocity exceeds a safe maximum. A limited amount of speed regulation can thus be achieved by adjusting the spring tension. If the tail is hinged, it may be connected to a lever near ground level in such a way that it can be shifted manually into a plane nearly parallel to the rotor arc, thus reorienting the rotor out of the air-stream. And this has the effect of shutting down the windmill for protection during storms. Movable tails should be designed for windmills meant for use in rural areas, especially when storms and summer *loo* winds are common.

The tower holds the windmill aloft, and should be higher than any obstruction — buildings, trees etc — within a radius of 30 metres of the windmill. Towers must be designed to withstand at least twice the maximum stresses due to wind pressure, rotor torque, and centrifugal forces expected under worst storm conditions. Towers are generally fabricated of angle iron, but low cost towers have been constructed using *ballis* and bamboo braces that have been thoroughly treated against termites (Fig. 14).

Useful formulae for windmill design

1. $P_o = 0.0000255 \times R^2 \times V^3 \times E_r \times E_t$
2. $P_s = 9.807\, D \times H\, E_p$
3. $N = \dfrac{406.5598 \times V}{R}$
4. $\mu = \dfrac{0.37704 \times R \times N}{V}$
5. $T_r = \dfrac{3552.9012 \times R\, P_o}{\mu \times V}$

where,

P_o = power output in horsepower (hp)
P_s = shaft horsepower of pump
N = rotor speed, revolutions per minute
μ = tip speed ratio of rotor at tip
T_r = rotor torque in foot pounds (ft-lb)
D = pump discharge in cm/second (m^3/sec)
H = total head of water in metres
E_r = efficiency of rotor within maximum theoretical efficiency of 59.3%
E_t = efficiency of mechanical power transmission
E_p = efficiency of pump
R = radius of rotor in metres
V = wind velocity in km/hr

Fig. 14. Low cost windmill tower made of **ballis** *and guyed with twisted GI wire.*

Summing up

The forgoing discussion indicates that there is considerable potential for development of windmills especially suited to wind conditions obtaining in well over half of India's land area. Windmills constructed at low cost with local expertize and materials can go a long way in providing rural societies with a reasonable proportion of their growing energy needs, with complementary savings to the country in terms of capital investment into large power projects and foreign exchange required for import of fuel oils.

Much work remains to be done to develop really appropriate windmill designs before large scale utilization of wind energy becomes possible. Just as local environmental and socio-economic factors determine the choice of technologies, as exemplified by area-wise disparity in selection of lift irrigation methods, so must a variety of different designs of windmills be evolved to suit areas with varying parameters of wind velocity, duration and direction, energy needs, load factors, socio-economic conditions, level of technical expertize available, social awareness, economic activities, cropping patterns, and so on. With such a wide variety of parameters, it is doubtful if a handful of research and development agencies can successfully take on the task of developing the numerous and distinctive variety of windmills required to suit these conditions, and at the same time organize reliable systems for their maintenance. Rather, the main thrust of any drive to popularize the harnessing of wind power in rural areas should be educational in nature, to make farmers and rural entrepreneurs aware of the energy potentially available to them in every gust of wind.

Government and voluntary rural development agencies should be encouraged to experiment with simple windmill designs, and to involve local farmers and technicians in their experiments. A growing fund of expertize would then begin to develop at the very point of utilization. This expertize would foster innovation in the ever-increasing applications of wind power thus benefiting the rural community and conserving traditional energy inputs for more efficient utilization.