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Wind water-pumping Applied to Egypt.

Dr. Attia El-Mallah

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I Introduction :

Historically, the major application of wind energy has been rural and agricultwe in nature. More than five thousand years ago, the Egyptians were already sailing boats along the river Nile. Windmil appears to have originated in Persia two thousand years ago. And now, thousands of small units are still used in different countries around the world.

Still limited applications of windenergy have been found its usage in rural and remote area For the most, rural areas are widly distributed and often located on sites where wind resources may be favourable. For this reason wind energy ma have its best opportunity of becoming reestablished as a power supply.

It is benifitaldy to select appropriate sized windmachines located close to these communities to eliminate transmission costs and reduce fuel transportation. Small units allow for decentralizatio of ownership and control, hence, it could be easily combined with the other existing power sources.

Major use of energy in rural areas is for pumpi water for irrigation and watering of livestock. Electric generation has a second priority, when modern applications is considered, as when pumping water at high pressure is needed for sprinklers irrigation. Lighting and small electrical domestic appliances may be next considerations.

The technology of small windpumping units are reasonably understood. Although some engineering modifications are required to be done. Most of the rural areas communities are located where water resources are available. Most of the water resources are underground water, where the multi-bladed wind machine could be used at relatively lower wind speed. This type is capable of operating deep well-bores at higher torques, where water could be stored less expensive than other storage methods. Hence the problem of availability and demand could be ~~reo~~ reasonably treated.

II Local wind potential based on Global estimation :

The solar flux at the earth's surface amounts to 2 cal/min/cm^2. The total flux intercepted by the earth is 1.8×10^{17} W, or 350 W/m^2 when averaged over the entire earth's surface. 2 % of this value represent the energy dissipation losses which feed into the earth's atmosphere to maintain the wind (1). This estimation gives an average for the total rate of solar input to wind energy over the earth of 7 W/m^2. For the whole earth this amounts to 3.6×10^{15} W. 35 % of this value occures near the earth's surface, i.e. 1.3×10^{14} W. There are limitations to capture the total dissipation energy near the surface, such as off-share areas and hight limitations. A value of 10 % of the global wind energy may be exploited to give an amount based on global estimations of 1.3×10^{14} W. This is equivalent to 0.25 W/m^2 assuming the surface of the earth is 5×10^{14} m^2.

Egypt is considered 1,002,000 square kilometer. If we apply the above mensioned figures, the following table may be obtained

	Wind energy available [W]		
	per m^2	Global	EGYPT @
Solar input rate	350	1.8×10^{17}	3.5×10^{14}
dissipation rate (2% of above)	7.0	3.6×10^{15}	7.0×10^{12}
near surface wind (35% " ")	2.5	1.3×10^{15}	2.45×10^{12}
Extraction rate limit (10 % of above)	0.25	1.3×10^{14}	2.45×10^{11}

If this value compared to the existing 4000 MW power generating facilities already exists in Egypt, then it would amounts to more than 60 times.

other estimations of the global wind resource is found in (2), (3), (4)

III Practical extraction limitation :

Wind machines may be installed in groups to form some sort of a power station. This means that for large areas uniformly covered with wind machines, they must be spaced at certain distance from each other. As a rule of thumb, the machines should be spaced 8 - 12 times the hight in order not to affect each other[1]. (other suggestions are found in (4)). Accordingly, the total collector area will be about 10 % of the land area covered. According to Betz relationship, no more than 59 % of the available wind energy could be transfered to mechanical energy. In addition, friction losses and other losses could be estimated to be about 20 % at the rated power. Another loss of about 15 % must be taken into consideration, if the maximum usable wind speed is chosen as twice the mean speed at a specified site.

These losses are all multiplicative. This means that the total efficiency of a wind conversion system according to the mentioned figures may be estimated as :-

$$0.1 \times 0.85 \times 0.59 \times 0.8 = 0.04$$

based on the energy available per unit land area, i.e. 4 % of the total energy available per unit land area could be converted into mechanical energy.

IV. Water pumping:

There is a complex relationship between the wind characteristics and the water resource at a particular site. This means that water and wind should be available to a certain user at a certain site. This makes the problem somewhat difficult.

Such relationship must be identified and rationalized before beginning with the design process and decision making. The following chart analyse the sequence of information base, chart 1.

V site selection

The importance of selecting the proper site for wind energy conversion system cannot be overemphasized. The choise of a site based on incorrect decisions or insuffici wind characteristics data can be the single most important factor leading to the failure of a system.

Preliminary estimations of the proper site stems from careful evaluation of wind characteristics at potential sites from long-term measurements at nearby measuring stations and limited short-term observations at the potential site. Wind speed records obtained from airports could give a crude information. National meteorological services is the most reliable source to give an idea about wind characteristics and potential sites.

According to the intermittent nature of the wind and the variability in magnitude of its speed and direction, it might be stated that there is no optimal location for wind machines, but there are some locations better than others.

The above mentioned sources of data should be used, however, only to provide background information and to confirm measurements taken at the site considered, as there may be topographical differences producing different wind characteristics. Trees, buildings, hills and even windmachine itself affect the wind characteristics. the influence of topographical conditions on wind power can be classified in four broad areas:

a) variations of wind velocity over flat or uniform terrain.

b) flow of wind over slight to moderate roughness elements

c) flow over mountains and ridges and
d) local wind currents and circulations
For water pumping systems it is preferable to ~~choose~~ locate the wind machine in flat or uniform terrain where the water might be available. ~~and~~

VI Wind characteristics for selected sites:

The amount of power available in a freely in a freely flowing windstream of cross-sectional area, A, is ~~equal~~ given by the change of momentum of the air according to the relation:

$$P = \frac{\dot{m} V^2}{2}, \text{ where } \dot{m} = \rho A V$$

$$\text{or } P = \frac{1}{2} \rho A V^3 \text{ Watt}$$

the power per unit cross-sectional area of the windstream i.e. the wind power density, is given by the equation

$$\bar{P} = \frac{1}{2} \rho V^3$$

This means that the power density is proportional to the cube of the wind speed, and depends to some extend on the density of air. Figs. 1, 2 shows these relations. It is evident from these figures that an error of just $\frac{1}{2}$ m/s in the mean wind speed causes large error in wind power estimates, e.g. the average wind power for 6 m/s wind speed is about 30% greater than that for 5.5 m/s wind speed. The variation in air density with temperature and elevation ~~is~~ results in lower errors ~~than the~~ in wind power estimations than that ~~that~~ corresponds to wind speed variations. As the available power of the wind is proportional the area intercepted by the wind stream (square of the radius), the parts of large radius contribute much more in the power than those at

The wind at a given site usually varies in direction and speed frequently. The average velocity changes significantly with season and may show large daily or even hourly variations. Therefore statistical analysis of ~~the~~ such informations is required in order to estimate the available potential of wind energy at a given site.

Surface wind are recorded in Egypt since 1952. New stations are starting recording wind speeds 1966. The total number of stations is 24 covering most of the Mediterranean sea-shore, the red sea-shore and the river Nile valley. The chart number 2 shows the ~~loc~~ location of the meteorological stations and the isovents (lines of constant wind speed) based on yearly mean wind speed. The lines on the chart define two windy regions, the mediterranean and the redsea coastal areas. The mean annual wind speed in those two areas ranges from about 4.4 to 5.8 m/s and from about 4.4 to 6.4 m/s respectively. The distribution of the isovents over the average wind chart show a marked decrease inland, particulary over the western desert and upper Egypt.

One of the most useful representations of the collected wind data is the annual duration curves. The annual average velocity-duration curve represent the number of hours per year (absolute or percentage value) that the wind speed achieves achieves hourly mean value ~~at~~ for a certain site. The power or power density-duration curve shows the number of hours per year that the given site will provide a specified amount of energy to a wind machine. Such ~~a~~ curves indicate the operation or run time

of a wind machine. The total amount of energy per year available in the wind per unit swept area of the rotor is the area under the power density curve. Figs. 3 and 4 shows such duration curves for selected sites in Egypt.
The actual power density of ~~an area~~ a wind machine should be considerably less than the total available power density illustrated by the area under the curve shown in figure 4. Regardless of the efficiency of the machine itself, the actual power extracted from the wind machine does depend on the cut-in and cut-off wind speeds. The cut-in speed is the wind speed at which the wind power developed by the rotor is capable to overcome the friction losses of the moving parts of the system. The cut-off speed is chosen to avoid damage of the system due to the high stresses created from high wind speeds and thrust developed by the rotor. The rated ~~p~~ wind speed of a system is ~~also~~ to be chosen between the cut-in and cut-off wind speed in such a manner to maintain a desired output power for a certain period (duration time) of the year.
Another useful representation of wind power variations is the annual average energy density for various wind speeds at the given site. These curves could be used in determining the speeds at which the majority of the wind energy exists. Fig. 5 shows such relation in combination with the hourly distribution of the wind speed at a selected site on the mediterranean sea-shore. It is of the interest to note that most of the energy exists above the observed mean wind speed. Furthermore, the contribution to the total annual mean energy content of all velocities, is generally small for ~~all velocities~~ winds having

speeds in excess of approximately three times the average wind speed. These facts could be understood by comparing the power output of actual wind machines and the theoretical calculated output based on the average annual wind speeds at the site. The plot on fig. 6 shows such comparison estimated by Sandia laboratories. The main reason is such phenomena is the cubic relationship between the wind power and the wind speed.

The above mensioned relationships, based on the yearly wind characteristics are not sufficient for designing a wind pumping system. The daily and seasonal variation of the wind speed may be of great importance, specially when the wind system is used for irrigation purposes. In order to minimize the use of a back-up system or to optimize the storage capability, the period of higher energy content should be ~~coman~~ coinside with periods of higher water demand.

VII Estimation of power output:

The actual power extracted from the wind system depends mainly on the characteristics of the machine and the design features for a given wind conditions. The power delivered by the system decided by the total power available in the cross-sectional area of the wind stream subtended by the wind rotor is defined as the power coefficient C_p, where

$$C_p = \frac{\text{power output}}{\frac{1}{2} \rho A V^3}$$

where, ρ is the air density,
A cross-sectional area and
V is the wind speed.

Turbines with a small total blade area has relatively small pressure drop resulting in low power inspite of higher flow rate. In addition, turbines with higher total blade area produces a higher pressure drop across the blades and has less flow rate resulting again in low power. The optimum total blade design therefore is the one that maximizes the product of volumetric flow rate and pressure drop across the turbine.

The power coefficient, C_p, of an ideal wind machine rotor, as shown in fig. 7, varies with ratio of blade tip speed to free-flow wind stream speed, the value of C_p approaches the maximum of 0.593 when this ratio reaches a value of 5 or 6. This ratio is called the tip-speed ratio. It is shown on the figure the characteristics of typical performance of different rotor types. Experimental evidence indicate that the lower the number of blades, with good aero-dynamic design, the higher the running speed of the rotor at a given wind speed, i.e. where the tip-speed ratio, λ, is as high as 5 or 6. The power coefficient reaches about 0.47. In accordance, the multi-bladed rotors are always low speed ones and develops more torque which is more suitable for water pumping devices. To counterbalance the low power of a multi-bladed rotor with lower C_p at a given site, the diameter of the rotor could be increased, ideally if the transmission between the rotor and the pump is built such that to avoide the use of gearboxes.

VIII Rotor-pump combination: (the Turbine.)

The main Problem in designing windpumping system is the sever mis-match that is found between positive displacement, constant-torque pumps that must generally be used and the roto-dynamic characteristics of a wind-turbine Producing $T \propto V^2$, ($T = \frac{Power}{\omega}$, $\omega = \lambda V$ Power $\propto V^3$, $\therefore$ $T \propto \frac{V^3}{V}$ i.e. $T \propto V^2$) at certain tip speed ratio. The result is that the rotor can only match the pump drive requireme efficiently for a few moments when starting, the rotor will dissipate surplus power at higher windspeeds by over running the speed range where maximum shaft outputs and conversion efficiency may be expected.

If too large a pump is fitted, then the rotor will fail to start except except in high winds or gusts, which occures ~~f~~ infrequently. If a pump allowing easy starting in low winds is fitted, then even more of the potential output at higher winds is sacrificed.

This should be clear from fig. 8, For a pump with a substantially constant torque requirement, the wind rotor will operate along a horizontal constant line. Hence,

as the wind speed increases, the operating line diverge increasingly from the optimum tip-speed ratio line.

It could be realised that the use of a double-acting pump could offer some slight improvement in matching, in the sense that the starting torque requirement of single and double acting pumps of the same diameter at similar water pressure heads will be the same, but a double acting pump will be able to absorb more power and deliver twice as much water as a single acting one at a given rotational speed.

Pumps with cyclic torque demands, as the case of single and double acting pumps, will not start until a certain peak value of the torque developed by the rotor is reached, T_p. The corresponding wind speed at which ~~F~~ T_p is achieved is the cut-in speed, V_m of the machine. Once the machine started, it will absorb a rotor output equivalent to T_m at wind speed, V_m, lower than the cut-in speed. The greater the difference between T_p and T_m, the larger the deviation from the optimum maximum power condition. For single acting pumps $T_p = \pi T_m$ and for double acting pumps $T_p = \frac{1}{2}\pi T_m$, where T_m is the mean operating torque of the pump. Therefore, to match a ~~As a matter~~ pump optimally to the rotor, there will be excessive periods with insufficient wind for pumping to commence, and the storage ~~will be~~ requirement may become excessive. To improve such condition, double acting pumps could be used, ~~which~~ By using this type of pumps, the total efficiency of the system could reach values up to 28% at the maximum C_p

compared to a values of 16% for ~~of~~ the single acting pump. A pump of increasing torque requirement will offer further improvements in productivity as indicated from fig. 8. ~~Pro~~ Different solutions may be recommended to such an approach. The first one is to unload the wind rotor at low wind speeds, which would allow a lower starting torque and hence the operating line of the pump will be lifted upwards toward the higher rotational and wind speeds. This may be achieved by introducing a controlled leakage at the pump. The second solution is to consider a variable stroke pump, ~~[illegible]~~ ~~[illegible]~~ having similar characteristics to operate at different torque requirements.

X conclusion.

Wind energy could be successfully used in Egypt, specially in the rural areas on the north and east sea shores. The mean wind speed and the duration curves obtained from the meteorological data bases collected through long period of times are sufficient to define the most promising area where wind energy could be used either for electric or in water pumping. ~~Wato~~ The use of conventional US farm model may be used to develop water for small farms or life stock uses. Modifications of such model is essential to improve the performance ~~of~~ and hence increase the quantity of water developed.

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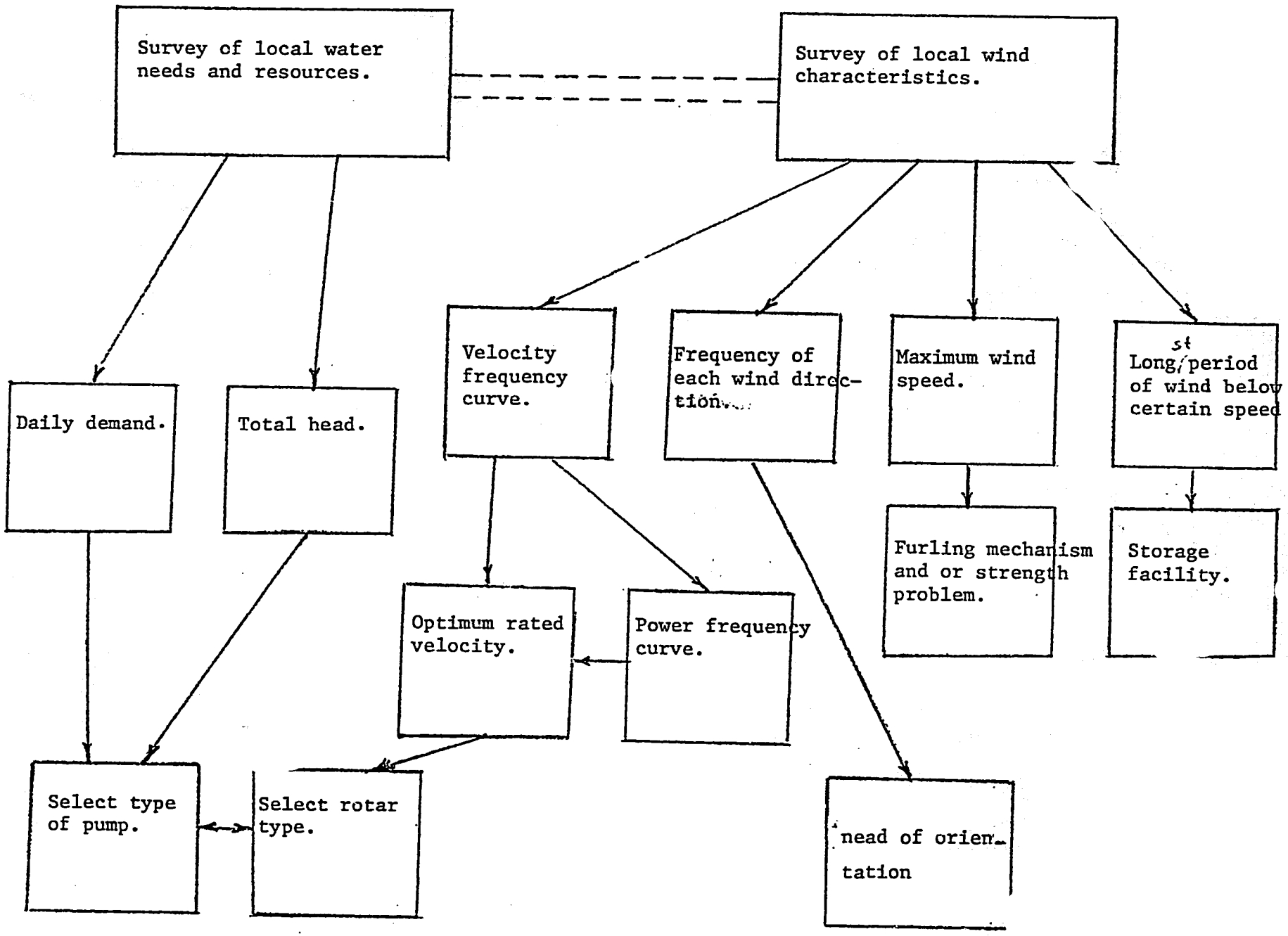

CHART 1: Sequance of information needed to develop a Wind Pumping System.

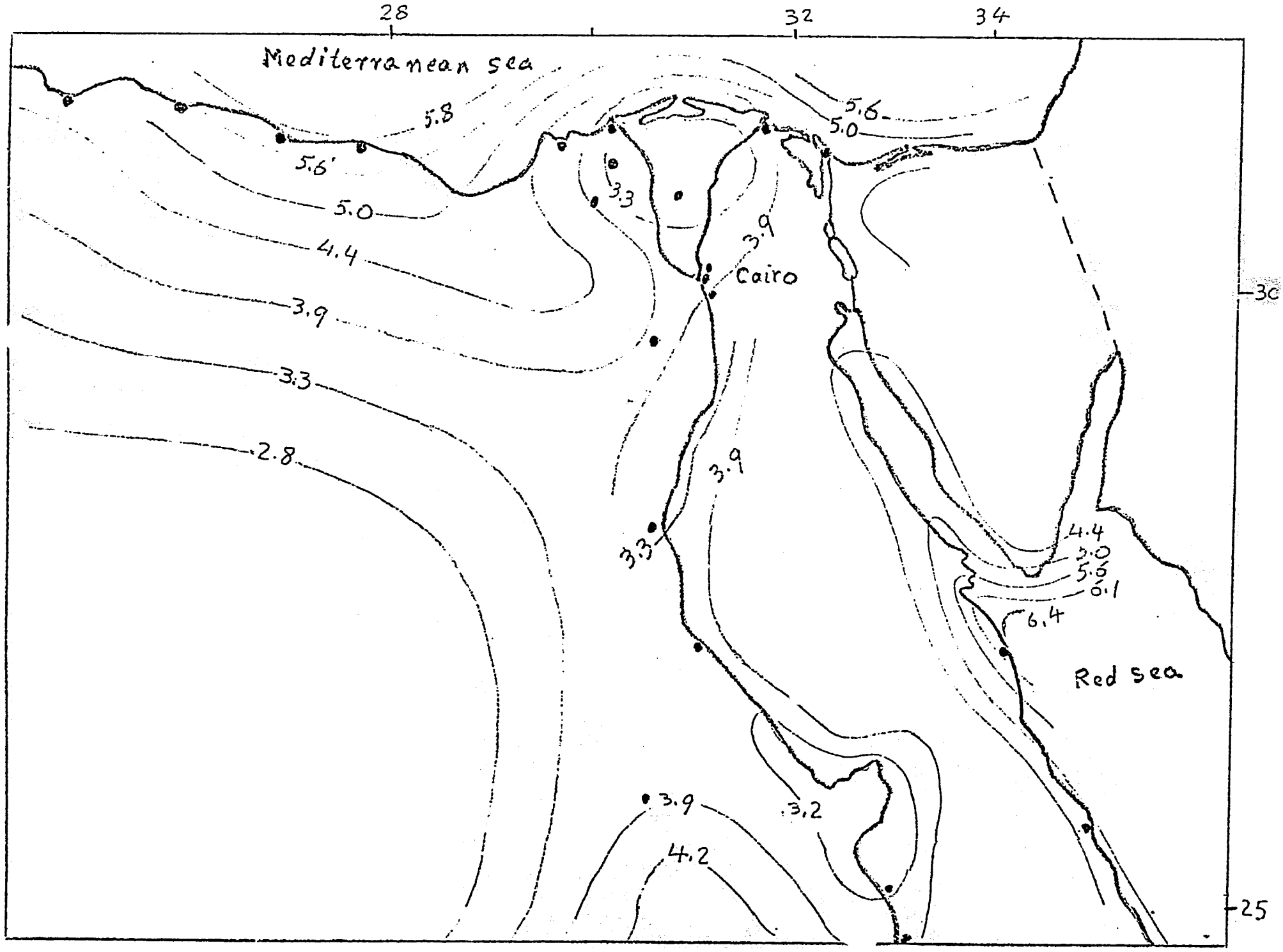

Chart 2: Lines of constant Windspeed in Egypt (m/s)

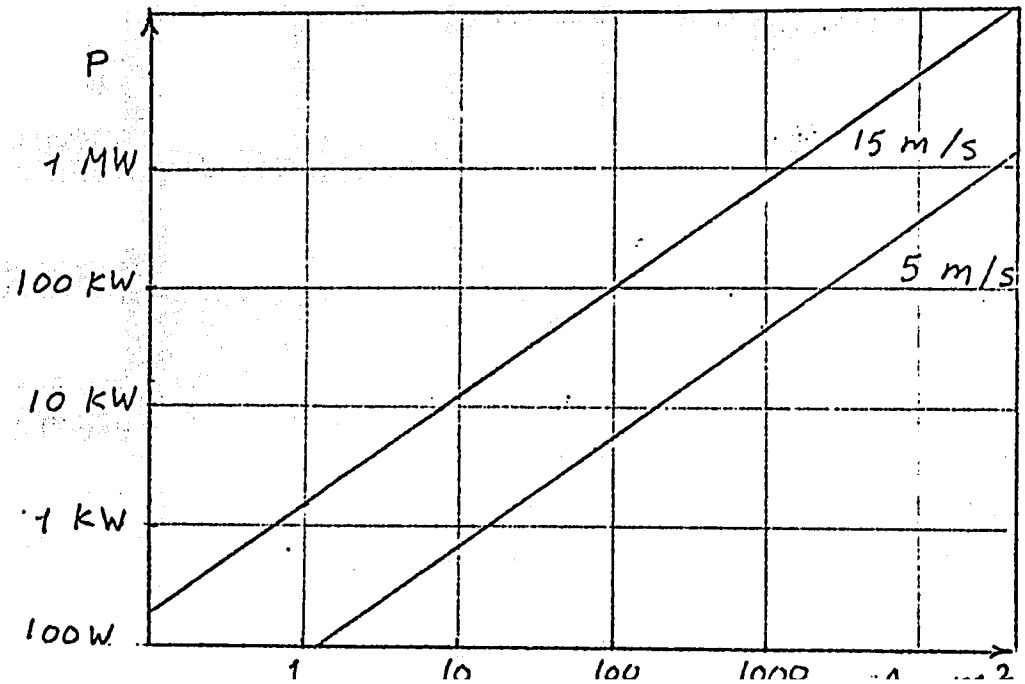

Fig. 1 : Change of windpower, P, with rotor area, A, at different windspeeds

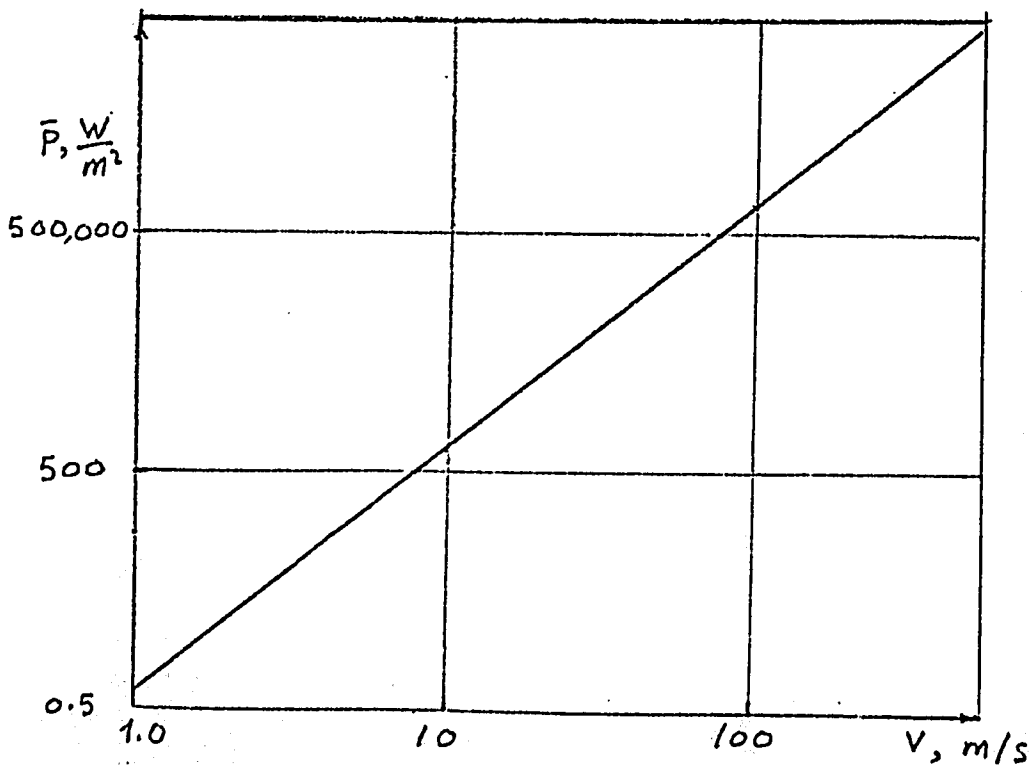

Fig. 2 : Change of windpower density with windspeed

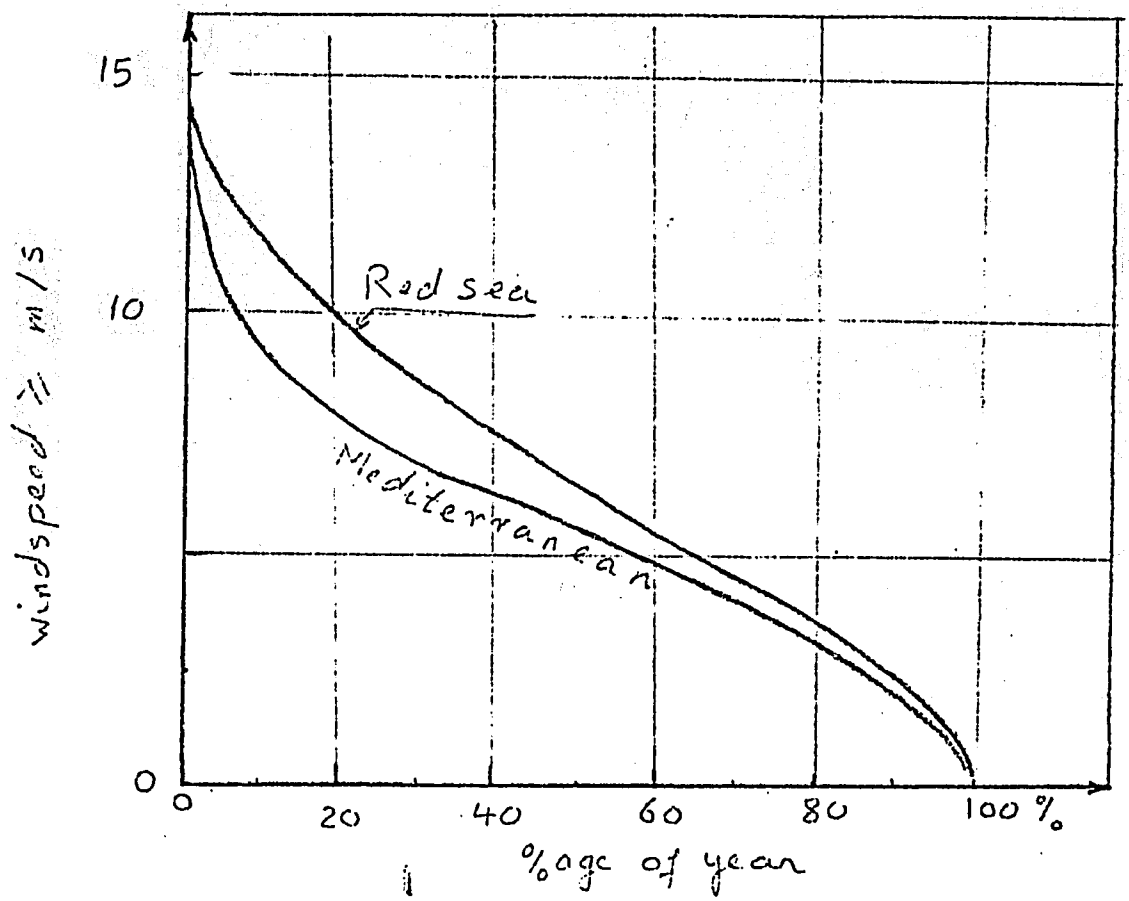

Fig. 3 : velocity duration curve

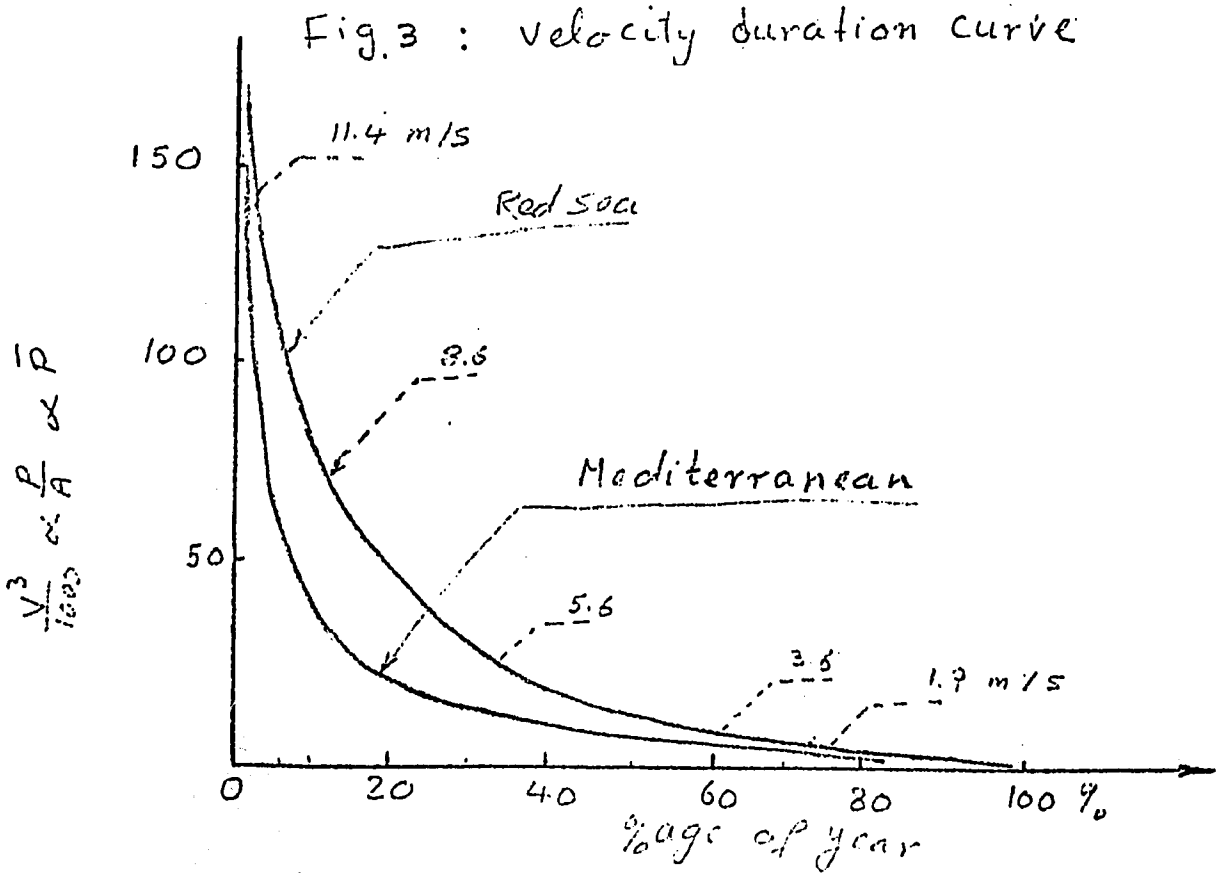

Fig. 4 Power density duration curve.

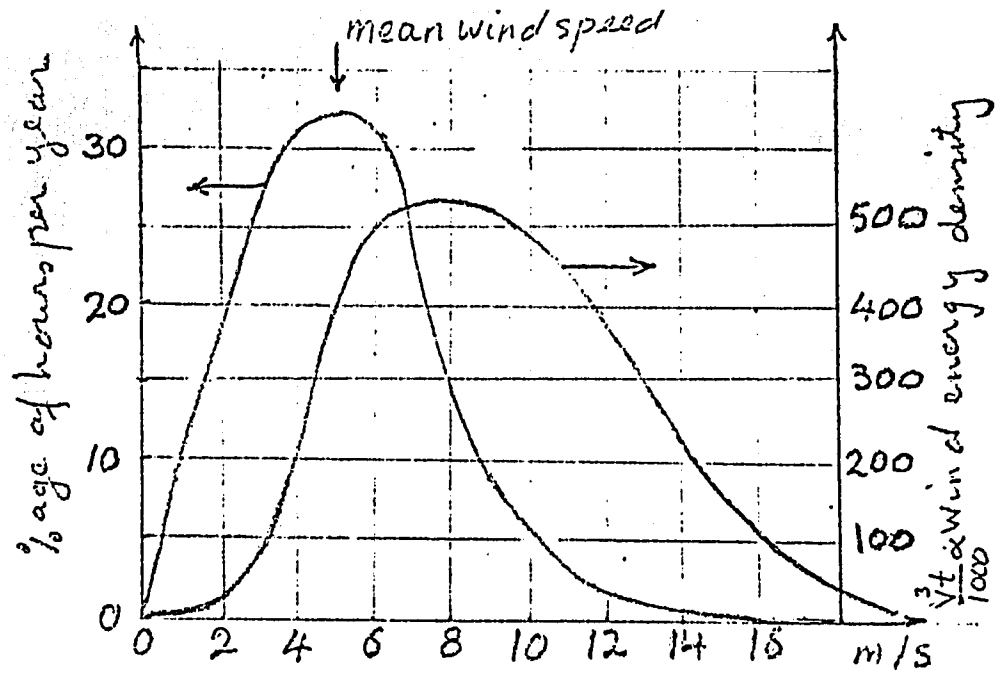

Fig.5: Distribution of hours per year and available energy density as a function of wind speed for a location on mediterranean sea.

V m/s	1.9	3.6	5.6	8.6	[illegible]	14.4	17.5
Annual duration t	1305	2532	2777	806	[illegible]	61	9
% hours per year	15	29	30	9	3	7	1
Energy $\propto t V^3/1000$	7.1	113	433	[illegible]	442	182	48

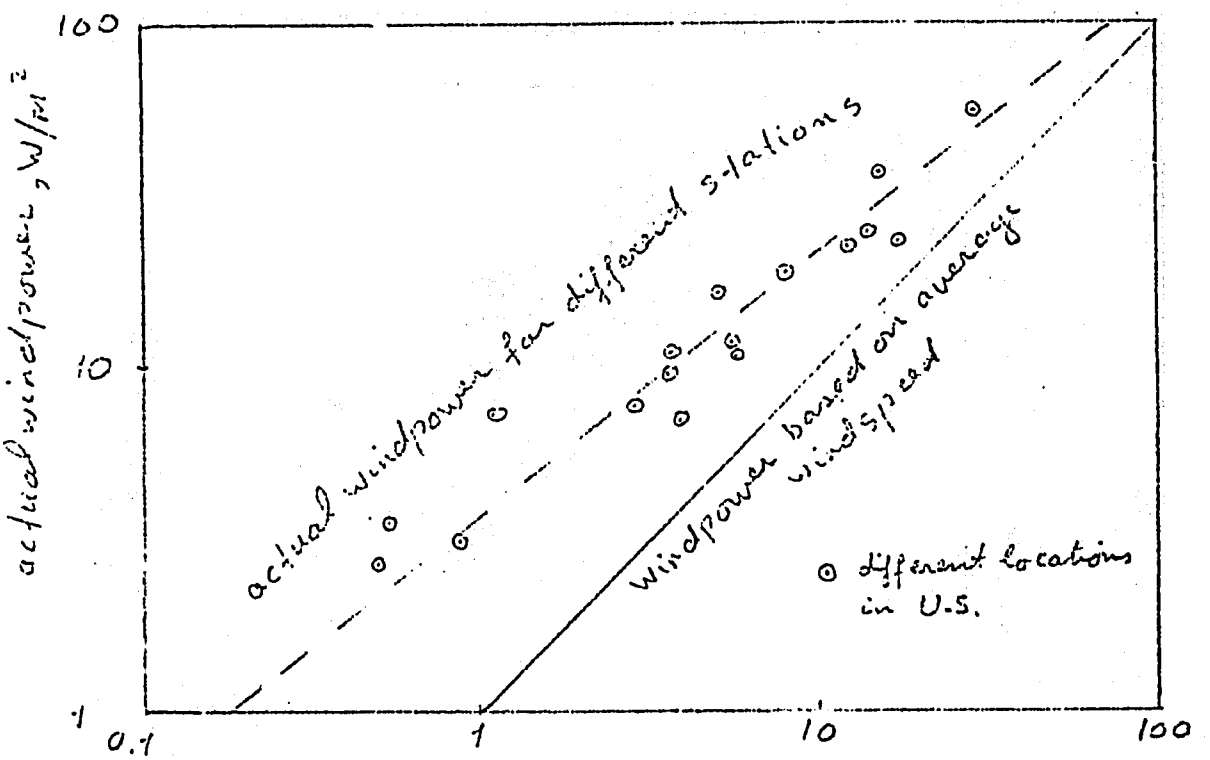

Fig. 6 : Comparison of actual and calculated wind power at different sites (estimated by sandia)

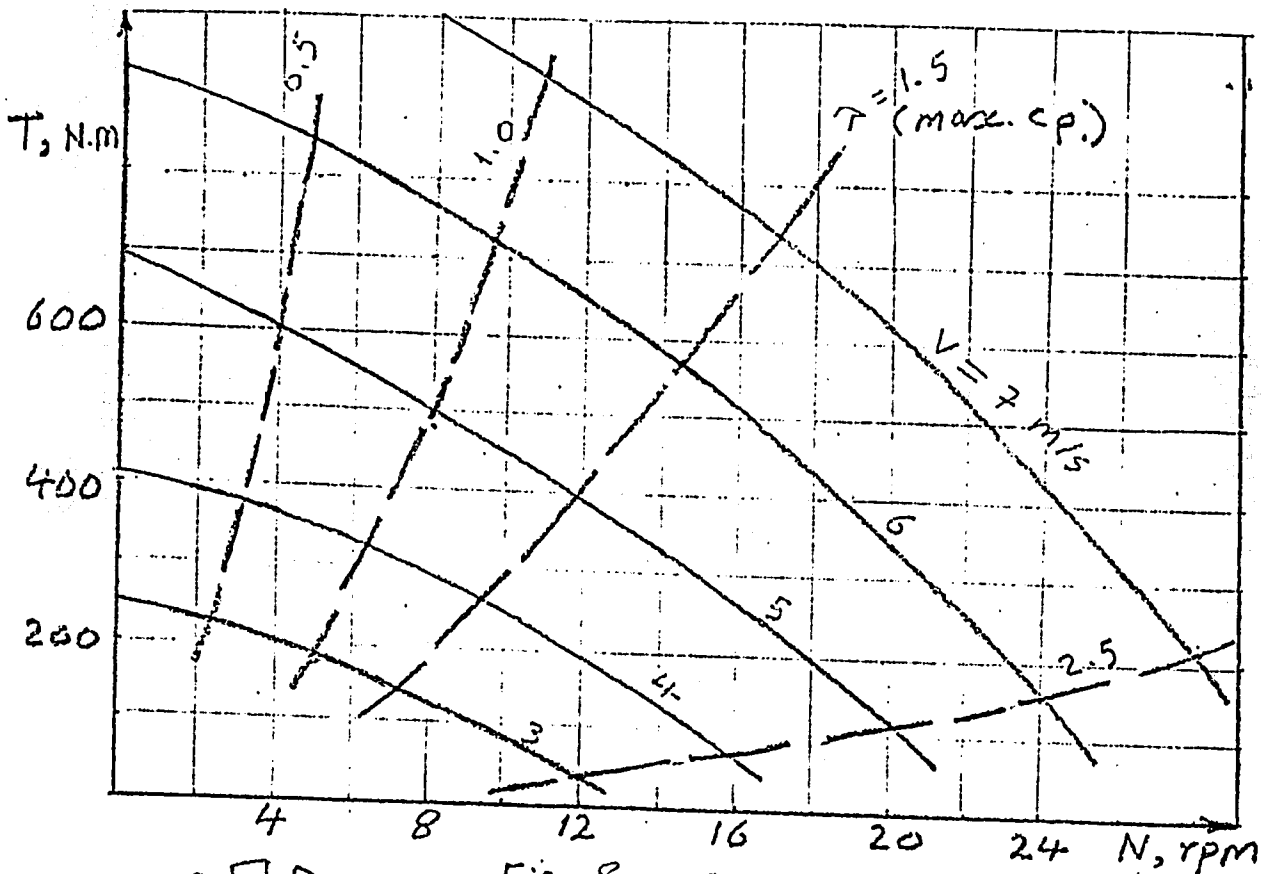

Fig. 8 Torque-speed relationship

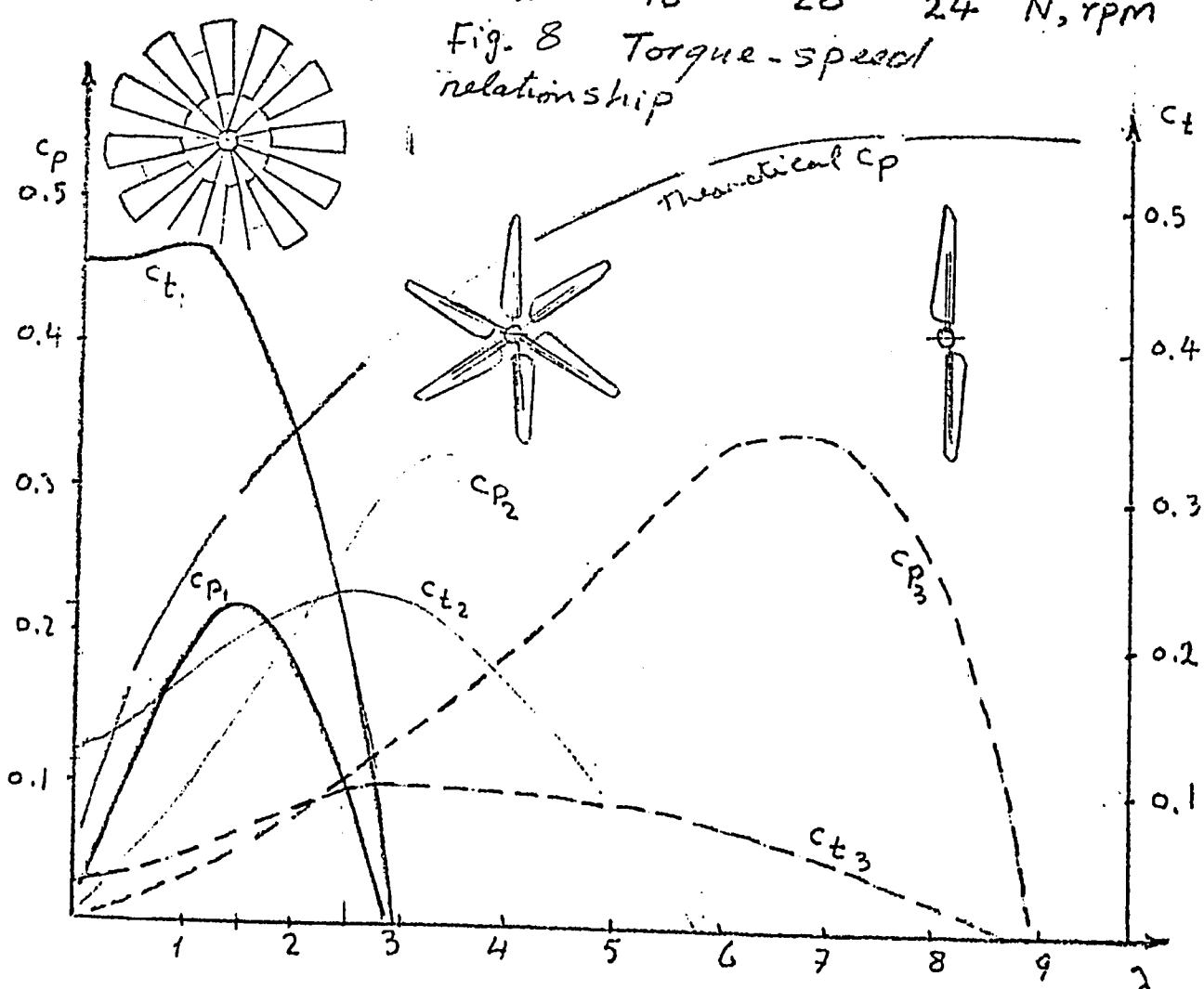

Fig. 7 Power coefficient & torque coeff. as a function of tip-speed ratio