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SEAS'S EXAMINATIONS OF WINDPOWER IN 1952: CHANGE OF A WIND POWER MILL FROM DIRECT CURRENT TO ALTERNATING CURRENT PRODUCTION.

J. Juul

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16. Abstract
A wind power mill built in 1942 by the firm of F. L. Smidth in Denmark is described. Various factors influencing the amount of electricity supplied by the mill are indicated. An experiment is described for changing the mill so that it could produce alternating current to be channeled into SEAS's high voltage cable. The principal wiring diagram for thr wind power mill is depicted.

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SEAS's examinations of windpower in 1952

CHANGE OF A WIND POWER MILL FROM DIRECT CURRENT TO ALTERNATING CURRENT PRODUCTION.

department engineer J. Juul

In the year 1942 the firm F. L. Smidth built a wind power mill on Bogoe. This mill produced direct current in series with the electricity plant on Bogoe, which was otherwise driven by diesel motors. /193*

The specifications of the mill were as follows:

Blade diameter	17.5 m
Generator 30 kW	rpm 700-1400
Gear Ratio	1:182
rpm of the mill	38-77
Blade tip velocity	35-70 m/s
Height of tower	20 m above ground level, which in turn is a hill 32 m above sea level

The blades had brake flaps on the backside of the outer part of the blades. The brake flaps began to function when the blades reached 77 rpm and when wind velocity reached approximately 10 mps. Partly due to this fact, partly due to a special shunt-winding on the generator connected to a magnetic generator, the output of the mill could be regulated to a certain extent to correspond to the load and voltage regulation of the electricity plant.

As a result the electricity production of the mill depended not only on the wind conditions but also on the load conditions of the electricity plants, which made it impossible to always use the potential production of the mill. Usually the mill did not function during night hours.

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*Numbers in the margin indicate pagination in the foreign text.

SEAS took over Bogoe E/V and its aeromotor in 1951. The motor was at that time without blades, which had been removed shortly before due to a breakdown.

As part of the experiment SEAS was conducting with the use of wind power, it was decided to change the mill on Bogoe so that it could produce alternating current to be channeled into SEAS's high voltage cable. In 1951 this cable had been laid to Bogoe to provide the direct current plant there with electricity by means of a rectifier in the plant.

The experiment which had been gained from SEAS's experimental mill at Vester-Egesborg was used in the construction of the new blades and in the overall modifications.

Experience from the experimental mill showed that it is appropriate to adjust any mill which is to produce alternating current by means of an asynchronous alternating current generator, so that it moves with a blade tip velocity of 38 mps. The gear available at the Bogoe mill had, as mentioned above, a ratio of 1:18.2. This made it necessary to have a blade diameter of 13 m and a swept area of 132 m^2 instead of as before, 17 m and 240 m^2.

Compared with the experimental mill, the Bogoe mill with 13 m blade diameter should yield a maximum of approximately 40 kW, which, with the blades turning at 56 rpm, proved to be the maximum load which the main axle and the gear of the mill could take, preserving the normal degree of security.

In contrast to the experimental mill in Vesler-Egesborg, which is built with 2 main blades and 2 smaller supporting blades, the Bogoe mill was provided with a set of 3 identical

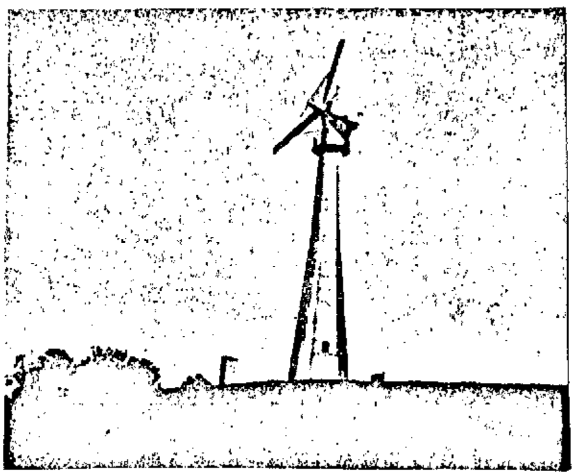

Fig. 1

blades. These were built with the same blade profile as the experimental mill and are connected to each other by staywires. Furthermore, the blades are provided with staywires in a frontal direction as shown on Fig. 1. In order to make the manufacture easier the blades are built with the same width in their whole length. The ends of the blades are provided with brake flaps, which,when the mill is working, are held by a spring that in turn is held taut by a capstan. The spring is kept taut by a brake magnet as shown in Fig. 2,which indicates the principle wiring diagram for the electric and mechanical equipment.

The functions of the mill are as follows:

1) When the main switch 21 is turned on, the capstan 7 starts working whereby the spring of the brake flaps is tightened and pulls the flaps 2 tight to the blades, while a guiding device holds the flaps parallel to the plane of the blade. At the same time the mechanical brake 4 is released.

2) If the wind velocity is more than 5 mps, the mill will start and gradually increase speed. When the generator is running at approximately 5% beyond the synchronic rate the centrifugal relay 11 will couple with the contact 10 and connect the generator with the network.

3) If the wind decreases to below approximately 4 mps, the generator will draw current from the network. As a result a return current relay 12 will disconnect the contact 10 and the generator's connection to the network, until the wind velocity increases enough for the centrigugal relay to connect the generator again.

4) When the main switch 21 is turned off, the brake magnet of the capstan will loose its purchase. The capstan is free, and the centrifugal power will, when the mill is working, pull the brake flaps approximately 15 cm from the blades. The guiding device will now turn the flaps approximately 45° from the plane

of the blades. As a result, the blades will slow down, and, simultaneously, the mechanical brake will function. Therefore, /194
the mill is brought to a stop.

Furthermore, the centrifugal regulator and the spring of the flaps there are safety disconnectors, which will disconnect the current when the mill rotates 10% faster than normal velocity. A vibration disconnector 15 will also stop the mill in case of unusual vibrations in the tower, caused, for example, by ice, etc.

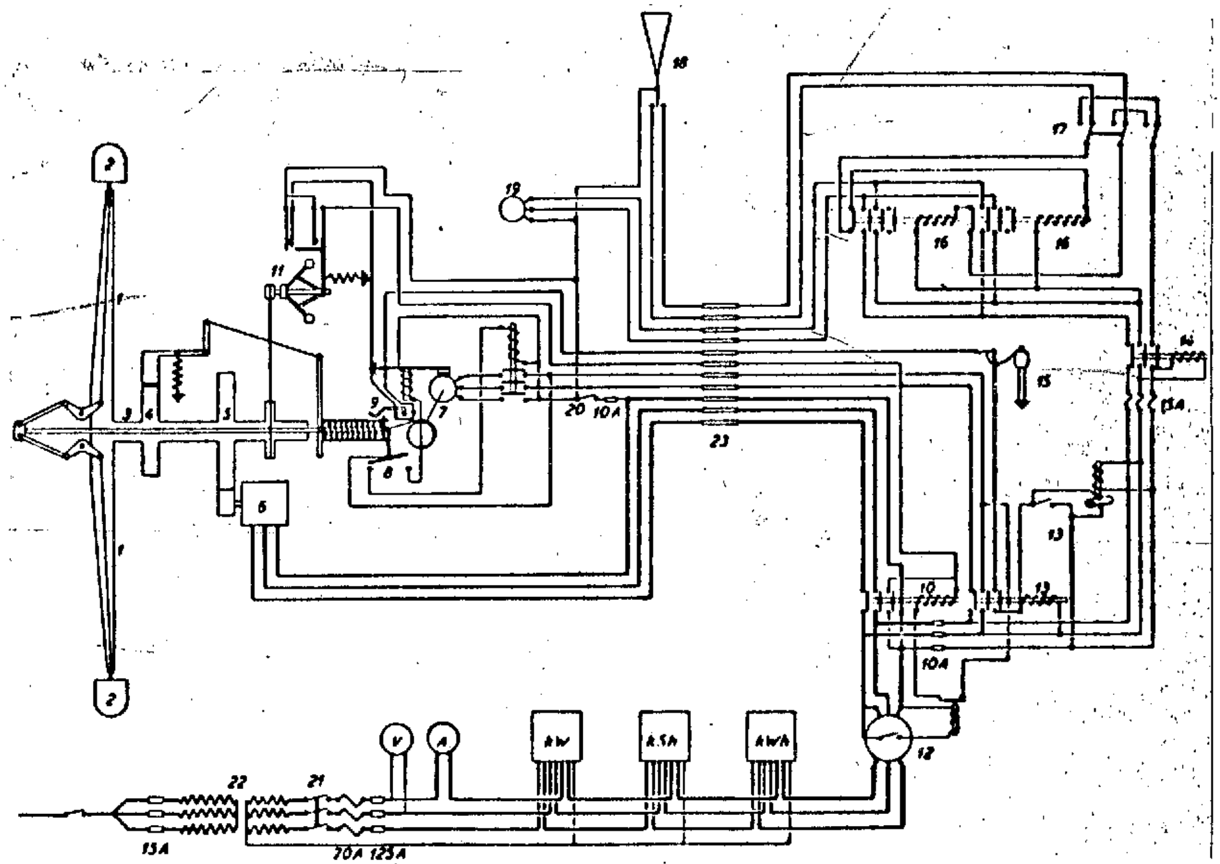

Fig.2. Principal wiring diagram for Bogoe wind power plant.

The modifications were completed so that the mill could begin regular operation on November 1, 1952.

In order to be able to control and measure the effect of the mill, an anemometer is mounted approximately 50 m to the southwest of the mill at the same height as the main axle. This anemometer, together with a registering anemometer, is placed at the control board in the tower of the mill.

By means of this anemomenter, the output and characteristic of the mill are determined, and are shown by curve 2 in Fig. 3. Curve 3 indicates the efficiency and curve 1, the theoretically computed windspeed of a wind-retardation of 60%. This computation is made for a plane area indentical to the swept area of the mill.

THE ELECTRICITY PRODUCTION OF THE BOGOE MILL AND THE EXPERIMENTAL MILL FROM NOVEMBER 1,1952 TO APRIL 1, 1953.

Month	a				b	
	Production kWh	Waste kWh	Total kWh	per m2 swept area kWh	Production kWh	per m2 swept area kWh
November 1952	3.633	480	4.113	31,2	851	19
December 1952	4.256	1.055	5.311	40,2	1.440	32
January 1953	6.300	1.911	8.211	62,2	1.860	41
February 1953	5.333	6.001	11.333	85,8	2.732	60,7
March 1953	6.578	2.463	9.033	68,4	2.415	53
	26.092	11.910	38.001	287,8	9.295	205,7

The experimental mill has produced 206 kWh per m^2 swept area. The Bogoe mill has produced 288 kWh per m^2 swept area or 40% more energy. a) Bogoe mill, 13 m diameter, 132 m^2 swept area. b) Experimental mill, 7.66 m diameter, 45 m^2 swept area.

In Fig. 4 the effect of the Bogoe mill per m^2 swept area, is shown by curve 2, while the effect of the experimental mill is shown by curve 1.

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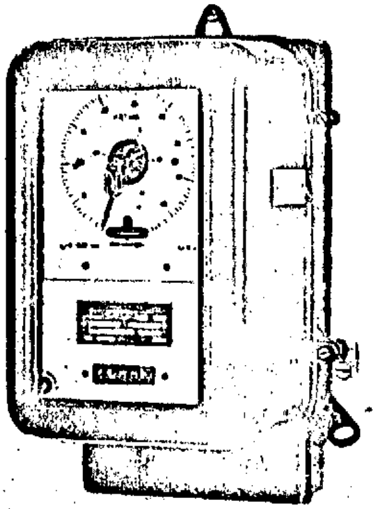

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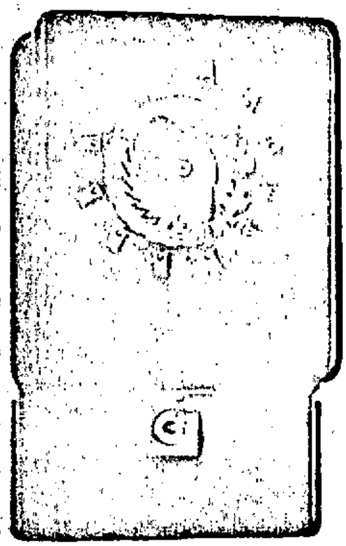

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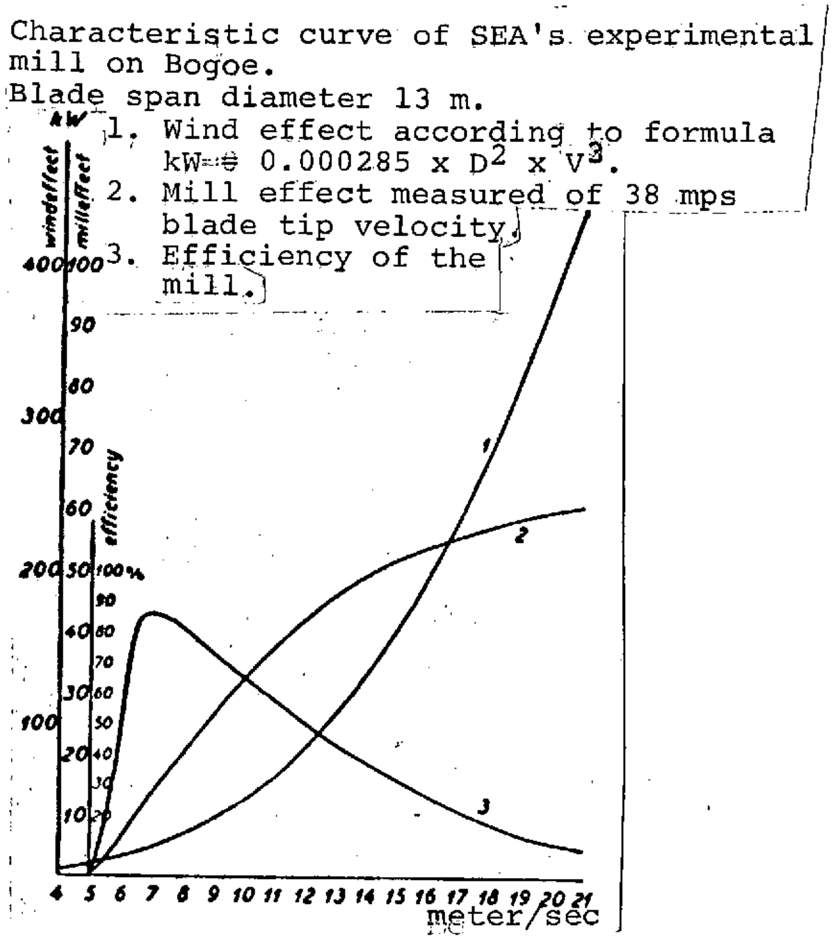
We see that the Bogoe mill gives sigificantly greater output than the experimental mill at wind velocities above 7 mps, and at 20 mps the output is about 37% greater than the output of the experimental mill. /195

At a 7 mps wind the mills are most efficient. At a blade tip velocity of 38 mps the 2-bladed mill can give the same relative effect as a corresponding 3-bladed mill. At wind velocities above this the latter has greater effect, because the blade tip velocity relative to the wind velocity decreases. As a result the wind has more time to influence the blades, and the effect per blade approximates the same magnitude as for the 2-bladed mill. Due to this, the output of the Bogoe mill is so great already at a 13-14 mps wind that the maximum load which the main axle and gear can carry is reached.

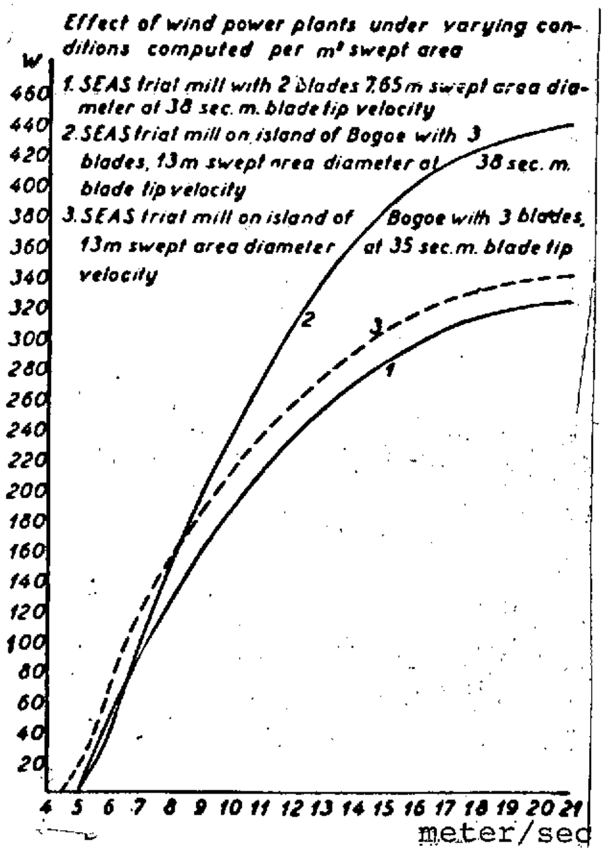
Since we did not wish to run any risk of breakdown of these parts, the main switch, which has thermostatic release switches, was adjusted to damp and switch off at a load of 45 kW.

In the construction of new wind power plants we will of course attempt to construct these so that they, like the experimental mill, can work at almost any wind velocity. To achieve this with the Bogoe mill, it will be provided with an extra transmission between gear and generator, whichwill reduce the blade velocity by 10%. The output of the mill will then be, according to computations, approximately as shown by curve 3 in Fig. 4. The output will be greater than it is now at wind velocities less than 8 mps and smaller than it is now at faster winds. Hence, according to the computations, the total energy will not be significantly less at a changed blade tip velocity of 34 mps, compared with the present blade tip velocity of 38 mps.



Characteristic curve of SEA's experimental mill on Bogoe.
Blade span diameter 13 m.
1. Wind effect according to formula kW = 0.000285 x D2 x V3.
2. Mill effect measured of 38 mps blade tip velocity.
3. Efficiency of the mill.
kW
windeffect
milleffect
efficiency
400
300
200
100
100
90
80
70
60
50
40
30
20
10
100%
90
80
70
60
50
40
30
20
4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
meter/sec

Fig. 3.



Effect of wind power plants under varying conditions computed per m² swept area
W
1. SEAS trial mill with 2 blades 7.65 m swept area diameter at 38 sec. m. blade tip velocity
2. SEAS trial mill on island of Bogoe with 3 blades, 13 m swept area diameter at 38 sec. m. blade tip velocity
3. SEAS trial mill on island of Bogoe with 3 blades, 13 m swept area diameter at 35 sec. m. blade tip velocity
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
meter/sec

Fig. 4.

In the following computations the energy which is lost because the main switch has stopped the mill at wind velocities above 13-14 mps, is estimated according to the indications of the anemometer and is added to the actual production.

This is done in order to be able to compare the production of the Bogoe and to that of the experimental mill. The latter has been working continuously for the whole period.

This computations is also used to see what a wind power plant, able to work at any wind, can produce given the conditions at Bogoe.

In Table 1, the production of the mills during the period November 1,1952 to April 1, 1953 is shown together with the estimated lost production of the Bogoe mill. In order to make a direct comparison, the production is computed per m^2 swept area.

A table exists which shows the production of the Bogoe mill in the years 1943-44-45. Fig. 5 shows the production per m^2 swept area per month, averaged over the 3 years mentioned, compared with what the Bogoe mill has produced and what it could have produced of alternating current, had it been provided with a main axle of sufficient dimensions. /196

It is seen that a wind power plant which is arranged for production of alternating current, and which can deliver its entire production to an alternating current network, is able to produce several times as much energy as a similar plant producing direct current in connection with a small direct current electricity plant.

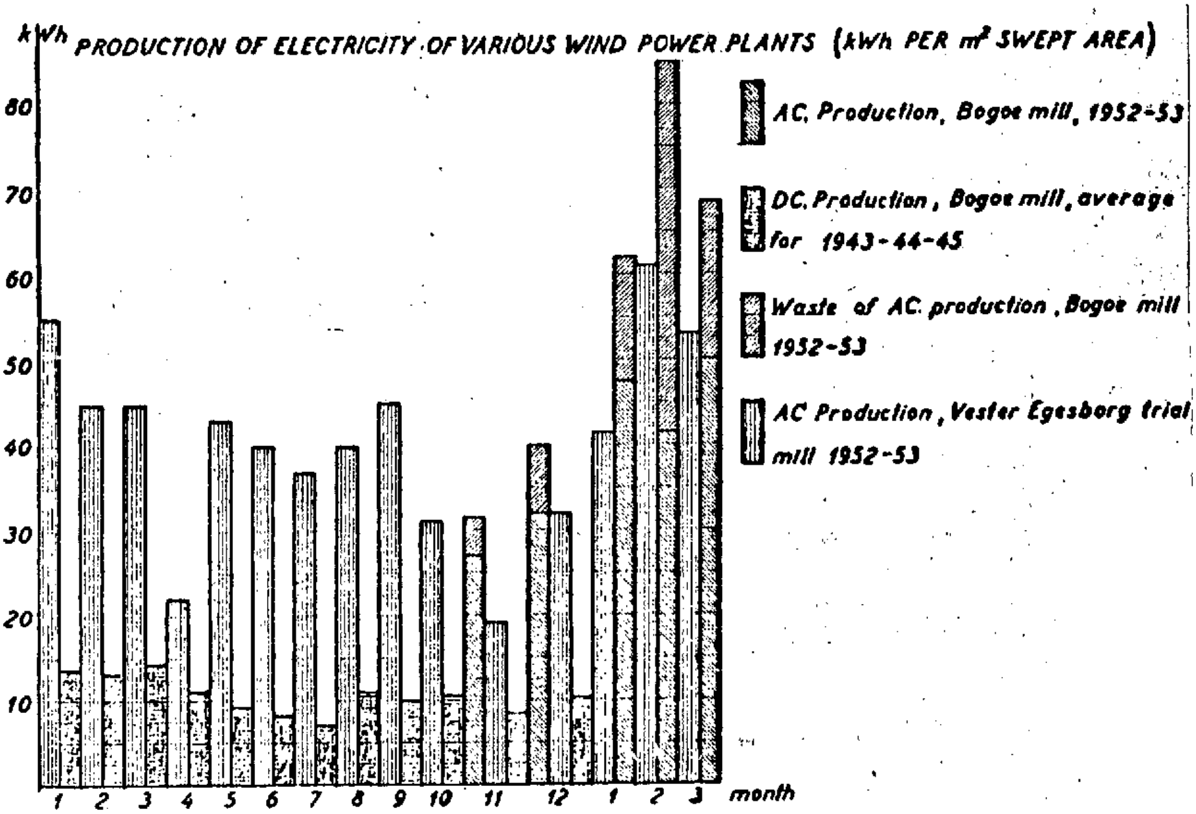


Fig. 5.

Furthermore, we see that the Bogoe mill is relatively able to produce considerably more energy than the experimental mill. This is due partly to the third blade, and partly to the fact that the axle height of the Bogoe mill is 20 m + 32 m, totaling 52 m above the neighboring sea level, while the experimental mill has only an axle height of 13 m + 20 m, totaling 33 m above sea level.

Wind velocity as a function of height over earth measured at a 55 m. hight mast near Masnedsund.

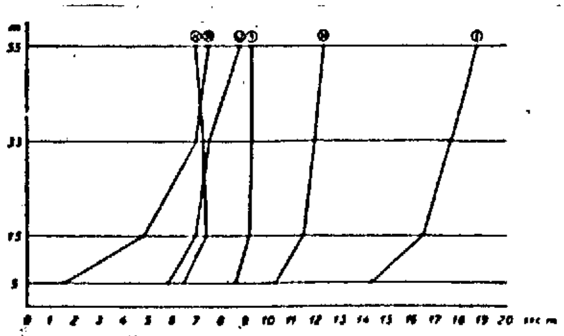


Fig. 6.

It has turned out that the yearly production of the experimental mill is approximatley 500 kWh per m^2 swept area. The Bogoe mill gives approximately 40% greater production or about 700 kWH per m^2 swept area, and the yearly production will be approximately 90,000 kWh, when the waste can be avoided.

The above mentioned comparison of production of alternating current by the Bogoe mill cannot be used to compare the construction of the mill itself before and after the reconstruction, because the blades before the reconstruction were specially constructed and adjusted to produce maximum electricity at weak winds, while the blades after the reconstruction have been made for maximum production with respect to all wind conditions.

As a result, comparision of the different amounts of production only illustrates the possibility for using the wind power in connection with a large alternating current network able to obtain the entire possible production, as opposed to a small d.c. plant unable to do this, with which it is more important to use the wind during the year because of the smaller maximum effect. The last mentioned plant is of an old design and has been exhaustively experimented with in Denmark, while the new one is in the adjustment to wind power produced electricity.

When a comparison nevertheless has been found valuable, it is because of the fact that the statistics of d.c. production by wind power have been used to claim that the use of wind power for a.c. production is not profitable.

Measurement of wind velocity at different heights.

As is well known, wind velocity increases relative to earth /194

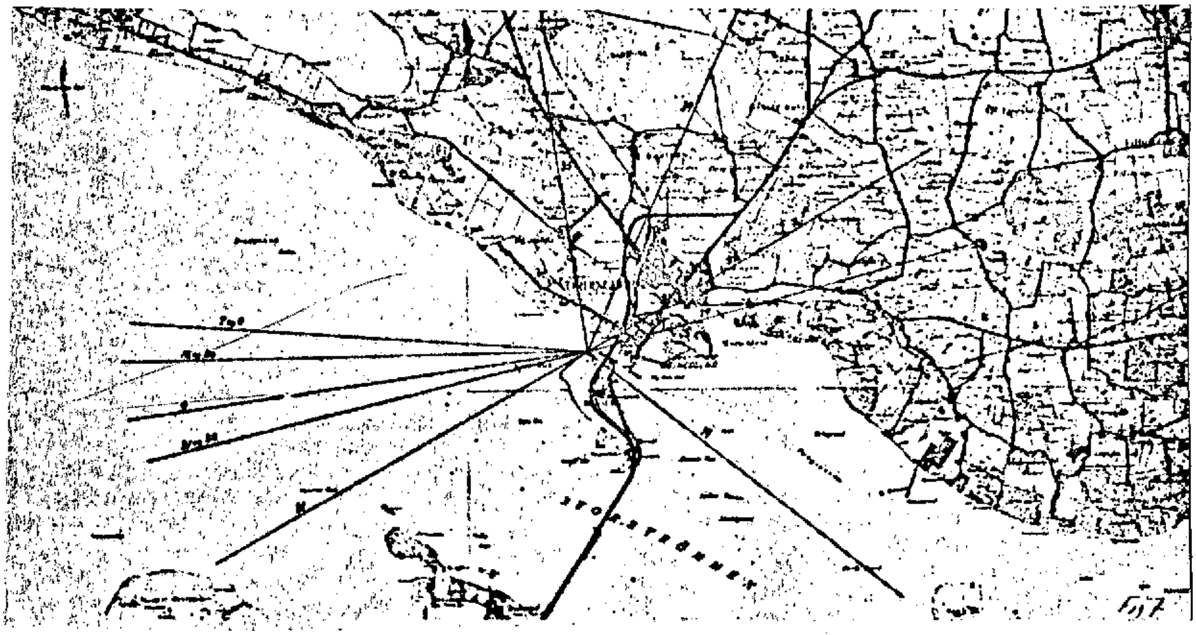


Fig. 7 (Translator's note: Denmark, South- west of Sjaelland.)

or sea level, because the wind is retarded by the friction between the air and the stationary parts.

If the surface is undulated or covered with trees or buildings, the resistance against the wind will of course be greater than if the terrain is smooth. On land the conditions will therefore depend on the locality, while over the sea, wind velocities will be more constant with respect to the height over sea level.

When constructing wind power plants it is of great importance to take these circumstances into consideration.

In the summer of 1952 simultaneous measurements of wind velocity were taken from a 55 m tall steel mast which leads 50 kV wires across Masnedsund. The measurements were taken at 5/15/35 and 55 m heights at different wind velocities and wind directions. The anemometers were hung from an extension away from the mast so that they could work without influence from it when the wind came from the southwest to the northeast. It was therefore possible to measure the velocity of the wind directly from the sea and from Sjaelland.

The anemometers were read simulteneously 25 times with a time interval of 30 seconds, after which the average for each was computed.

There are available such averages from approximately 50 different readings.

The curves in Fig. 6 show some of the most typical results. The numbers at each line indicate the number of the measurement, and on the map in Fig. 7, the corresponding wind directions are indicated with the same number.

We see that the wind velocity is almost the same at 15, 35 and 55 m height, where it comes directly from the sea, and when the wind is not stronger than 10-12 mps. This is shown by curves nos.9 and 30. In strong winds of 15-18 mps, however, there is a significant difference. In a single case shown by curve 15 a weaker wind at 55 m than at 15 m is shown.

In contrast to this, the wind coming from land has significantly increasing velocity as a function of the height above earth level. This is deomonstrated by the curves 32-42.

Since the wind effect grows proportionally to curve of the wind velocity, the efficiency of land wind increases greatly with the height.

The results of the measurements show that on the coasts, good wind conditions may be achieved at low height. Since the western wind is dominating in Denmark, the western coasts will give the best conditions for wind power plants.

The best conditions for these are obtained on isthmuses or flat islands.

Locations like this may be found in SEAS's area of supply on the south of Falster, Knudshoued, Enoe, Dybsoe, and Svinoe. Here the wind from the northwest, west, southwest, and south will be sea wind, and since the land near the coasts is flat, eastern wind will also be able to work relatively well.

Wind from the north is rare and usually weak. During the period the measurements were taken, i.e., from the beginning of June to December, there were only a couple of times that wind directly from the north was stronger than 5 mps. Over land there is of course wind of the same strength as at the coasts, but you must go to a height of 50-100 m to find the same velocity as exists at 15-20 m on the coasts.

On elevated points inland we may find wind conditions similar to those at the coasts, but more unstable in strength.