DESIGN OF WIND POWER PLANTS IN DENMARK

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Sydøstsjællands Elektricitets Aktieselskab (SEAS) in 1947 inaugurated a series of investigations on the feasibility of utilizing wind power for the production of electricity to be fed into existing AC grids. These investigations were made in recognition of the fact that extensive networks, built for the distribution of electric energy from one or several main power stations, may also be used for the collection of energy from many smaller wind power plants. Since its foundation in 1914, SEAS had noticed also that fuel shortage may occur. Fuel is found in scant quantities in Denmark, and during the two world wars and other political difficulties it was very expensive and difficult to obtain.

In order to determine the amount of wind energy and the seasons of its occurrence, automatically recording anemometers were mounted in various places in Denmark. Figure 1 shows a map of Western Europe on which are marked — in the case of Denmark — the measurements taken by SEAS and the (Danish) Meteorological Institute. In Germany, the measurements are by Meteorologisches Amt für Nordwest-Deutschland, in Great Britain by the Electrical Research Association and in France by Électricité de France.

The figures quoted represent annual mean wind velocity in m/s and, as far as Denmark and France are concerned, also the annual wind energy expressed in kWh per m² in the vertical plane.

In a corner at the foot of the map is shown a large scale section of North Jutland on which is drawn to scale the expanse of swept area necessary for the production of the 4 000 million kWh corresponding to the annual consumption of electricity in Denmark. Subsequently, a provisional wind tunnel was built, in which wind mills with 2 m² swept areas could be tested at wind velocities of up to 6 m/s. About 30 different blade designs and blade profiles were tested. On the basis of these experiments a pilot mill with a swept area of 7.5 m diameter was built in 1950 near Vester Egesborg on the island of Zealand.

By means of this pilot mill, measurements of effect at various blade tip velocities and wind velocities were taken. The thrust, also, was measured and various devices for making the mill fully automatic were tested. These investigations were mainly finished during 1950, after which the mill was put into continual operation until the summer of 1960. It was then dismantled, its task as experimental mill being considered at an end and its small size making its continued operation unprofitable.

On the basis of the experiments with the Vester Egesborg mill, a DC wind power plant on the island of Bogø, built by the firm of F. L. Smidth & Co., was reconstructed for AC production. It was originally erected in 1942 because during the war it was difficult to obtain fuel oil for the Diesel engines which produced DC for the local power plant. This plant was taken over by SEAS later on and reconstructed for AC production.

The existing mill tower with its machine cabin and gear box was still serviceable and was provided with 3 blades having a swept area diameter of 13.5 m, corresponding to a swept area of 132 m², as well with a 45 kW AC generator. Electric automatics were also installed in accordance with asystem worked out by experiments and tested at the Vester Egesborg mill. The same applies to the blade construction.

The Bogø mill was put into operation in 1952 and has virtually been in continual operation ever since, without any apparent defects. During one period of 9 months, it was actually in continual operation without anything being done to its mechanical or electrical parts. When after that period it was at last stopped, it was only for the purpose of lubrication and routine inspection.

The results obtained with the two experimental mills were so promising that the Association of Danish Electricity Works (Danske Elværkers Forening = DEF), on a proposal from SEAS, appointed a wind power committee to carry on the work on wind power problems.

On application from the committee, the Danish Government granted the DEF an amount of 300 000 Danish crowns (about £15 000) for the erection of a larger sized experimental mill near Gedser with a swept area of 24 m diameter. Later on, a further amount of 225 000 crowns was granted for investigations and measurements of wind velocities at heights above ground of 25 and 45 m in various places in Denmark. Details of the costs of the Gedser Mill are as follows:

	Crowns
Tower (incl. examination of ground of the site)	76 000.00
Machine cabin (incl. mounting)	75 000.00
Blades and rotor hub	44 000.00
Chain drive, brake, hydraulic brake lever	20 000.00
Generator, transformer, distribution switch board etc.	57 000.00
	272 000.00
Projecting blades, transformer and tower	48 000.00
TOTAL COST	320 000.00
Special measuring instruments, measurements and scientific investigations	55 000.00
($ 56.000)	375 000.00

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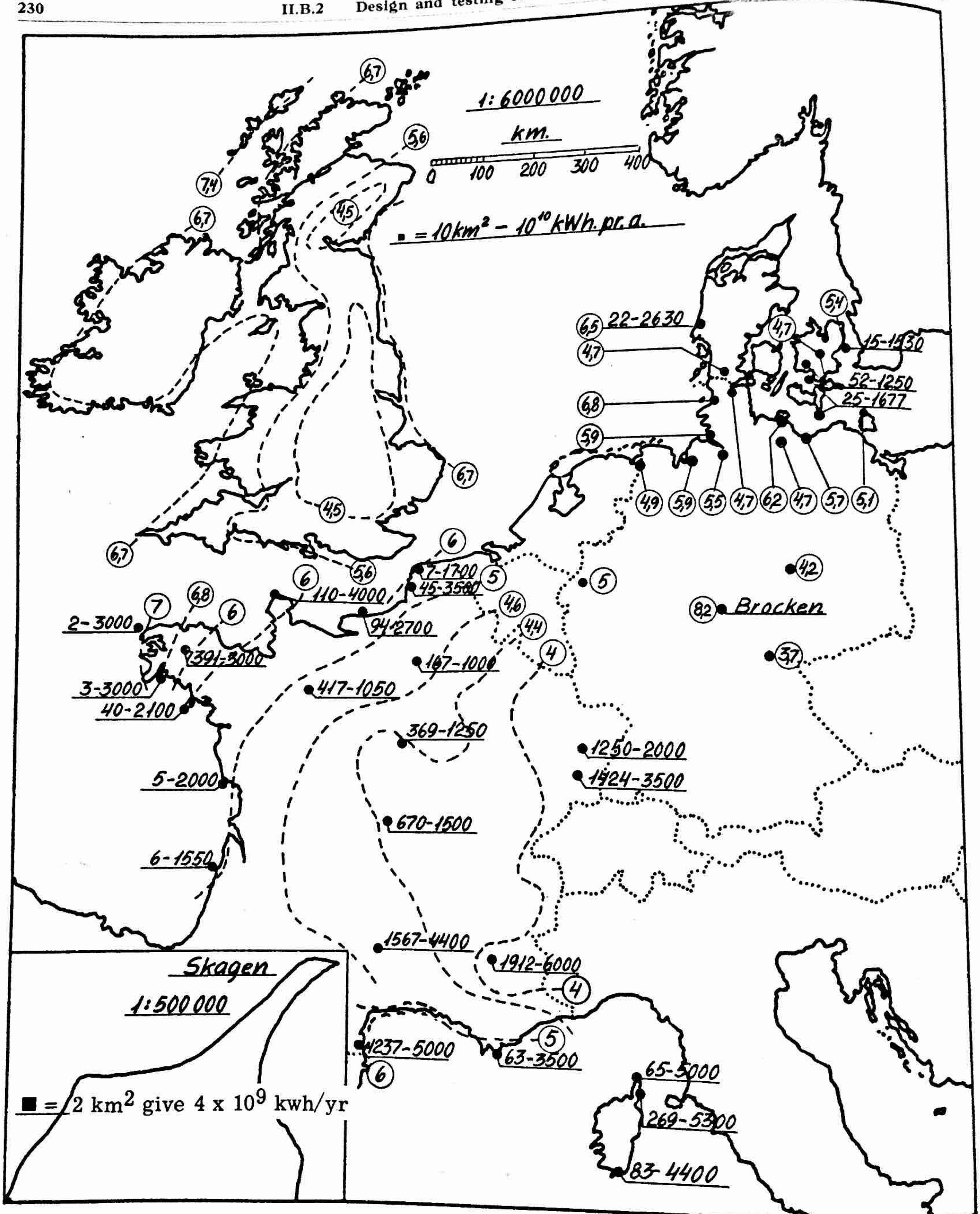

Figure 1. Map of western Europe with wind speeds and wind energies

The figures in the circles indicate the mean annual wind speeds. In the double figures, the first indicates the height of measurement, the second the energy in kWh/m², measured in the vertical plane. About 60 per cent of this energy can be fed to the electric network. The top of the map shows the scale together with the swept area required to produce 100 000 million kWh. At the bottom of the map, a part of Jutland is shown, with the swept area required to supply the present electricity consumption of Denmark drawn to scale on it

The blades, the electrical equipment and transformer station as well as the connection to the grid were all made by SEAS. The machine cabin was made and the mounting done by Aarhus Maskinfabrik and the prestressed concrete tower was built by the firm of Nielson & Co., contractors of Copenhagen.

All the work involved was performed with craftsmanlike methods and without special tools, excepting the tower for which special forms had to be made. Hence the building of the tower was fairly expensive, i.e., 75 000 crowns. When building similar plants and producing the component parts in series, the building costs can be reduced.

The specifications of the Gedser Mill are the following:

Swept area diameter: 24 m.
Swept area: 450 m^2.
Number of blades: 3.
Blade tip velocity: 38 m/s.
Rpm of blades: 30.
Height of tower: 25 m.
Generator: 200 kW, asynchronous, 8-polar, 750 rpm.
Generator slip: from 0 to full load 1 per cent.
Wind velocity for (automatic) start: 5 m/s.
Capacity: 200 kW at 15 m/s wind velocity and 5°C air temperature.
Transmission from rotor shaft to generator: double chain drive, ratio 1/25.

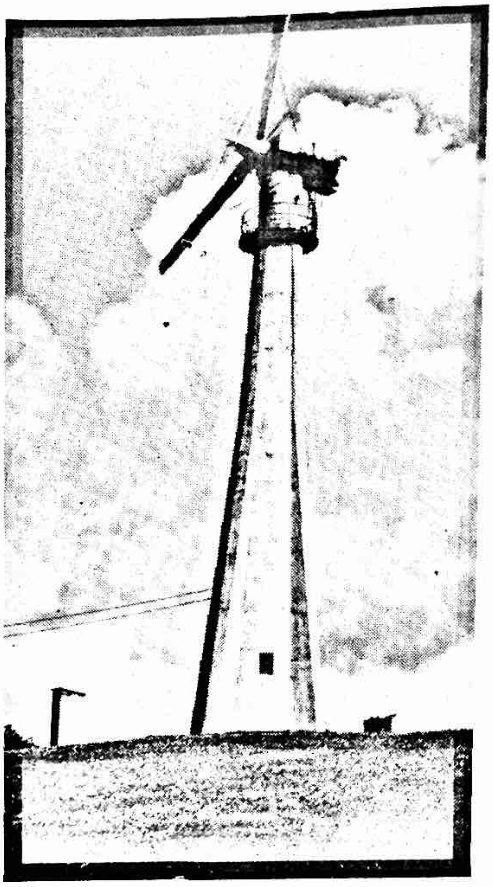

Figure 3. Bogø mill
Swept area 132 m^2. Diameter 13 m. 45 kW at 38 m/s wind speed

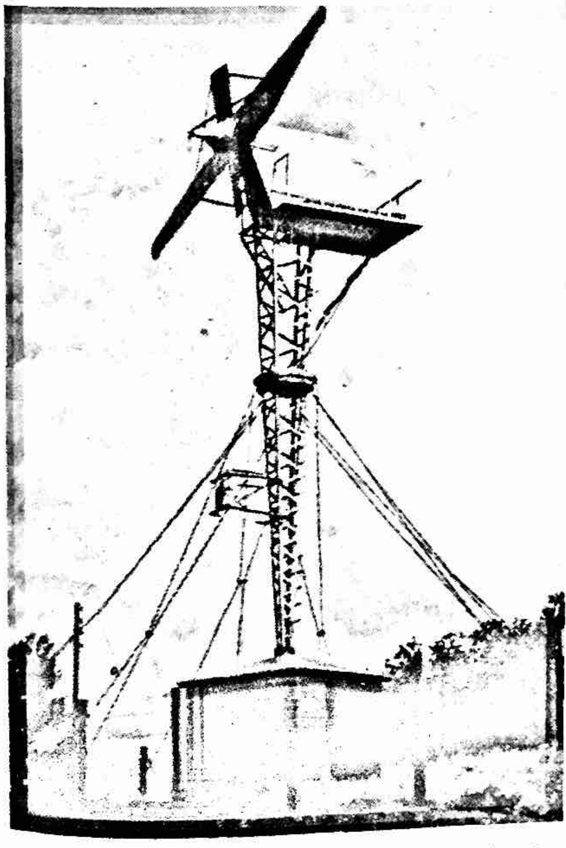

Figure 2. Pilot mill near Vester Egesborg
Swept area 45 m^2. Diameter 7.6 m. 13 kW at 38 m/s wind speed

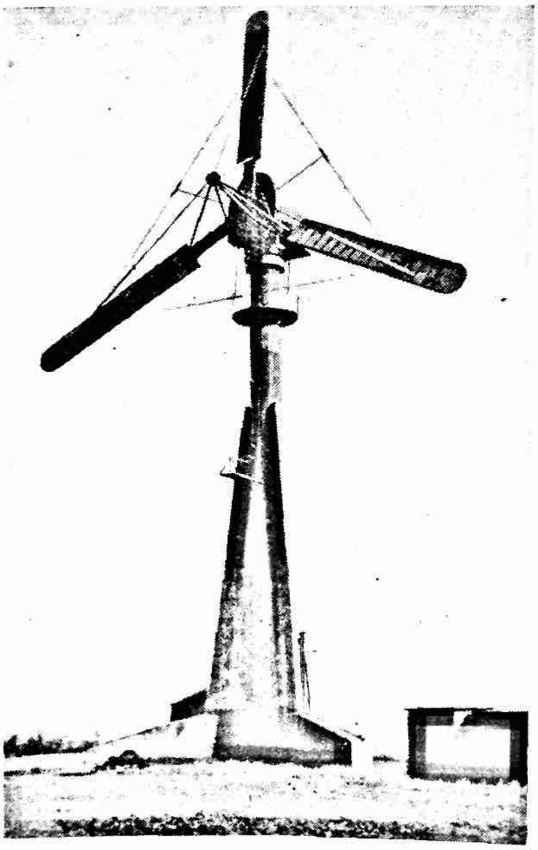

Figure 4a. Gedser Mill
Swept area 450 m^2. Diameter 24 m. 200 kW at 38 m/s wind speed

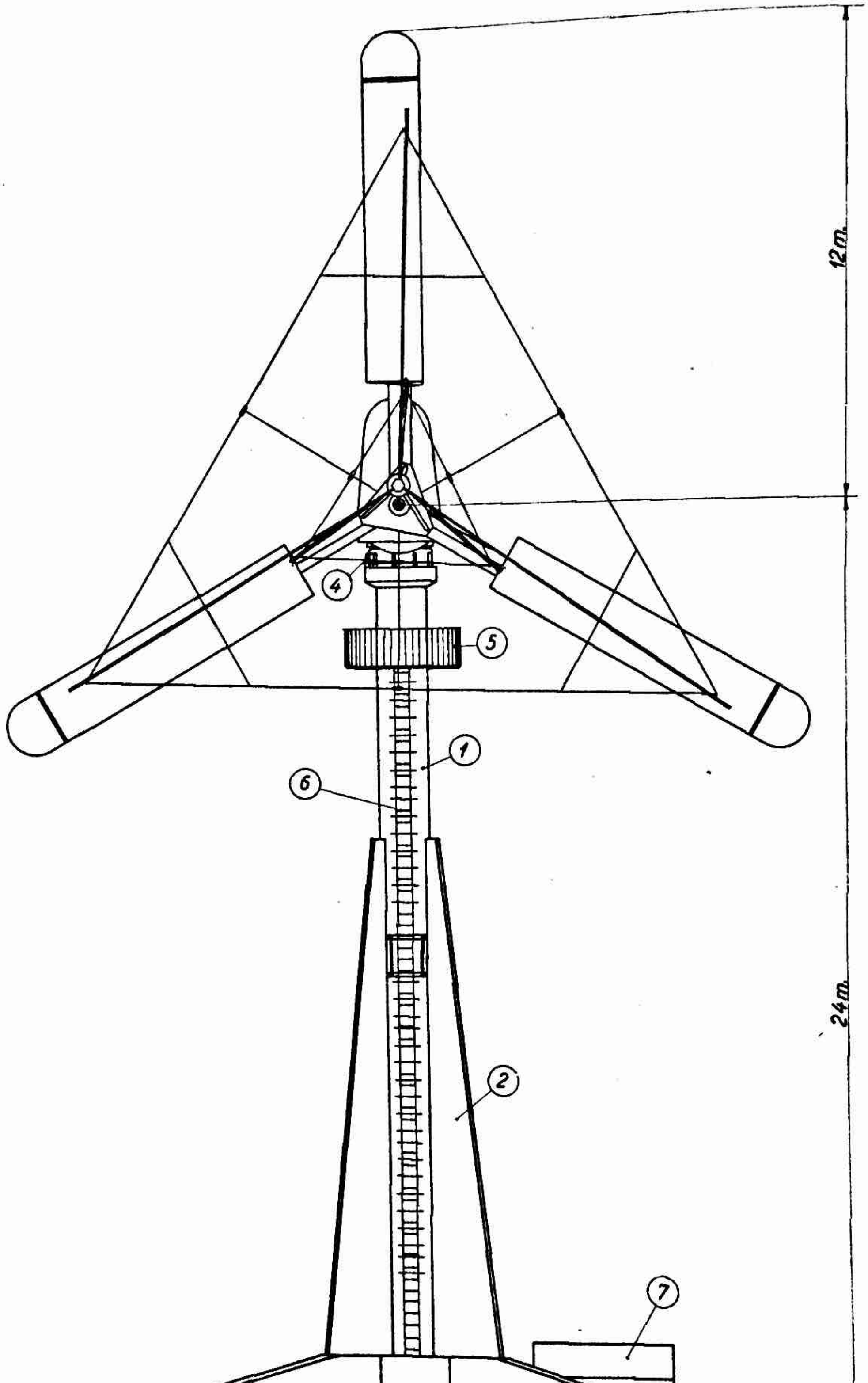

Figure 4b. Gedser Mill. Swept area 450 m². Diameter 24 m; 200 kW at 38 m/s wind speed

Design and construction of the Gedser Mill are based on the results attained by experiments and the experience gained during the research work and from the experimental plants at Vester Egesborg and on the island of Bogø.

The Gedser Mill was completed in the summer of 1957. After the mill had been tested and adjusted and some minor alterations had been made and when various measurements of efficiency and mechanical conditions had been worked up, the mill was put into continual operation in June 1958. Since that time it has been working, practically day and night, in connection with the SEAS grid, without mishaps of any significance.

A description of the more important details of the construction of the mill are given below.

The blades

Through experiments in the SEAS provisional wind tunnel, the blade profile shown in figure 5 was found to be the most advantageous. It was also found that a 3-blade mill with this blade profile had, at 6 m/s wind velocity, the power coefficient shown in the figure and that this coefficient has its maximum value when the blade tip velocity is 5 to 6 times as high as the wind velocity.

Curve 1 in figure 6 indicating the annual number of hours during which the various wind velocities occur, was found through wind energy measurements taken in the southern part of Zealand by SEAS. Curve 2 indicates the corresponding annual amount of energy, which has its maximum at 8 m/s. As wind mills which are coupled with normal asynchronous AC generators in connection with extensive AC grids are bound to operate at a number of revolutions which only varies in relation to the generator-slip — which is normally between 1 per cent and 4 per cent — a number of revolutions and a blade tip velocity must be chosen which best take advantage of the maximum annual wind energy occurring locally, which in this present case was 8 m/s. The mill has its maximal power coefficient at a blade tip velocity of about 5 times the wind velocity and as shown in figure 5 the blade tip velocity chosen was 38-40 m/s.

It may possibly be advantageous to arrange the transmission between blades and generator so as to make the blade tip velocity higher or lower than 38 m/s, where different wind conditions from those of South Zealand are prevailing. The question whether great effect of the mill during fewer hours per annum or less effect during many hours of the year is to be preferred should also be taken into consideration. In either case the actual amount of

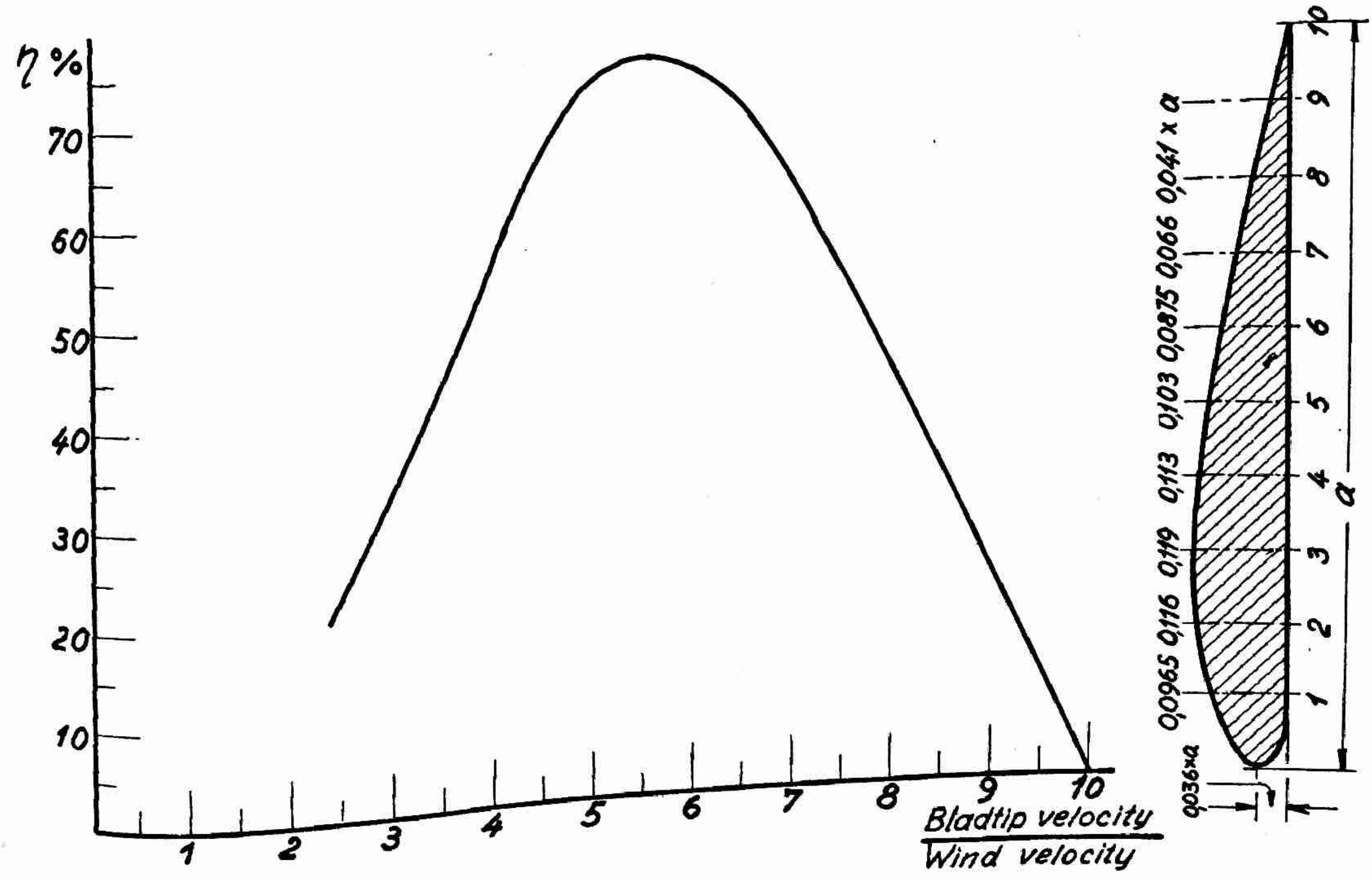

Figure 5. Blade profile and efficiency curve
λ = blade-tip velocity/wind speed

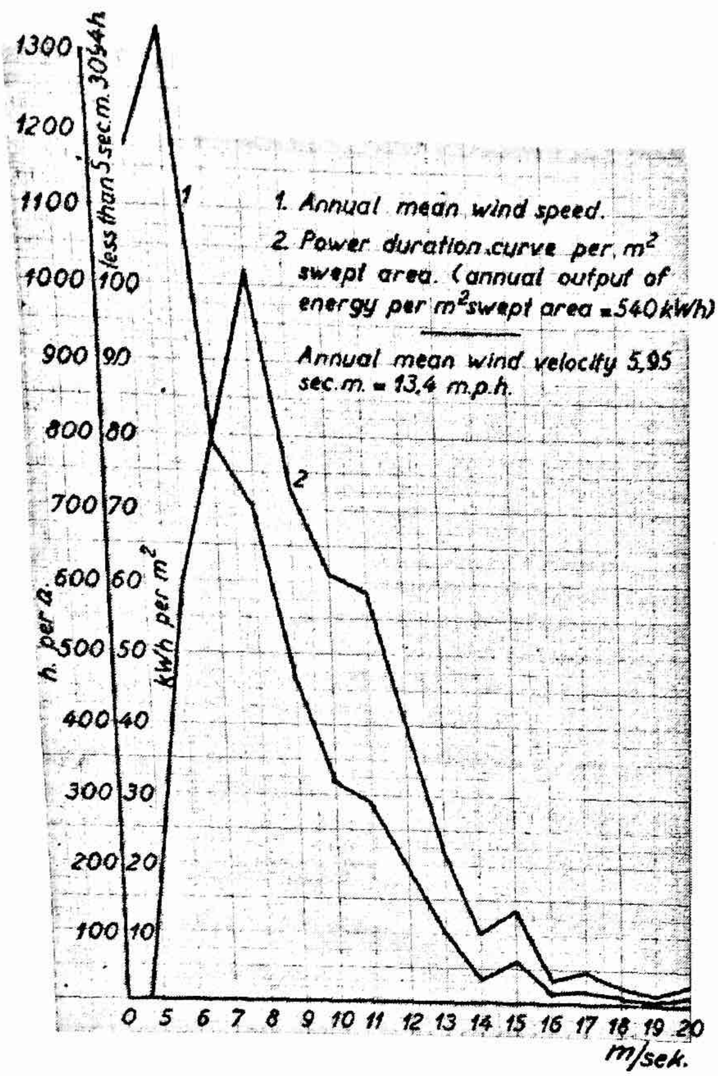

Figure 6

Curve 1. Annual mean wind speed 5.95 m/s, measured near Vester Egesborg mill; curve 2. Calculated annual output : 540 kWh/m² of swept area. Measured output in 1953 : 525 kWh/m² of swept area.

energy would appear to be nearly equal but this of course depends upon whether the wind energy is available in the shape of high wind in a few hours of the year or as lighter winds of daily occurrence.

By using the relation, as shown in figure 7, between the effect curve 3 of the wind and the power coefficient curve 1 of the mill, the effect curve 2 of the mill can be constructed or, if the latter is known, the power coefficient curve can likewise be constructed. In figure 7 the mill effect curve is seen to be nearly flat at 15 m/s wind velocity. This is due to the phenomenon called "stalling", in airmen's parlance, which may cause an aeroplane to crash when the air current, for some reason or other, hits the wings at too obtuse an angle of attack, thus causing an unfavorable flow-off of the streaming air from the wings and bringing about a reduced lift coefficient corresponding, in the case of the mills, to a relatively smaller pulling power at increasing wind velocity.

In the design of the pilot mills constructed by SEAS, the stalling phenomenon is used for controlling the effect. In this manner a simple method of preventing overloading in a gale has been found. Such fluctuations of the mill effect are caused by the natural changes of the wind velocity which are absorbed without difficulty by an extensive supply network.

The mill, however, must be so contrived that it can be stopped whenever necessary because of lubrication or a breaking-off of the connection to the grid. This purpose is served by special break flaps at the tips of the blades. They are shown in figure 8.

The brake flaps (1) constitute 12 per cent of the surface area of the blades and are, under normal operating conditions of the mill, an integral part of the blades. Each of the flaps is fixed to a tubular carrying rod (2) which will, when actuated by the automatics of the mill, travel about 300 mm along the longitudinal axis of the blade and move in a link-motion (3) in the fixed part of the blade. By this movement, the brake flap is twisted about 60° out of the plane of the blade, thus counteracting the remaining part of the blade and bringing the mill to a dead stop. The brake flaps are governed by a

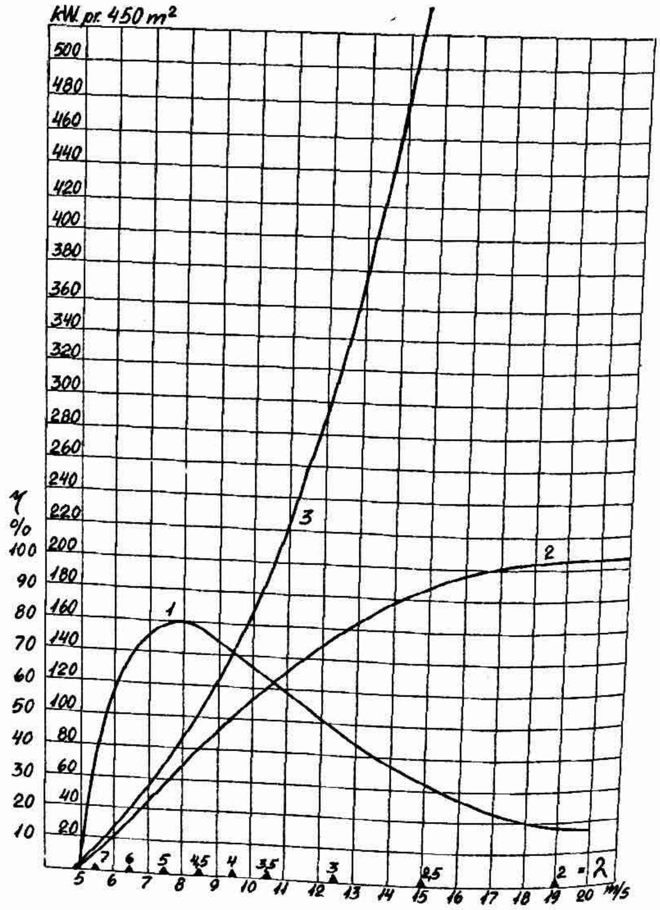

Figure 7

Curve 1. Power coefficient curve*; curve 2. Effect curve of Gedser mill; curve 3. Wind energy, calculated by the formula $D^2 \times V^3 \times 0.000285$, for $D = 24$ m

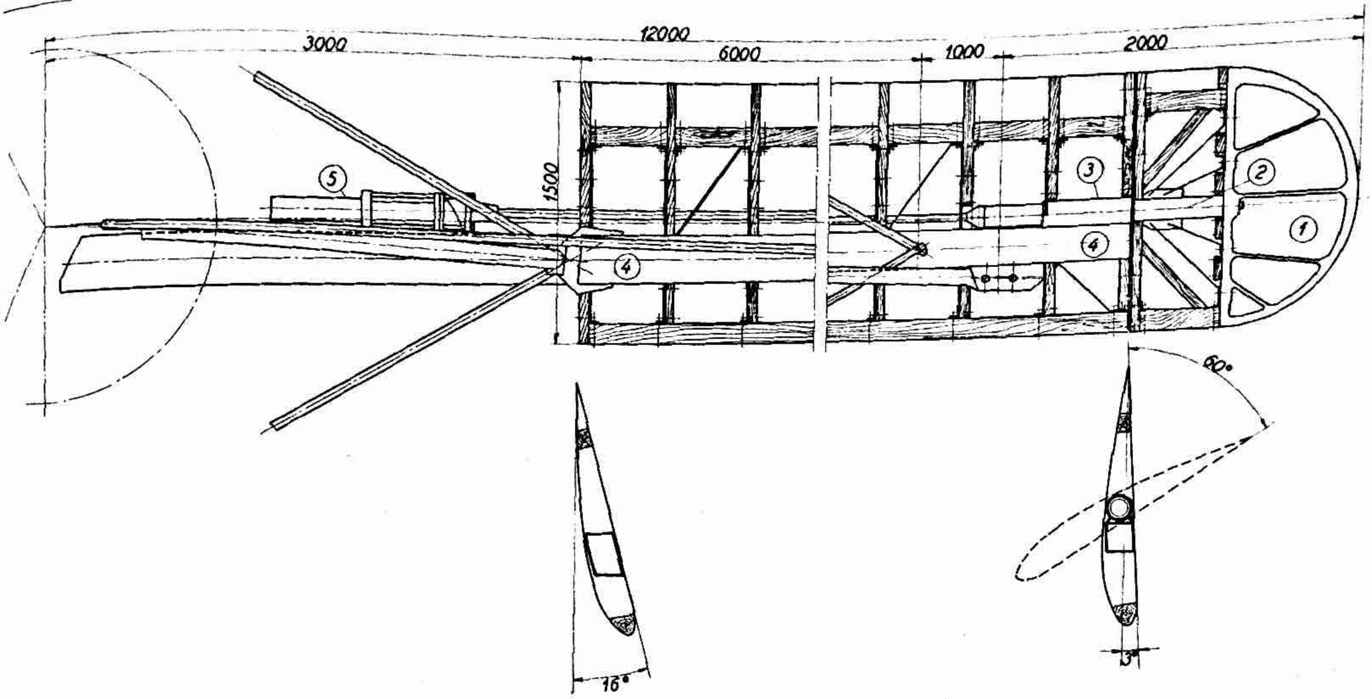

Figure 8. Design of blades used at Gedser Mill

hydraulic servo-motor (5) in connection with the mill system of automatics. When the mill starts, the servo-motor will pull the brake flaps into working position. When it stops, the centrifugal power will force the flaps out into braking position.

The blade beam (4) is quadrangular and made of 16 mm and 10 mm welded steel plates. The cross section of the beam alters linearly from the hub to the extreme beam end as shown in the figure. Flat bar fish plates are welded on the beam and streamlined wooden transverse ribs are fastened to the fish plates with screws. In the leading edge and near the trailing edge of the blade wooden mouldings are mounted.

Light alloy metal sheeting of 1 mm thickness is fastened to the transverse rib system by galvanized flat-headed wood screws, the sheeting thus forming the streamlined body of the blade. The blade has a twist at the blade root of 14° decreasing to 3° at the brake flap.

Through wind tunnel experiments, this was found to be the minimal twist necessary for making the mill start automatically at 5 m/s wind velocity, and at the same time it lends the blade the greatest possible pull.

When the blades were designed as described above, it should be remembered that the possibilities of production were restricted, as they could only be made by manual power craftsmanship. In a possible future industrial production in series, these blades can undoubtedly be more cheaply made of pressed steel sheets welded into hollow shell-like constructions to be bolted to the hub by flanges. It is possible as well to make the blades of other material than steel, e.g., plastic reinforced with glass fibre, if this proves economically advantageous.

The pressure of the wind and the mechanical strains on the blades depend on the speed of the blades in relation to that of the wind. At 38 m/s blade tip velocity the thrust per m² swept area of a 3-blade mill has been determined, through the research work done by SEAS at the Vester Egesborg mill, to be as shown by curve 1 in figure 9 while curve 2 indicates the thrust when the mill is at a standstill.

During investigations of such variations of the wind velocity as occur within the width of the swept area (24 m), calculations of such torsional stresses

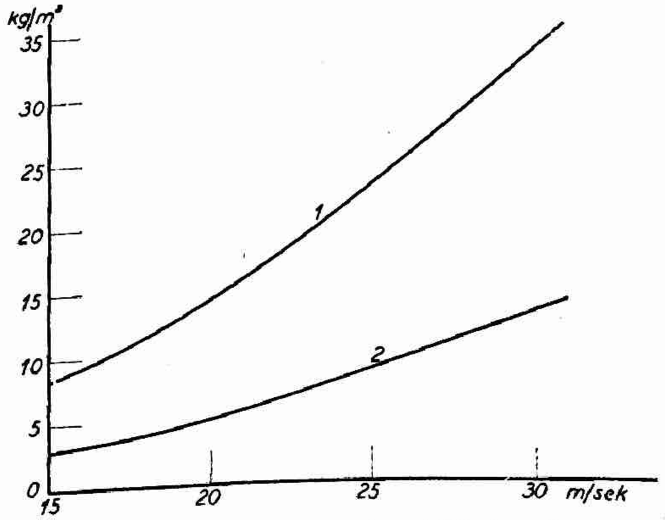

Figure 9. Axial pressure at Gedser Mill, kg/m² per m² of swept surface

Curve 1. Pressure per m² while operating at 38 m/s wind speed; curve 2. Pressure per m² after mill has stopped as may arise around the vertical axis of the mill tower have been made. This moment of torsion was found to be 5 300 kgm which in addition to the above mentioned thrust has been used as a basis of calculation of the dimensions of blades, machine cabin and constructive parts of the tower.

During the calculations it appeared that, when an aerodynamically advantageous profile is to be used, it is practically impossible to build steel blades to be freely suspended from the hub without stays or guy wires. Hence the construction of the blades is based on the use of stays for carrying the thrust and guy wires for absorbing its varying plus and minus bending moments arising in the blade beams at the rotating of the blades.

When calculating the steel constructions, a stress of 600 kg per cm² was considered the maximum where fluctuating one-way forces are concerned, and 200 kg per cm² where strain and stress change between opposite directions on account of the rotation.

In the Gedser Mill, a measurement cylinder is placed between the tower and machine cabin. It is 450 mm high and it has strain gauges. Measurements by these have been taken at wind velocities up to 20 m/s and the results seem to agree quite well with the thrust calculated in advance, whereas the precalculated 30 m/s velocity torsional stresses attained the calculated value already at 20 m/s wind velocity. In view of the thrust and the weight of the several parts, however, the dimensions of blades, tower and cabin are on a rather liberal scale, so that the parts in question will easily resist the greater tortional strains.

Mr. Askegaard, a civil engineer who has been in charge of strain gauge measuring of the mill, gives an account of the measurements in Paper W/15. The Electrical Research Association has taken strain gauge measurements on the blades of the Gedser mill. Opportunities to take these measurements offered only wind velocities up to 15 m/s, but the results seem to agree with the values determined in advance by SEAS.

The machine cabin

The design of the machine cabin is shown in figure 10. The blade beams (1) are bolted on the blade hub (2) which has two built-in ball bearings (3) and (4). The latter (4) cannot be replaced without removing the blades and hub. Its dimensions are therefore very ample so that according to calculations it should have a very long life. Ball bearing (3) is the axial pressure bearing and can be replaced without removing the blades and the hub which are mounted on a spindle (5) fixed in the cabin and bored. The bore (6) serves as an oil pressure pipe for the service motors which are mounted on the blades for pulling the brake flaps into flush position.

Between the bore (6) in the fixed spindle and the rotating oil pipe system of the hub, a self-tightening stuffing box (7) is inserted. Connecting with the oil pressure pipe of the spindle is a safety valve (8), sealed by a stopper made of a metal which will melt at 110°C. In case of heating of the spindle, due to defects in the bearings, the stopper will melt and let out the oil, thus stopping the mill.

On the hub is mounted a twin sprocket (9) which, by means of double 2½″ roller chains (10), pulls the sprocket (11) on the secondary shaft (12). The secondary shaft has a triple sprocket (13) with appurtenant 1½″ roller chain (14) pulling the generator shaft (15). The shaft is connected to the generator (16) by an elastic coupling (17) fitted with snap pegs (18) that will snap in case of relay defects which may cause a faulty coupling of the generator to the grid and thus give rise to dangerous jolts in the mechanical parts and the blades.

The bearing pedestals (19) and (20) as well as the hydraulic pumping plant (21) and the generator are mounted on a bottom frame (22). The bull gear is made of welded sheet steel and is fixed to the bottom of that frame.

The stationary inner ring is a toothed rim, the teeth of which are in mesh with the yawing motor gear which has a built-in worm gear that locks the yawing mechanism, in the cabin, when the yawing motor is stopped. The yawing motor is automatically governed by a vane (24) mounted on top of the cabin. Access to the cabin is from the tower platform by means of the ladder (25). Above the ladder is a manhole in the frame bottom. The stationary inner part of the bull gear is fastened to the tower by means of a 450 mm high measuring cylinder (26), on which strain gauges are placed. By means of these and the appurtenant measuring instruments, the axial pressure and the torsional influences can be measured. The dimensions of the measuring cylinder have been kept fairly small for the greatest possible sensitivity.

For this reason another cylinder (27) of more ample dimensions has been placed outside and

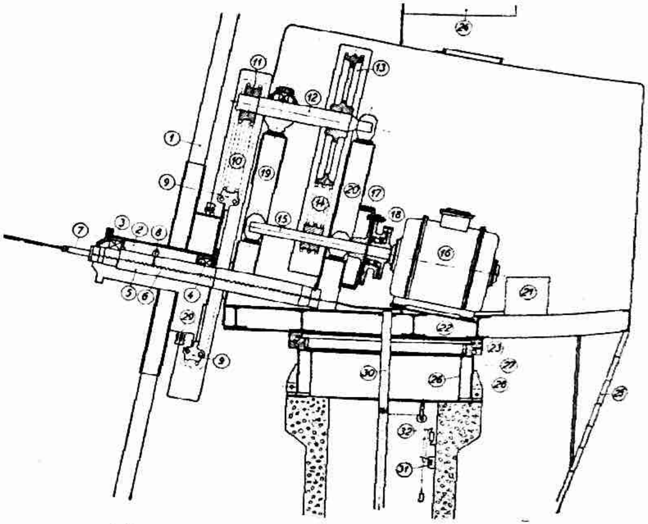

Figure 10. Design of machine room

around the measuring cylinder. It is of larger dimensions and is provided with fish plates (28) that grip around cams on the bottom plate to which the measuring cylinder is welded. Whenever no measuring is going on, the cams and some conical loose-fitting bolts in the fish plates take over the load.

The sprockets and the chains are contained in a chain casing. The primary chain drive is lubricated by means of an oil bath, while the secondary chain drive is lubricated by an oil pump with an oil pressure relay that will stop the mill if the oil pressure ceases. To prevent the oil from leaking and the rain from penetrating into the casing of the primary chain, a labyrinthine obtorator is inserted between the stationary and the rotating part.

The elastic coupling (17) is bowl-shaped, thus having an outer face that is used as a mechanical brake. The brake-shoes are released when the oil pressure of the hydraulic system is turned on at the starting of the mill. When the oil pressure ceases on stopping of the mill the brake-shoes will be pressed against the braking face by a lever. The brake will not be able to stop the mill, however. This is done by means of the brake flaps of the blades but the mechanical brake will secure the blades if work on the mill has to be done. The entire machinery of the mill is encased in a housing of galvanized sheet steel and on top of the housing the vane (24) is mounted. The vane is in mechanical connection with a relay that governs the yawing motor.

The cables to the generator as well as the control cables are carried to the machine cabin through a rubber tube fixed in the floor of the cabin and freely suspended in the tower so that it will stand being twisted ten turns either way without being damaged.

In that way the use of slip rings for cable connection to the cabin has been avoided. Experience shows that the yawing will cause, annually, only about 10 turns, clockwise.

In the tower is placed a relay (31) connected with a cord that passes a pulley and is wound round the rubber tube (30) so as to disconnect the control cables, thereby stopping the yawing mechanism and the mill, in case the cables get too many turns. At the monthly inspection the mill — if necessary — is turned back the opposite way, by manual operation of the yawing mechanism, until the cord round the rubber tube has been unwound.

Another cord is also fastened to the relay. It is connected with a loosely placed weight that will fall off its stand and influence the relay, thus stopping the mill, in case abnormal vibrations occur in the tower.

The tower

Figure 4 shows the complete construction of the tower. It also shows how the blades with their stays and guy wires as well as the machine cabin are mounted on the tower. This consists of a vertical tube (1) made of prestressed concrete, whereas the buttresses (2) and the foundation (3) consist of ordinary reinforced concrete. (4) is the above-mentioned measuring cylinder, placed between tower and cabin. There, (5) is a service platform by which access is gained by an inside as well as by an outside ladder (6). Near the tower there is a steel sheet house (7). The tower was conceived and and calculated by B. Hejlund Rasmussen, Copenhagen.

Diagram of the Gedser Mill

The diagram is shown in figure 11. The mechanical parts are shown schematically and cables of generator and auxiliary motors are drawn as single lines for the purpose of simplifying the diagram.

When starting the mill the high tension circuit breaker (31), the low tension breaker (28), as well as the control cable circuit breaker (41), are switched on. The cut-in magneto (15) will then close the valve (16) and the electromotor (19) and the oil pumps (20) will start and put pressure on the hydraulic system. The pressure causes the service motors (5) to pull the brake flaps (2) of the blades (1) into position for operating the mill, in which position they form an integrating part of the blades. Further, the service motor (7) will release the mechanical brake (6) on the generator shaft (8). If the wind velocity is 5-6 m/s the mill will start. As soon as the 8-pole generator has attained 750 rpm the centrifugal relay (9) will switch on the contactor (24) and connect the generator to the grid system, into which it will feed energy when the wind velocity is above 5 m/s. In case the wind velocity decreases to less than 5 m/s, the generator will take energy from the grid system and the return current relay (26) will then switch off the current for the cut-in magneto of the contactor (24) which then switches off the generator from the grid system until a wind of 5-6 m/s velocity starts blowing again and the centrifugal relay switches the generator on to the grid system once more. In the Vester Egesborg and Bogø mills the generator slip is 5 per cent and 4 per cent, and in the case of these two plants the required selectivity between the centrifugal relay and the return current relay can be obtained.

The Gedser Mill generator, however, has but 1 per cent slip and here the centrifugal relay could not with sufficient accuracy switch off the connection to the generator contactor after the return current had gone into action. Hence it became necessary to build a damping switch into the return current relay to retard its action and prevent it from switching on the connection to the centrifugal relay until the latter had, on account of the reduced number of rpm of the mill, had sufficient time to switch off the connection with the cut-in magneto of the contactor.

The mill is stopped by switching off the low tension circuit breaker (28) or the control cable circuit breaker (41). The tension on the contactor (24) will then be cut off as will also the generator connection with the grid system. The tension on the cut-in magneto (15), also, will be cut off. The valve (16) will turn on the oil for the service motors (5) and (7)

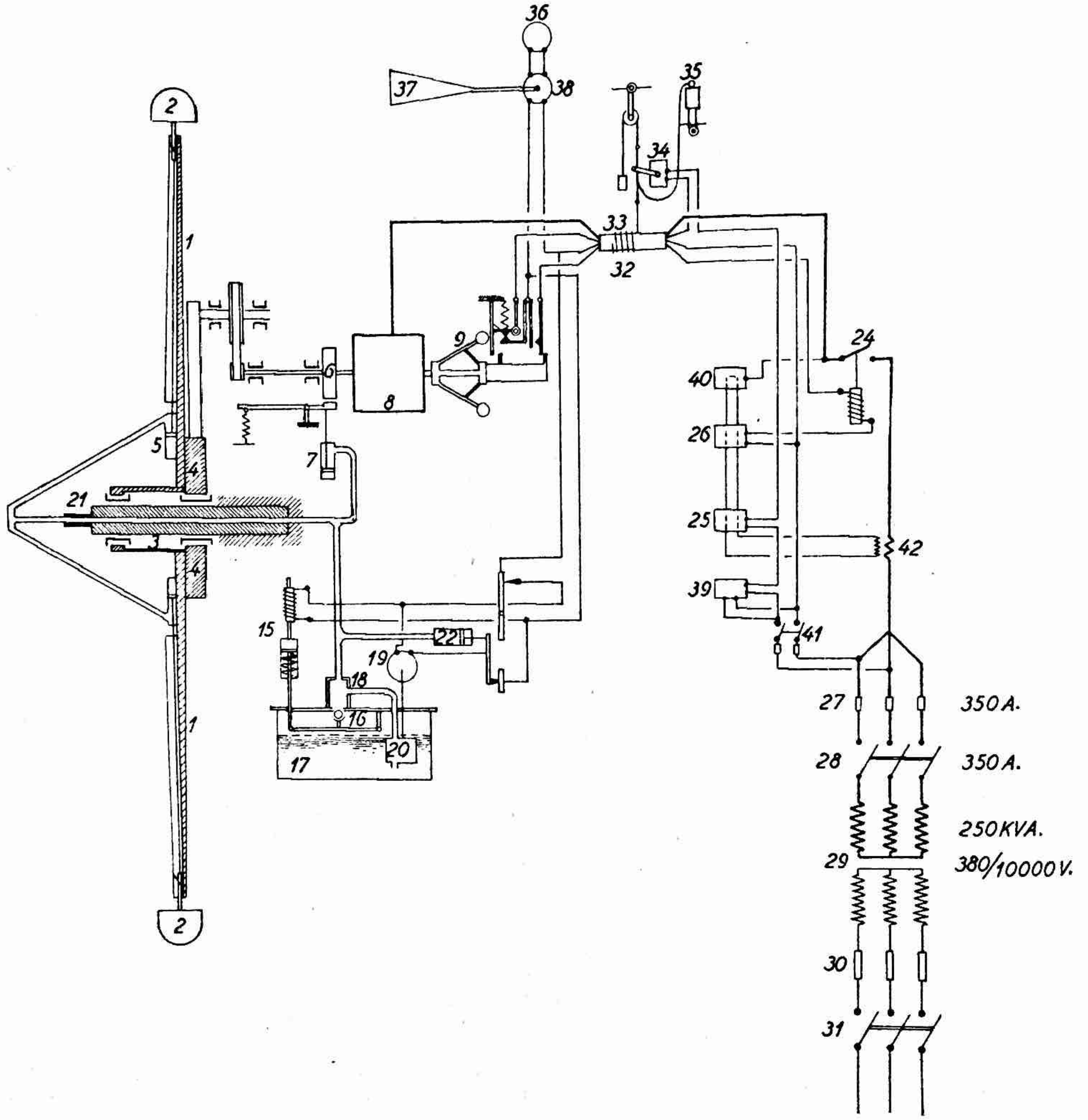

Figure 11. Schematic diagram of mechanical operation and electrical circuit

and put the brake flaps of the blades as well as the mechanical brake (6) into operation, thereby stopping the mill.

The vane (37) serves to keep the blades in the right position in relation to the direction of the wind; it is connected with the reversing device (38). The latter can cross two phase cables to the yawing motor (36) so as to reverse its direction of yawing, when the wind veers towards the right or the left respectively. When the wind attacks the swept area perpendicularly, the mill will be kept in this position by means of a worm gear in the yawing motor gear box. The movements of the vane are damped by means of a shock absorber filled with oil.

Various precautionary measures have been taken for stopping the mill when any damage occurs or in case the connection to the grid system is broken off.

If the grid system connection is broken off and the generator is not excited by the grid, its contactor

(24) will be switched off, as will the cut-in magneto (15); the oil pressure will then cease and the mill be stopped by the braking devices.

If there are capacitors of the requisite capacity in such part of the grid as may remain connected with the mill generator, the grid will be excited capacitively. If the load exceeds the output which the mill is capable of bearing, its rpm and its generator voltage will automatically drop until at length it stops. If the load, however, happens to be less than the output, the mill will increase its rpm and its generator voltage.

In that case the overvoltage relay (39) will switch off the control cable, if this has not already been done by action of the centrifugal relay safety switch which can likewise switch off the control cable. The switching off may also be done by an overpressure switch built into the hydraulic system and influenced by the pressure cylinder (21).

In the draw bar of the cut-in magneto (15) is a built-in spring that makes the closing-valve (16) function also as a safety valve that will open for the oil in case of overpressure. Thereby the brake flaps of the blades will prevent the occurrence of dangerous situations caused by an excessive number of revolutions. Thus safeguards against racing of the mill have been established in several ways.

The various safeguarding appliances lock themselves when they have been in operation, so that the mill cannot be started before they have been released by hand. The several appliances are made selective so that only one of them need function to bring the mill to a standstill.

Normally the generator cannot be overloaded even in the most violent hurricane, the mill effect being automatically limited by the stalling of the blades in high wind.

If a break of phase occurs in the grid system, the generator windings in phases *r* and *s* may be overloaded, hence an overcurrent relay (25) is inserted which, in that case, will switch off the control cable, thus stopping the mill. The relays (25) and (26) and the kWh-meter (40) operate together with current transformers (42) in the main cable.

The control system diagrams of the former Vester Egesborg mill and the Bogø mill are on the whole identical. In the Bogø mill, instead of a hydraulic regulating system, a powerful spiral spring is used. The spring is loaded by means of a winch and an electromotor and keeps the brake flaps of the blades pulled into their flush position when the mill is operating. In the Vester Egesborg mill, instead of oil pressure, compressed air is used. Condensation water can, however, form in the system. This is unfortunate, especially in frosty weather, but all three systems have been able to function in such manner that no mishaps of any importance have occurred.

Summary

In 1947, Sydøstsjællands Elektricitets Aktieselskab, SEAS (The South-East Zealand Electricity Co. Ltd.) inaugurated a series of investigations on the possibilities of utilizing wind power for the production of electricity in connection with the existing AC grid.

On various sites in Denmark, anemographs for the measuring and recording of wind velocity were mounted and a temporary wind tunnel was made in which wind motors of up to 2 m² swept area could be tested. About 30 different blade designs and blade profiles were tested. On the basis of these experiments, a pilot plant of 7.5 m swept area diameter (44 m² swept area) was built, in 1950, near Vester Egesborg on Zealand. By means of this plant, measurements of the effect were taken at various blade tip velocities and wind velocities. As well as this, the thrust was measured and various devices for making the plant fully automatic were tested.

On the basis of the experiments made with the Vester Egesborg plant, a DC wind power plant on the island of Bogø, designed and constructed by the firm of F. L. Smidth & Co., was converted into an AC plant. Since 1942 this plant had been producing DC, in connection with a local diesel-electric power works which had been dismantled and reconstructed for AC supply from the SEAS grid. The existing tower and machinery were used and the wind motor was provided with 3 blades. An asynchronous AC generator as well as the automatics necessary for the production of AC and the feeding of it into the grid were installed as well. The plant started operating in the autumn of 1952 and is still working.

The operating results of the two experimental plants were so promising that, at the suggestion of SEAS, the Association of Danish Electricity Works appointed a Wind Power Committee to carry on the wind power work.

The Wind Power Committee received grants from the Danish Government totalling 525 000 Danish crowns (about $80.000) for the erection of a 200 kW pilot plant — the "Gedser Mill" — and of 3 wind measuring stations.

The Gedser Mill, the construction cost of which (apart from 55 000 crowns for measuring equipment and 48 000 crowns for projecting) amounted to 272 000 crowns (about $41.000), was finished during the summer of 1957. After some adjustments of the plant had been made, measurements of the produced energy taken and investigation of such phenomena as gradually appeared in connection with its operation made, it was finally put into service in June 1958 and has been in operation since then.

The "Gedser Mill" is the most recently built and largest Danish experimental wind power plant and is to a material extent designed on the basis of experience gained from the aforesaid pilot plants.

The "Gedser Mill" has a 25 m high tower made of prestressed concrete. On top of the tower is mounted a measuring cylinder carrying the machinery.

The three blades of the rotor have a length of 12 m, thus forming a swept area of 450 m². Through a chain drive with a ratio of 1:25 the blades drive an eightpole, 200 kW asynchronous generator (3 × 380 V, 50 periods). The blade tip velocity is about 38 m/sec. corresponding to ½ r/sec. The wind motor starts automatically at a wind velocity of 4-5 m/sec. and the plant renders 200 kW at 15 m/sec.

RÉALISATION DES CENTRALES ÉOLIENNES

Résumé

En 1947, la compagnie d'électricité du Sud-Est de la Zélande (Sydøstsjællands Elektricitets Aktieselskab, SEAS) a commencé une série de recherches sur la possibilité d'utiliser l'énergie éolienne en vue d'une production d'électricité susceptible de s'intégrer dans le réseau de distribution en courant alternatif déjà en service.

On a, en divers lieux du Danemark, des anémographes destinés à la mesure et à l'enregistrement de la vitesse du vent et on a construit un tunnel aérodynamique provisoire se prêtant à l'essai d'aéromoteurs ayant une surface balayée pouvant aller jusqu'à 2 m². On a soumis à ces essais environ 30 modèles de pales et de profils de pales. Sur la base de ces expériences, (1950) on a réalisé une centrale-pilote ayant un diamètre balayé de 7,5 m (surface balayée 44 m²) près de Vester Egesborg dans l'île de Zélande. On a mesuré les débits réalisés au moyen de cette installation pour diverses vitesses en bout de pale, ainsi qu'en fonction de la vitesse du vent. On a mesuré en outre la poussée et on a essayé plusieurs dispositifs visant à rendre l'installation complètement automatique.

Sur la base des expériences faites à la centrale de Vester Egesborg, on a converti une centrale productrice de courant continu, installée sur l'île de Bogø, mise au point et construite par la firme F.L. Smidth & Compagnie, en installation fournissant du courant alternatif. Depuis 1942, la compagnie débitait du courant continu en association avec une centrale à moteur diesel qui avait été démontée et reconstruite pour fournir du C.A. au réseau de la SEAS. La tour et les machines restaient utilisables et l'aéromoteur a été doté de trois pales. Un alternateur asynchrone et les dispositifs automatiques nécessaires pour la production de courant alternatif et sa fourniture au réseau ont également été installés. Le fonctionnement de l'installation a commencé au cours de l'automne de 1952 et elle marche encore.

Les résultats donnés par l'exploitation des 2 centrales expérimentales étaient si prometteurs que, sur la recommandation de la SEAS, l'Association des centrales électriques danoises a nommé un comité spécial de l'énergie éolienne qui a été chargé de poursuivre les travaux sur cette question. Le comité a reçu des octrois de fonds du gouvernement danois atteignant un total de 525 000 couronnes danoises (environ 80 000 dollars) en vue de l'installation d'une usine-pilote de 200 kW — la centrale de Gedser — et de trois stations anémométriques.

La centrale de Gedser, dont les frais de construction (à part 55 000 couronnes danoises pour le matériel de mesure et 48 000 couronnes danoises pour les projets) s'élevaient à 272 000 couronnes danoises (environ 41 000 dollars) a été terminée pendant l'été de 1957. Après avoir procédé à quelques réglages, on a fait des mesures sur l'énergie produite et étudié les phénomènes qui apparaissaient en liaison avec son exploitation, puis on l'a mise en service définitivement en juin de l'année 1958 : *elle fonctionne* depuis lors.

La centrale de Gedser est la plus grande centrale à énergie éolienne danoise de construction récente et elle a été réalisée, dans une large mesure, sur la base de l'expérience acquise au moyen des installations-pilote mentionnées ci-dessus.

La centrale de Gedser a une tour de 25 m, en béton précontraint. A la partie supérieure de cette tour, on trouve un cylindre de mesure sur lequel repose la machine.

Les trois pales du rotor ont une longueur de 12 m, si bien que la surface balayée est de 450 m². Ces pales entraînent un groupe moteur-alternateur asynchrone de 200 kW à huit pôles par l'entremise d'une commande à chaîne (réduction, 25 à 1) (3 × 380 V, 50 périodes). La vitesse linéaire en bout de pale est de l'ordre de 38 m/s, ce qui correspond à ½ tour par seconde. Le moteur démarre automatiquement quand la vitesse du vent atteint 4 ou 5 m/s et l'installation débite 200 kW pour une brise de 15 m/s.