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XP521

The ERIGEN combined Darrieus - Savonius type of wind generator

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1. INTRODUCTION

The Erigen wind generator is a Darrieus-Savouius type of wind generator. When designing this wind generator for remote location and use in telecommunications systems, the highest of reliability and long term safe operation has been the main target. The picture, fig. 1, illustrates the type of location and application it is intended for.

Fig. 1 The CERRO NEGRITO REPEATER located 4500 m above sea level in Argentina has a complete ERIGEN hybrid power system and a datalogger installed.

Also the highest of efficiency in the electrical power generation and power processing system has been required, especially in low wind speeds, in order to produce the maximum of energy during the year.

The Darrieus-Savounius wind generator to be described in this paper has a diameter of 3 m and a height of 3 m. It has a maximum power output of 950 W at a wind speed of 11 m/s. This concept was selected for the highest possible reliability of mechanical design.

- It operates independently of wind direction and is not negatively affected by gusty and turbulent winds.
- It can form an integrated part of the lightning protection of the power generating system and complete installation.
- Its mechanical design is simple and robust with very few moving parts.

2. WIND TURBINE

The turbine is of combined Savounius - Darrieus type with straight vertical airfoil blade sections and a Savounius turbine in the center of the axis, fig. 1. The vertical axis design makes it independent of the wind direction which is an advantage on sites where the wind direction changes rapidly and often. The turbine is started by the Savounius turbine at a wind speed of 3 m/s and the Darrieus turbine starts to operate at about 4 m/s and stays generating down to approx. 3.5 m/s.

The airfoil blades and spokes are manufactured of extruded aluminium and their joints are made of acid proof stainless steel. The "Savounius" is made of aluminium plate and armoured plastic and the axis itself is of heavy-duty steel. The moving parts are reduced to an absolute minimum and the turbine contains virtually only one moving part. This is a guarantee for the highest possible reliability and the least need for maintenance.

The aerodynamic generation of driving torque is produced by the three blades individually, and varies sinoidally during rotation. At the shaft, a rectified 3-phase sinoid type of driving torque is generated.

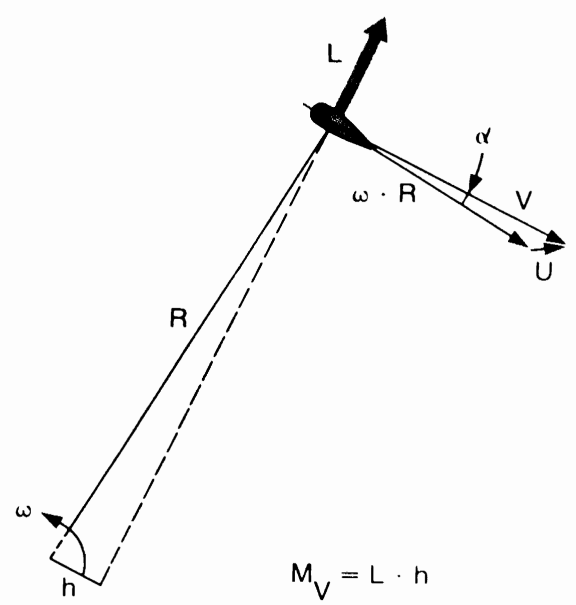

Fig. 2 Aerodynamic generation of driving torque.

The wing section of the Darrieus type turbine is subject to an airflow (V) which is the resultant of the wind velocity (U) and the tangential speed of the wing section (wR) by an angle of attack (α), which varies cyclically during the rotation.

In the position shown here, the air flow with the speed vector (V) generates a force (L) perpendicular to (V). This can be compared to lift force on an airplane wing. As V has the angle of attack (α), (L) will have a moment arm (h) through the turbine centre resulting in a driving torque: Mv=Lh, fig. 2.

In order to limit the rpm at high wind speeds, the turbine has been equipped with a maintenance-free, highly-reliable mechanism which turns the blades a few degrees so that they stall and lose their thrust. The mechanism is activated independently and only by centrifugal force. When the stall occurs the force (L) is reduced, and the drag force (D) increases, fig. 3. Together with the turbine radius (R) as a lever (D) forms a braking torque M = D R, which brakes the turbine to a maximum speed of about 300 rpm.

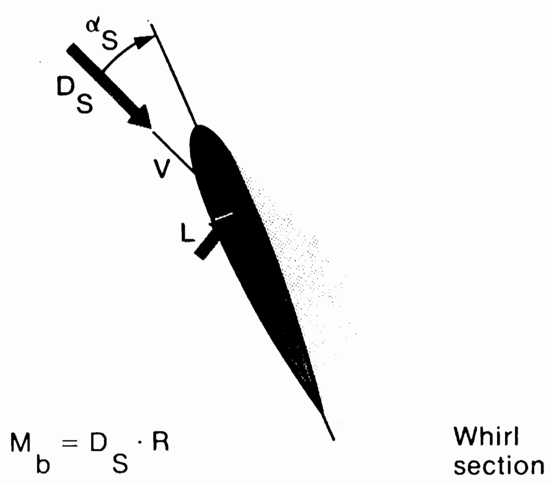

Fig. 3 Aerodynamic generation of braking torque.

Because the turbine has a vertical axis, the generator can be placed under the turbine attachment plate inside the mast or tower. No slip rings and brushes are required to transfer the electrical power.

Inspection and service can be carried out from inside the radio link mast, which makes these activities safer and easier.

3. LIGHTNING PROTECTION

Since a wind generator, to catch the wind best, shall be mounted at the highest point above ground, it usually becomes the highest point in the surroundings. Consequently it will be the most probable unit to be hit by a direct lightning strike.

The electric damage of a lightning strike in a small conventional wind generator hits the windings of the alternator as they are located on top of the unit. Actually, in this case the alternator connected to the power cable will be the lightning conductor, and will be destroyed as well as the generator's ball bearings.
Because the Erigen turbine is of vertical axis type, it has an outstanding advantage over conventional type of wind generators in the respect of lightning protection. Direct lightning strikes in the alternator windings are impossible. The vertical axis turbine is used as a rotating lightningrod for the tower or mast and conducts the lightning-current to the earthed mast. The alternator plus the electronics are protected against induced overvoltages.

Fig. 4 Roller bearing from a car hit by lightning.

The damages of lightning strikes are of both mechanical and electrical nature. A wind generator needs to be fitted with protections for both. The mechanical damage is related to the ball bearings in the system. Ball bearings, if not protected, cannot withstand a high electric current. If a high electric current flows through a ball bearing, the result will be welding of the bearing, and the very fine metal surfaces needed for proper functioning will get burnt, fig. 4. Sooner or later the ball bearing will stop working. The Erigen turbine is equipped with insulators which prevent the current from passing through the ball bearings. A patent is achieved for this design and it is tested in a high voltage laboratory, fig. 5.

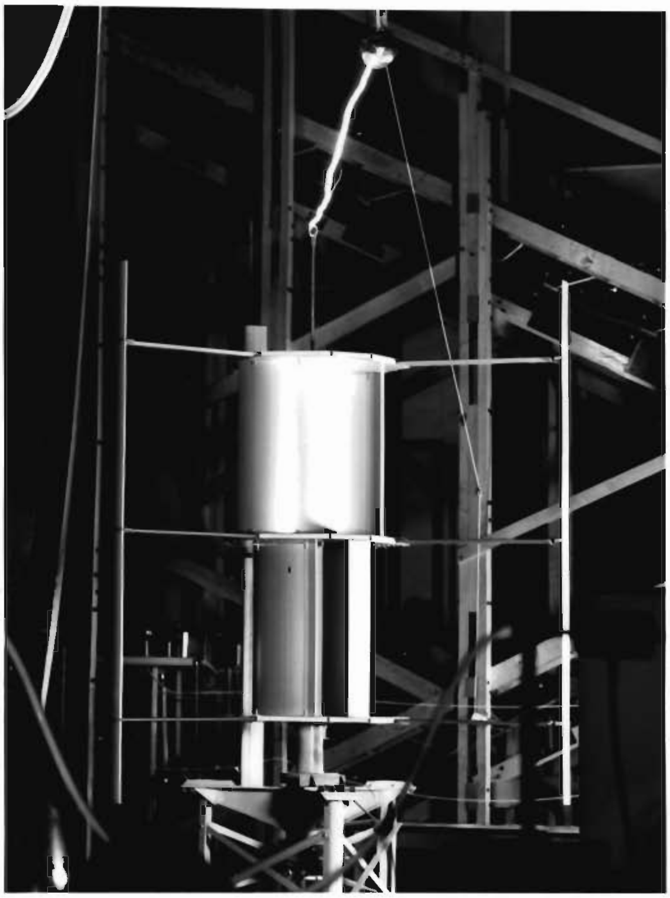

Fig. 5 The ERIGEN turbine in lightning-strike-test in a high voltage laboratory.

4. ALTERNATOR

In order to achieve the highest efficiency in low wind speeds, a permanent magnetized alternator without iron in the structure has been designed. Because the windings do not have iron cores, the permanent magnets cannot lock the wind turbine during start up. This is important, because the wind generator needs to start and operate with the highest rate of efficiency at the most frequently occuring low winds, in order to produce the maximum amount of energy.

Only the bearing frictions in the turbine and the generator need to be overcome during start up.

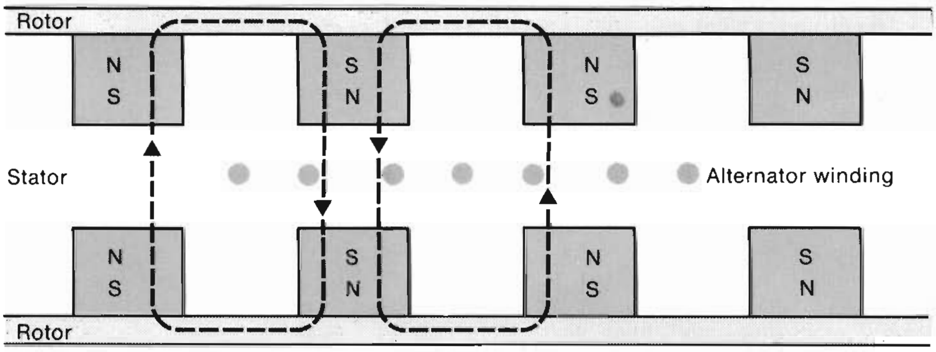

Fig. 6 Principle of the alternator design.

The alternator has a multipole design so that it can be connected directly to the slowly rotating turbine. It is of the "pancake" type, with 56 pairs of permanent magnets placed along the rotor's periphery. Electrically, it is of three-phase type and without brushes. The high efficiency is achieved by eliminating the magnetisation and iron losses which in conventional designs are heavy, especially during slow rotation. The stator winding is encased in a layer of selfsupporting iron-free composite material and placed between the two rotor discs which are rotated by the turbine shaft, fig. 6.

The design of the stator is an interesting achievement of high technology. The stator is a giant multilayer type of circular printed circuit board, fig. 7. The advantage is a high percentage of copper regarding volume without a need for heavy support structures of iron.
With the improvement of permanent magnets with stronger material to come, this type of alternator design becomes even more interesting.

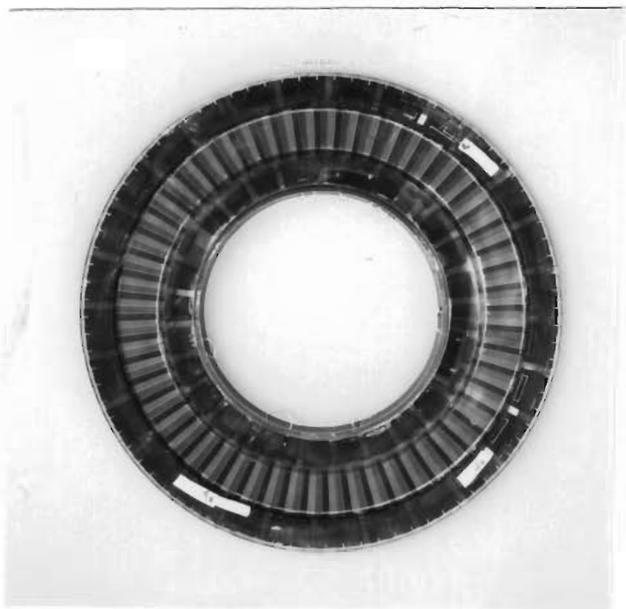

Fig. 7 Picture of the stator after processing.

5. CONTROL AND POWER REGULATION

A Darrieus type of wind turbine has a typical efficiency curve shown in fig. 8. The curve indicates that the aerodynamic efficiency of the turbine is greatly dependent on the ratio of the wind speed to the turbine blade speed. The power output must be regulated so that the blade speed is approximately 3.5 times the wind speed in order to use the turbine at the maximum efficiency. If the power load is too large, the turbine will slow down quickly and finally stop alltogether. Too low power output gives a stable working point with lower efficiency to the right of the optimum working point.

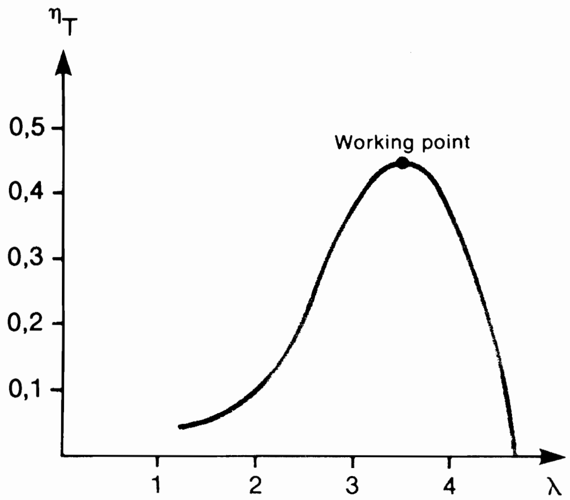

Fig. 8 Efficiency of the Darrieus turbine.

$\eta_T = f(\lambda)$ (1)

$\lambda = Rw/v$ (2)

λ is the ratio between the blade speed and the wind speed.

R is the turbine radius.

The inertia of the rotating mass is another factor of great importance for the regulation. The inertia determines how quickly the optimum working point can be reached when the wind speed changes. At the same time the inertia constitutes an energy buffer between the turbine and the battery. Fig. 9 shows the rotating mechanical system with the associated mathematical equations.

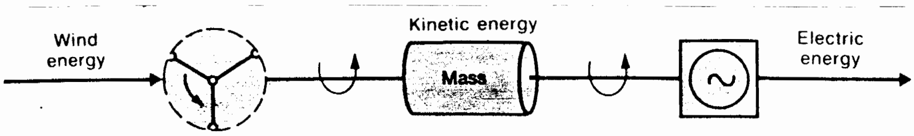

Fig. 9 The rotating mechanical system.

The associated mathematical equations are:

$M_v + M_m + M_{el} = 0$ (3)

M_v is the torque generated by wind.

$M_m = Jdw/dt$ (4)

M_m is the torque of the mass about the axis.

M_{el} is the torque from the alternator.

$J = \int_0^R r^2\, dw$ (5)

J is the moment of inertia of the mass.

$W = 1/2\, Jw^2$ (6)

The structure of the control and power regulating system is shown in the fig. 10. The microprocessor-based control equipment has a data program which continuously guides the power regulators according to the above mentioned basic conditions, in order to track the maximum power available from the wind.
Data needed for the processor to execute the program includes battery and rectifier voltages, the frequency of the alternator and the output current from the regulator. Calculated values which form part of the decision making include different efficiency values, generator impedance, moment of inertia, rotation speed, retardation and acceleration.

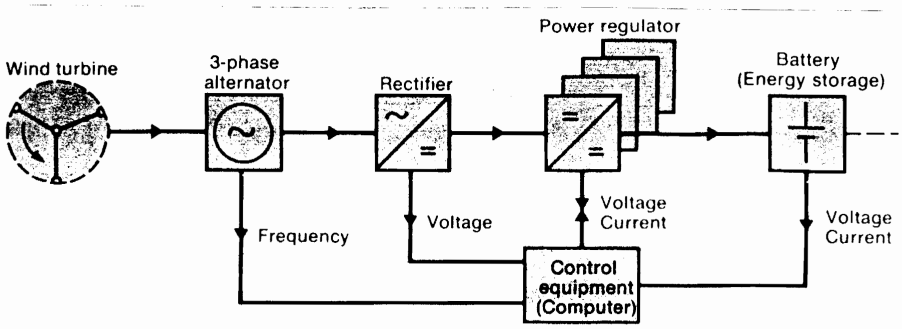

Fig. 10 A block diagram of the wind power system.

The power regulator in the system consists of a number of choppers connected in parallel. Each has a nominal peak power of 200 W at an output voltage of 50 V DC and a maximum input voltage of 375 V DC. The input voltage to the choppers varies greatly with the variation in wind force. In the regulator the choppers can regulate both output voltage and output current fully. In this way the output power is kept completely under control.

The chopper efficiency is 94 % under the most common load conditions. This high value has been achieved by using relatively high operating voltages and by excluding an isolating transformer.
The control of the output power is executed in any one of three different modes:

Mode 1. Charging with maximum power i.e. max. power tracking
Mode 2. Trickle charging
Mode 3. No charging, the processor inactive.

Mode 1 is the most extensive operating mode and places the greatest demands on the capability of the processor. The turbine must be given a load such that its blade speed is approximately 3.5 times the wind speed. Even small deviations from this value result in reduced efficiency, fig. 12. The regulation process uses an actual value, the real load, and an optimum value, the desired load. The difference between the two values can be determined and the regulation can reduce the difference. The actual value is readily available since it can easily be calculated by the processor. The optimum value is difficult to find.

A method which does not require measurement of the wind speed has been chosen.

Basically the method for maximizing the power output consists of determining the position and movement of the working point along the turbine power curve.

The rotation speed and acceleration of the turbine are measured for a defined time immediately after a change in the power output. With the aid of these values, the shortage or surplus of power in the mechanical system can be calculated. If the turbine is accelerating, it will be permitted to continue so, as long as a surplus is increasing, but a reduction of surplus must result in an immediate increase in the power output, so that the acceleration ceases. The latter case is equivalent to the optimum working point being reached.

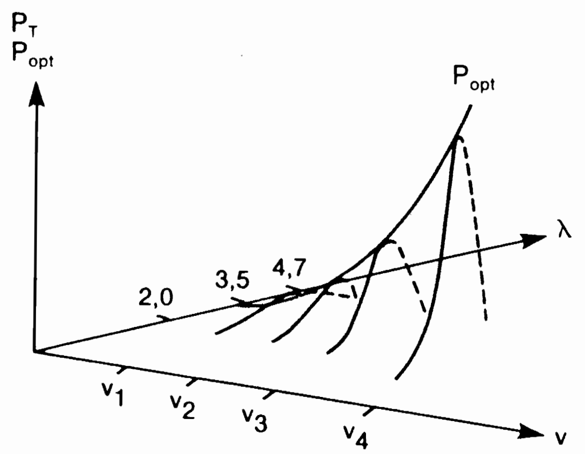

Fig. 12 A three dimensional picture of the maxpower tracking.

The associated mathematical equations are:

$P_T = f(v, \lambda)$ (7)

P_T is turbine power, V is windspeed.

λ is ratio of the blade speed to the wind speed.

$P_{opt} = Kv^3$ (8)

P_{opt} is the optimum turbine power.

If instead the turbine is retarding, it will be permitted to continue so, as long as a power shortage is being reduced, but an increase in a power shortage must result in an immediate reduction of the power output, to stop the retardation.

In this way, the power from the turbine is continuously optimized by means of corrections of the position of the working point.
If the total wind power is lower than the processor's own consumption, a deactivating signal is sent to the internal power supply equipment, and the system changes over to mode 3.

If the battery is almost fully charged, the system changes over to mode 2, trickle charging.

Mode 2 for trickle charging is used

When the battery is fully charged. The system remains in this mode as long as the wind power is greater than the power required by the battery and the load. The micro-processor, which has no regulating function in mode 2, slowly steps down the voltage control value to the level for trickle charging. The regulator will then be in a voltage-controlled state.
Changeover from mode 2 to mode 1 normally takes place automatically when the voltage difference between the battery and the rectifier has fallen to a certain value.

Mode 3 means that the processor has switched off its own power supply. Only the alarm functions and the circuits for reactivation remain active. The changeover to mode 3 takes place when the mean wind speed is less than 3.5 m/s. In mode 3, the power consumption is approximately 200 mW.

When the wind is gusting, the equipment can swing quickly between mode 1 and mode 3. The return from mode 3 takes place with the aid of a voltage monitor. When the voltage has reached a value that corresponds to 4.3 m/s (=4.7) a signal is given to switch on the power supply to the processor.

5. FIELD EXPERIENCE

The first Erigen hybrid wind and minidiesel power system was installed 1983 at a lighthouse some 15 km off shore in the Baltic south of Sweden, fig. 13.

Fig. 13 The Erigen powered lighthouse.

The major part of the power consumption is power for the light beacon and follows directly the variation of the length of the nights during the year. The maximum power consumption is 350 W average in December and minimum 100 W in June.

As the turbine is mounted beside the tower, one important condition which has been analyzed is how much the lighthouse tower itself reduced the wind power output by disturbing the airflow from different wind directions. The result is presented in fig 14.

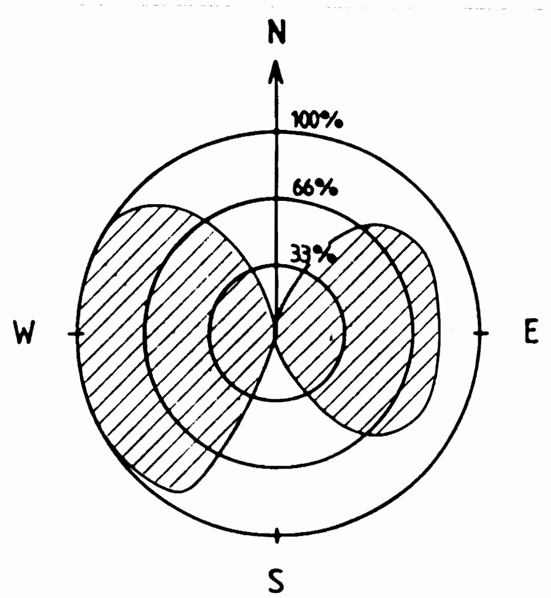

Fig. 14 Reduction of power from wind generator mounted beside a lighthouse tower.

Eighty percent off the consumed power over the year is produced by the wind generator. Twenty percent is produced by the minidiesel which has been running 380 hours/year to produce this amount. Thanks to the unique characteristics, the Darrieus -Savonieus type of wind generator in combination with the sophisticated microprocessor control and independent maxpower tracking, this rather difficult wind generator installation has been successful.

The lighthouse has been monitored by an Erigen datalogger since 1984. It has been of great value for the evaluation and understanding of this hybrid power system's performance and behaviour. Like many remote installations, the lighthouse can only be reached by helicopter. Analyzing and trouble shooting on site can only be made during short visits because of the uncomfortable working conditions. With these conditions in mind, the value of the datalogger for analyzing the system is even more obvious, when considering the fact that the course of events to be observed in a hybrid power station takes place over periods of varying lengths from days to months, depending on weather conditions and power consumption.

Another station in northern Sweden, fig. 15, which is a typical forest country site, has been in operation since early 1986. This system is a complete Erigen hybrid solar wind and minidiesel power system with 8 solar modules, 350 W peak and the Erigen wind generator, 950 W peak. The minidiesel generator, 1.5 kW has contributed 17 % of the total energy produced.

Fig. 15 The Erigen powered radiorepeater for the Swedish Railways.

For one year, the station has been observed with a datalogger, and an energy diagram, fig. 16, has been made up. The solar and wind power show a good complementary nature. However, during the cold December and January, the wind contribution was less than expected.

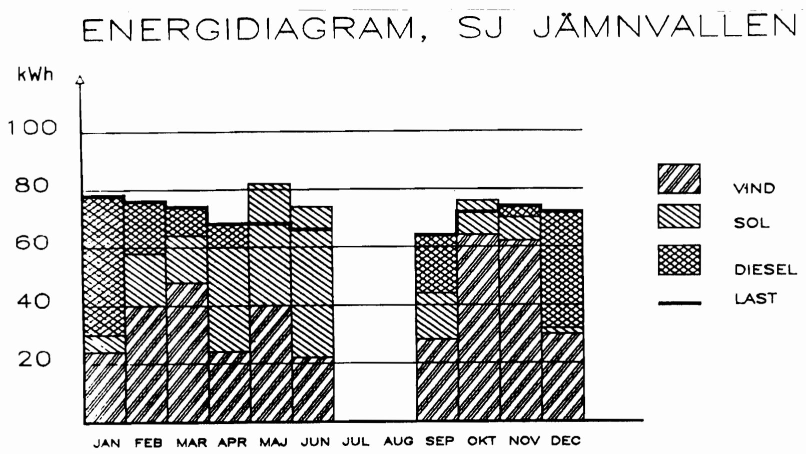

Fig. 16 An energy production diagram from one year of data collection from the Swedish Railways radio repeater.

FINAL REMARKS

The ERIGEN wind generator is one of the highly reliable components in the Erigen primary power system. Its robust design combined with the highly efficient alternator, advanced control and supervision electronics is a proven guarantee for the best of performance. With the built-in lightning protection of ball bearings, the ERIGEN wind generator is unique, with its advanced technology among wind generators for remote locations.

References

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2. Eriksson, M and Ottosson, J: Optimizing the power from a wind turbine, Ericsson Rev. No. 3, 1983.