intelec 83

FIFTH INTERNATIONAL TELECOMMUNICATIONS ENERGY CONFERENCE

October 18, 19, 20, 21, 1983

HOTEL PACIFIC

Tokyo, Japan

IECE

IEEE

Sponsored by

The IECE of Japan

(The Professional Group for Power Engineering in Electronics and Communications)

in association with

The IEEE Communications Society

83CH1855-6

13— 4

HYBRID POWER SYSTEMS FOR REMOTE SITES - SOLAR, WIND AND MINI DIESEL

J. Åkerlund

Power Supply Department, Telefonaktiebolaget L M Ericsson
126 25 Stockholm, Sweden

ABSTRACT

This paper describes a hybrid power supply system for remote sites, ERICSSON SUNWIND, consisting of solar, wind and mini diesel generators. As the system uses both solar and wind generators the particular advantages of this combination are discussed.

A highly reliable wind generator of vertical axis type will be described. It is virtually maintenancefree and equipped with unique lightning and overspeed protections. Also it is equipped with a microprocessor-based control system for output power optimization, which will be described in another paper presented at this INTELEC Conference.

The system includes two reserve energy sources, i.e. the station battery and the mini diesel generator set. The minidiesel which uses DC-generation will be described together with its control equipment. Its most important characteristics are the simple auxiliary system and the start up safety.

INTRODUCTION

Telecommunication sites where solar and wind generators are suitable and justified are often remote with rough climate and difficult terrain. To visit such distant places and carry out maintenance is timeconsuming and expensive. For these reasons high reliability and low maintenance will be of paramount importance in the long run.

ERICSSON has developed a hybrid solar and wind power system (fig. 1) consisting of a highly reliable wind generator of unique design, solar cell modules, a max. power tracking control equipment, batteries and a minidiesel generator set. The system can supply remotely located telecommunication equipment with up to 500 W power for 24 or 48 V dc. The most important characteristics of the system are a high degree of reliability and very low maintenance requirements.

ERICSSON Sunwind uses the complementary nature of sun and wind to smooth out the variations in the power supply from the separate sources. A lower level of the peak power installed can be selected as compared with a non-combined system. Also the battery can be smaller. The amount of solar and wind

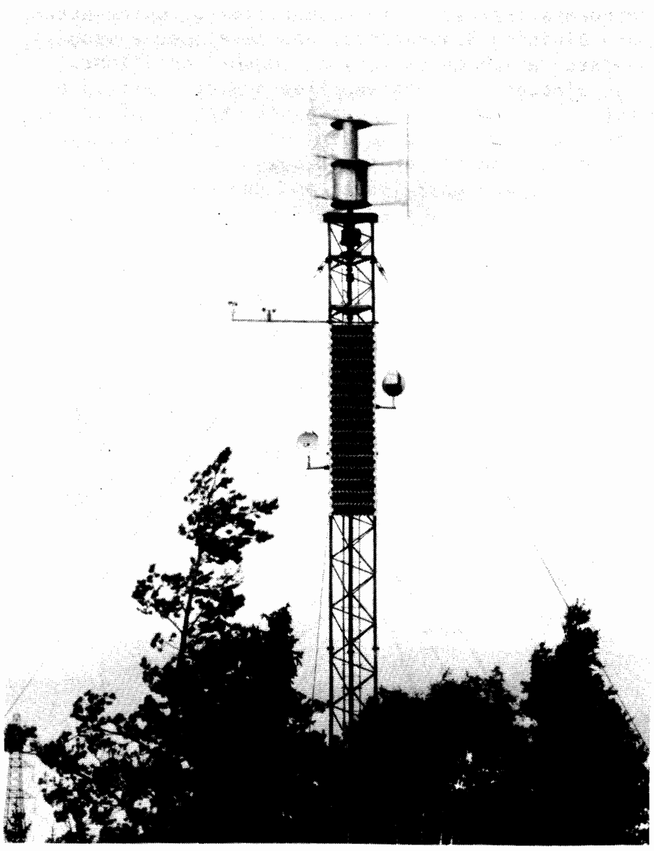


Fig. 1
The Sunwind solar-wind power plant

energy available varies continually in an irregular pattern. There can be major deviations from year to year and between locations in the same area. When there is an abnormal shortage of solar and wind energy the minidiesel will be started up to charge the plant battery. The availability of this reserve reduces the need for exact meteorological data, making it easier to design the system.

Depending on the power requirements, as well as meteorological and geographical conditions, different combinations of the system components can be selected. The wind turbine, solar cells and the

CH1855-6/1983 IEEE

mini-diesel can also be used alone or in pairs. Solar cells and the mini-diesel are frequently selected where there is a low power requirement in an area with a high level of solar radiation.

Solar cells are reliable but expensive for high power outputs. At windy locations a wind generator can be very cost effective. When combining wind and solar generators it is, however, very important to choose a wind generator of high reliability in order not to loose the reliability in the system.

WIND GENERATOR

A wind generator which is used to supply power to a telecommunication system must have at least the same degree of reliability as the other system components. Ericsson, in cooperation with the Aerospace Division Saab-Scania, has developed a wind generator which meets very stringent conditions. It is virtually maintenancefree and consists of a single moving part, without a gear-box or slip rings. It is designed to be mounted on top of radio link masts, and has at least the same mechanical strenght as the mast itself and the parabolic an-

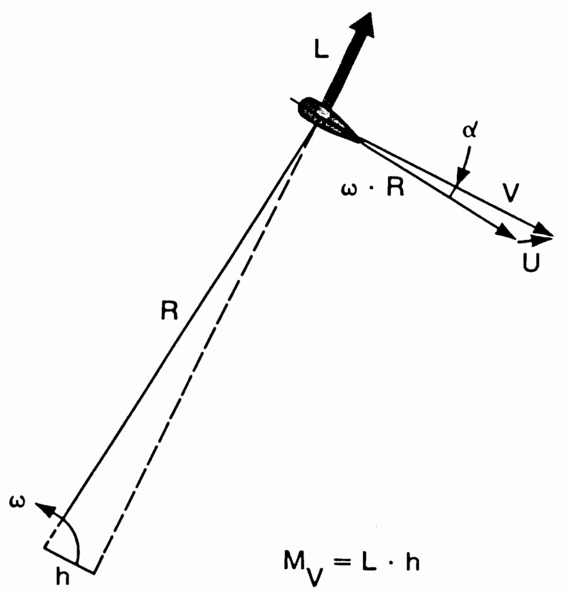


Fig. 2

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). V is displaced relative to wR by an angle of attack (α), which varies cyclically during the rotation. In the position shown here, the airflow 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 center resulting in a driving torque: $Mv = L \cdot h$. A positive torque normally is maintained during rotation.

tennas to withstand high wind velocities. The windspeed increases with the height above ground and since the power in the wind is proportional to the cube of the windspeed the highest possible installation of a windgenerator is of major importance.

The wind turbine SAAB-Ericsson VA 3 is of the Darrieus type with straight, vertical airfoil blade sections (fig. 2). It has a vertical axis which makes it independent of the wind direction. The turbine starts when the wind velocity reaches a value of about 3 meters per second. Good start-up characteristics have been obtained with a Savonius turbine which has the same axis as the Darrieus turbine.

Because the turbine has a vertical axis, the alternator can be placed under the turbine attachment plate inside the mast. The turbine axis bearing is simple compared with that of a conventional wind generator.

In order to limit the rpm (revolutions per minute) at high wind speeds, the turbine has been equipped with a maintenancefree, patented bladepitch mechanism which turns the blades so that they stall and lose their thrust. The turbine and the bladepitch mechanism has been fullscale tested in a windtunnel.

The alternator is of a new type that is specifically designed for wind power application. It has a multipole design so that it can be connected directly to the slowly rotating turbine. It is a brushless, three-phase, permanently magnetized alternator and does not suffer from magnetization losses. The windings are located in a selfsupporting stator of iron-free composite material. Because the windings do not have iron cores, the permanent magnets cannot lock the wind turbine during start-up, and the iron losses are eliminated. This is very important because the wind generator must function with the highest rate of efficiency at the most frequently occurring low wind velocities in order to produce the maximum amount of energy. Only the bearing friction in the turbine and generator needs to be overcome during start-up.

LIGHTNING PROTECTION FEATURES

The high reliability demanded in telecommunications implies adequately designed lightning protection for all system components including the wind generator. This matter however is difficult and often neglected in wind generator designs. ERICSSON has particularly paid attention to this problem and developed a unique and patented lightning protection system for wind turbines.

Since a wind generator shall be mounted as high above ground as possible, it usually becomes the highest point in the surroundings. This circumstance, however, makes it exposed to lightning strikes. Probability calculations shows that one to two strikes a year can be probable figures in Central Europe.

The damages of lightning strikes are of both mechanical and electrical nature. A wind generator need 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 high electric currents. If a high electric current flow 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. Sooner or later the ball bearing will stop working. The SAAB-ERICSSON VA3 turbine is equipped with insulators which prevents the current from passing through the ball bearings. A patent is applied for this design.

The electric damage of a lightning strike in a small horisontal axis wind generator hits the windings of the alternator as they are located on top of the unit. Actually in this case the windings together with the power cables work as the lightning conductor and will be destroyed. A vertical axis wind generator however is better off. Direct lightning strikes in the alternator windings are impossible. The alternator plus the electronics need only to be protected against induced overvoltages. The lightning protection of the turbine has been tested in a high voltage laboratory (fig. 3).

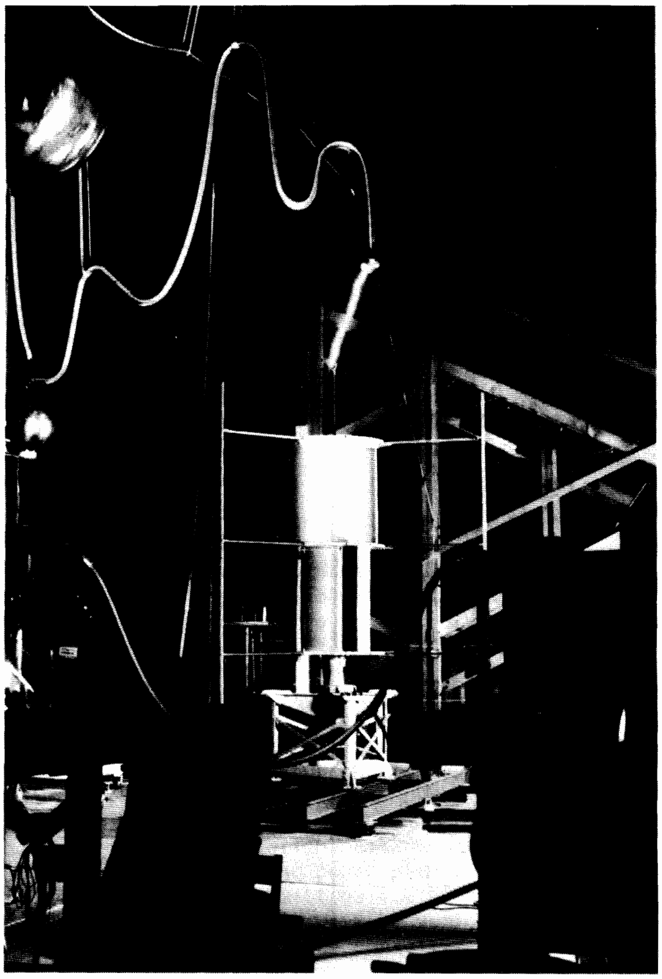


Fig. 3

The SAAB-ERICSSON VA3 turbine during lightning strike test in a high voltage laboratory.

SOLAR CELLS

The solar cell panels can be connected directly to the battery or via dc to dc converters in the power processing equipment (fig. 6). If the solar cell panels are connected via the converters, their output voltage can be controlled and the power output maximized. This also avoids a voltage increase across the battery.

With solar cells, voltage and peak power increases as the temperature decreases. The solar cell panels are designed with a large number of cells in series, so the voltage at the maximum panel temperature, 80°C (Celsius), will be the same as the charging voltage for the battery. With an average temperature of 0°C during the winter it will be possible, using dc to dc converters, to increase the average power output by at least 25 % (fig. 4).

During the cold and dark period of the year, the maximum power of the solar cells increases when it is most needed and compensates for the reduced solar radiation. A power-maximizing control system smoothes out seasonal variations, so that fewer solar cell panels and lower battery capacity are required.

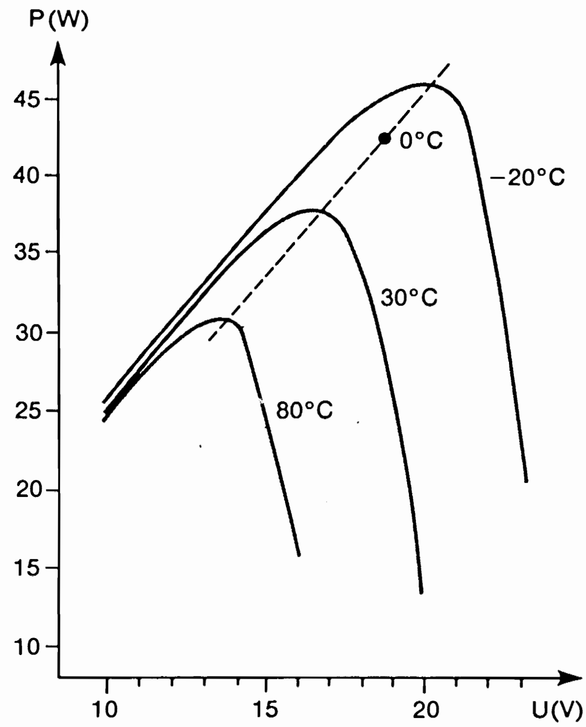


Fig. 4

The output from a 12 V solar cell panel with constant solar radiation of 1000 W/m^2 for various panel temperatures.

POWER PROCESSING EQUIPMENT

The power processing equipment is intended to maximize power output and regulate the charging voltage from the wind generator. The equipment is also used to maximize power output and regulate the charging voltage from the solar cells.

Wind power varies greatly with the wind velocity. It is important that the power output from the wind generator carefully follows these variations and that the turbine is kept at its most efficient working point (fig. 5).

The power processing equipment (fig. 6) consists of a rectifier, a number of dc to dc converters and a microprocessor with interface circuits. There is also a mini-diesel control.

The dc to dc converters are choppers. They convert the varied voltage from the rectifier to a constant voltage for charging the system battery. The microprocessor continually calculates the maximum available power from the varying energy flows of the wind and sun, and controls the converters. See further the other paper presented at this INTELEC Conference "Microprocessor control system for output optimization of a wind turbine.

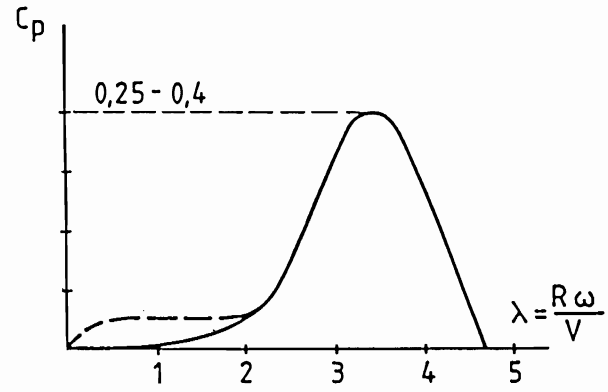


Fig. 5

Efficiency of a triple-bladed Darrieus turbine

——— Darrieus

– – – – Darrieus and Savonius

$$\lambda = \frac{R\omega}{V}$$

λ ratio of blade speed to wind speed
R turbine radius
ω rotation speed (angle velocity)
V wind velocity

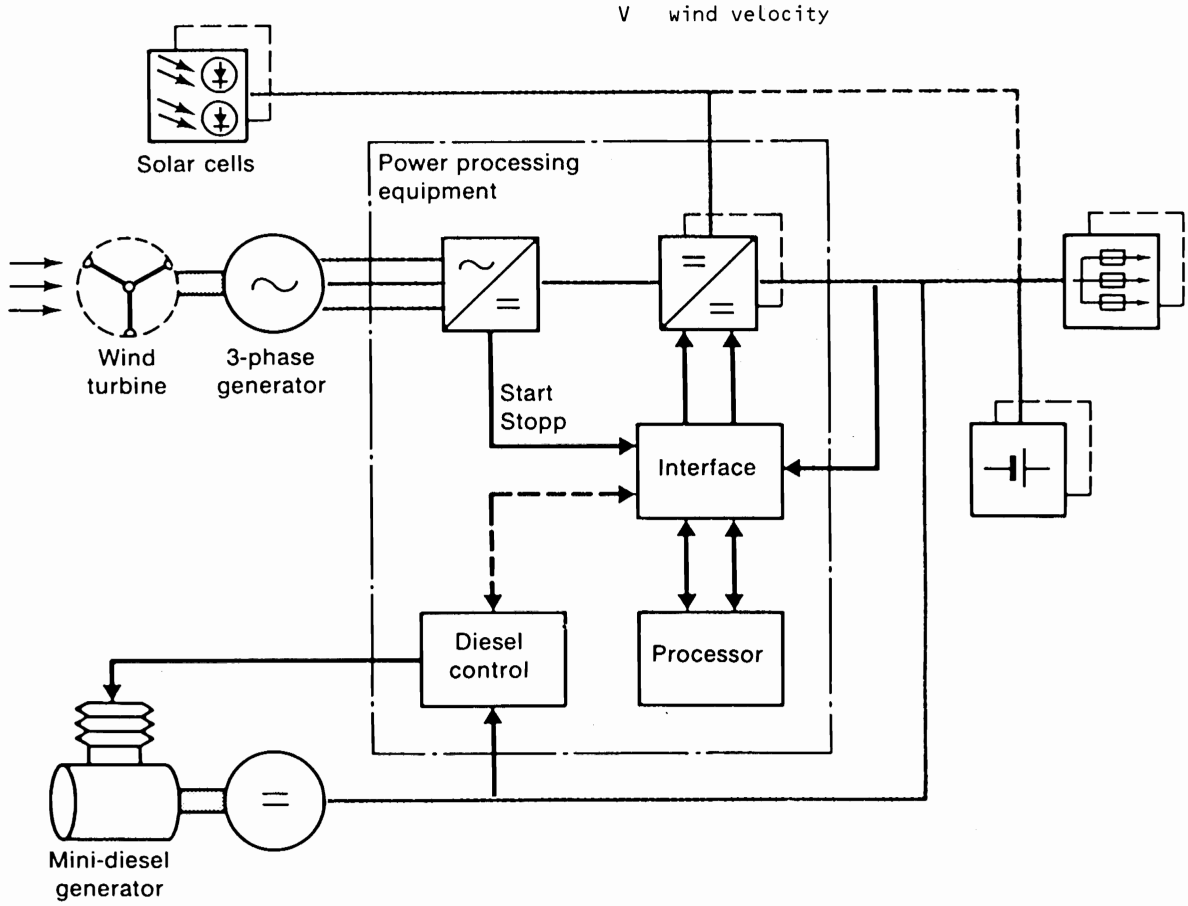


Fig. 6
Block diagram of the Sunwind power supply system

MINI-DIESEL AND CONTROL

A minidiesel generator in a solar-wind power supply system reduces the required size and generation capacity in the solar and wind generators as well as the size of the battery. Dimensioning of the system is simplified. Unforeseen variations in both solar radiation and/or winds as well as in load do not cause interruption of operation.

The strongest arguments against conventional diesel generators at remote locations are the reliability problem and the high cost of operation and maintenance. These problems can be reduced by using a simple auxiliary system and strictly limiting the running hours.

A diesel generator must be very start-up reliable in order to be used in solar-wind systems. There must be little doubt about its ability to switch-in as a final source of reserve power. Analyses of start failures in conventional diesel generators have shown that the majority of missed starts have been caused by faults in the auxiliary system. These have included missed start motor engagement, faults in the start motor, badly maintained or faulty starting battery, faults in the start-up battery charger or faults in the motor's supervision circuits. In order to eliminate the majority of these problems and to increase the reliability in the diesel generator system the separate starting motor, its starting battery and the intermediate recitifiers have been excluded (fig. 7).

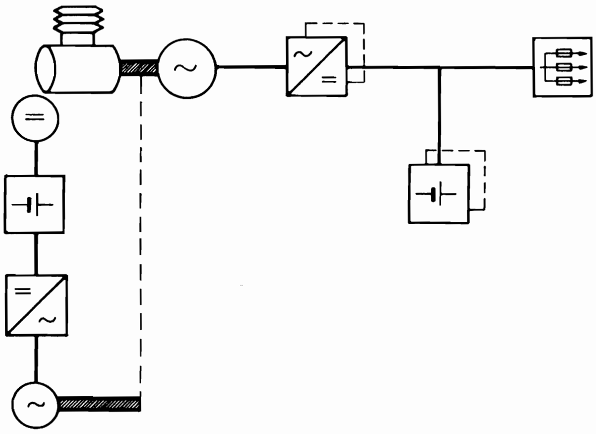
The mini-diesel generator set consists of an air-cooled single-cylinder diesel motor and a dc generator. The generator is equipped with a starter winding and is also used as the starting motor. The starter winding is strong enough to start up the engine without using decompresssion devices. Consequently, a separate starting motor with associated starter battery and charging equipment are not required. The plant battery serves simultaneously as a start-up battery.

The mini-diesel can be installed in a steel shelter on top of its fuel and lubrication oil tanks thus forming a complete self-contained power package. This almost eliminates civil work on behalf of the mini-diesel set (fig. 8).

A control unit has been developed to control the mini-diesel generator and to supervise the battery in the solar-wind power system. The main objective is to strictly limit the running hours of the mini-diesel generator and to prevent the mini-diesel starting unnecessary number of times.

Normally the station battery will be rather big in a solar and wind power plant. The batteries discharge current/Ah will be low and the battery voltage discharge curve will be very fault. Detecting the remaining battery capacity and to start the mini-diesel by voltage detection only, would be insufficient since the batteries' voltage discharge curve is affected both by the age of the batteries and by the temperature. To master this problem the control unit, which is based on a microprocessor, supervises the battery charging

A conventional diesel generator system.



A mini-diesel generator system.

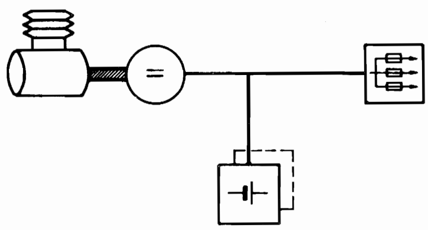


Fig. 7

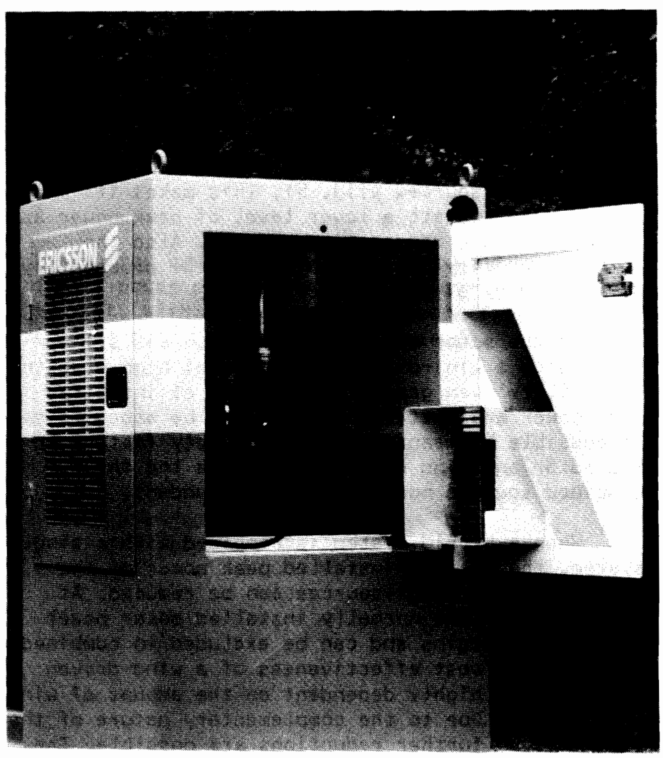


Fig. 8

state by both voltage detection and digital ampere hour counting, which continually registers the current to and from the battery. In this way, the charging state can be monitored with precision and the mini-diesel can always be started at the pre-determined minimum remaining charge level.

In solar wind plants, the batteries work under special conditions. Daily low-rate charging and discharging are combined with slower monthly and seasonal charging and discharging on a major scale. The battery current will be small in relation to the capacity of the battery. There is an increased risk for sulphate build-up and a subsequent degra-d ation in capacity if the battery is allowed to stay in a half-charged state for long periods. Charging on a regular basis several times per year is recommended to prevent sulphate build-up in the battery. Because the system includes a mini-diesel with a programmable control unit, such charging occurs at regular intervals, providing secure full charging and extended battery life. The batteries are usually sized to permit a reserve time of 1 to 2 weeks.

Because the running hours for the mini-diesel set has been strictly limited with the help of the charging monitor, fuel consumption and repair requirements have been reduced significantly. Consequently, fuel and lubrication oil tanks can be designed for several years of operation in order to reduce transportation costs. Power rating is 1.5 or 3 kW 48 V (or 24 V) nominal.

SIZING

Solar, wind and diesel generators have their own specific advantages and disadvantages. The aim of combining those different power sources is to use the advantages of the individual sources in a complementary way in order to obtain the most cost effective system. There is an inherent advantage of combining the sun and the wind. They often have a complementary nature during the year which smoothes out the variations in the power supply from the separate sources (fig. 9). This makes it possible to install a lower level of peak power as compared with a non-combined system. Also the battery capacity may be smaller as the probability of continuity of supply increases.

If the solar and wind energy sources are combined with a mini-diesel generator of high starting reliability even greater reductions of installed peak power and battery capacity can be made. This is possible by means of reduced safety factors in the solar and wind energy sources as the three combined sources now are partly redundant.

When a hybrid system is compared with a single system, the cost of installed peak power of the solar and wind power sources can be reduced. At least 20 % of the normally installed solar power are safety margins and can be excluded in combined systems. The cost effectiveness of a wind driven generator is highly dependent on the amount of wind at the site. Due to the complementary nature of the wind and sun further reductions are possible. The tilt of the solar modules can be chosen to optimize for the summer period instead of for the winter period or for the season when the wind energy is low. This increases the local energy production per module and reduces the required number of solar modules. The reduction can be made without any penalty in fuel consumption or overall system reliability.

Before sizing a hybrid system the following factors need to be assessed

- meteorological, geographical and topographical conditions
- the final battery reserve available, if it becomes necessary to reach the site in an emergency situation, when the mini-diesel has failed to start up
- the amount of energy the mini-diesel may be assigned to produce.

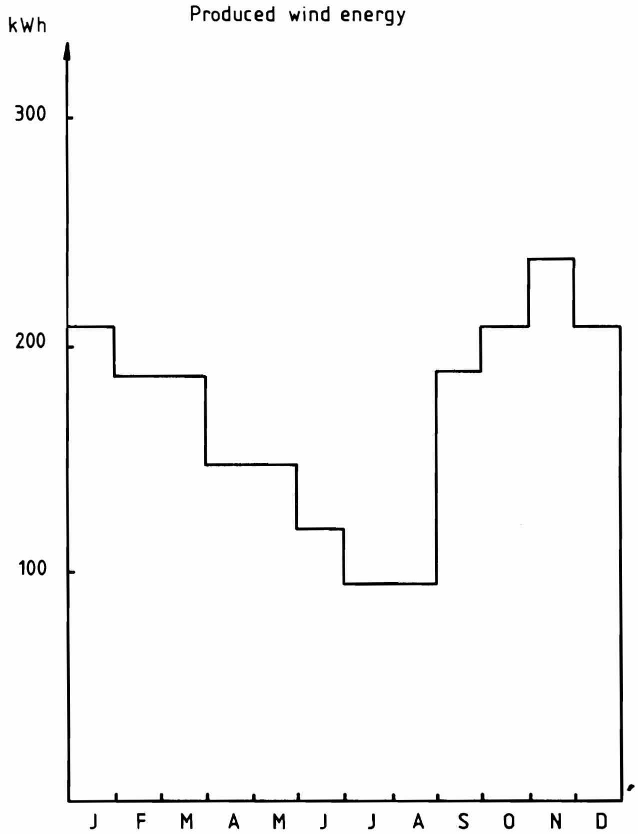
According to the meteorological conditions and the needed power output the balance between wind and solar and mini-diesel energy production can be defined. The possible energy output from the wind driven generator at the site is calculated at first. The better modularity of solar modules compared to a wind generator now makes it easy to size a solar generator that can produce the additional energy amount needed to supply the total power demand.

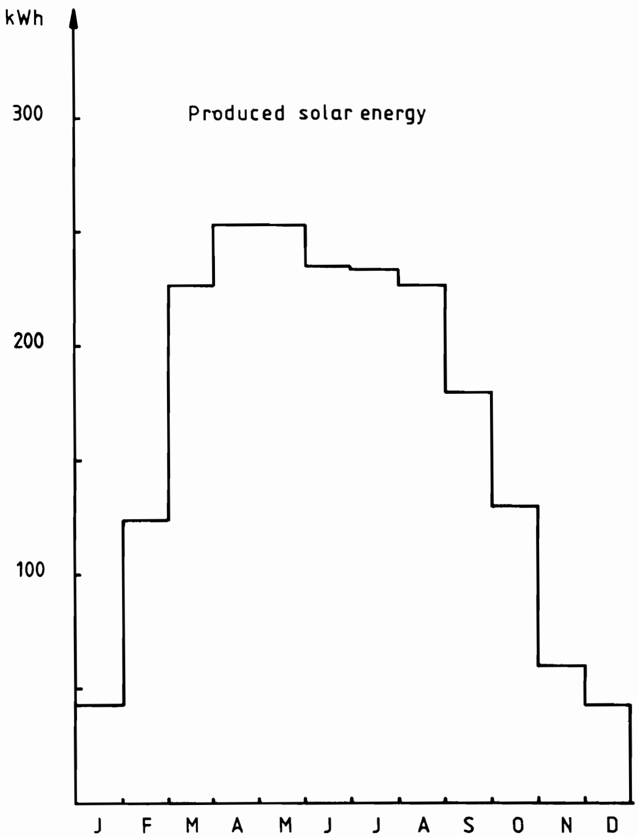
When proper meteorological data are at hand and presented monthly an energy budget as in fig. 9 can be set up. This makes it possible to size the plant tightly and to take advantage of the complementary nature of sun and wind. The size of the solar generator and the tilt of the panels are now selected in order to add the optimal amount of energy when the wind energy supply is low.

FINAL REMARKS

ERICSSON SUNWIND is designed to use the continually varying flow of random energy in the best possible way. With microprocessor control the solar and wind energy converters can be guided to their optimal working points and at each moment extract the maximum amount of power. The vertical-axis turbine with its patented blade-pitch-adjustment and lightning protection offers secure operation in extremely high wind velocities and in thunderstorms. It is virtually maintenance-free and highly reliable.

The mini-diesel generator permits a reduction in the size of the random power sources and battery while extending battery service life.





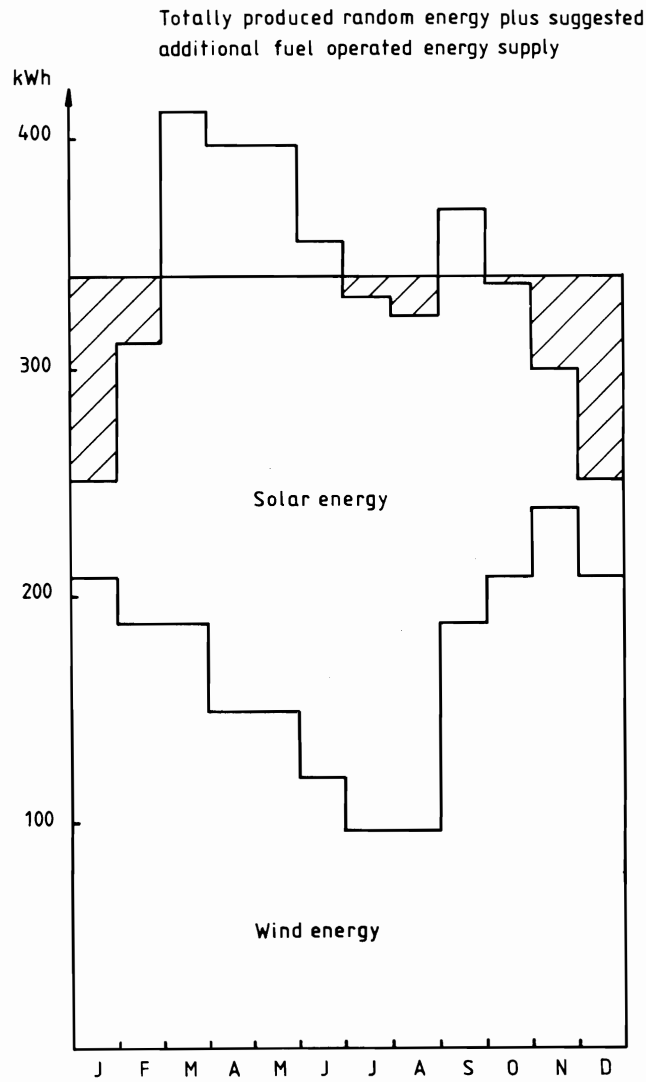


Fig. 9

The energy budget for a solar and wind plus mini-diesel power plant at a coastal location at about 60° lat. with an average windspeed of 6.7 m/s and a power consumption of 450 W average.