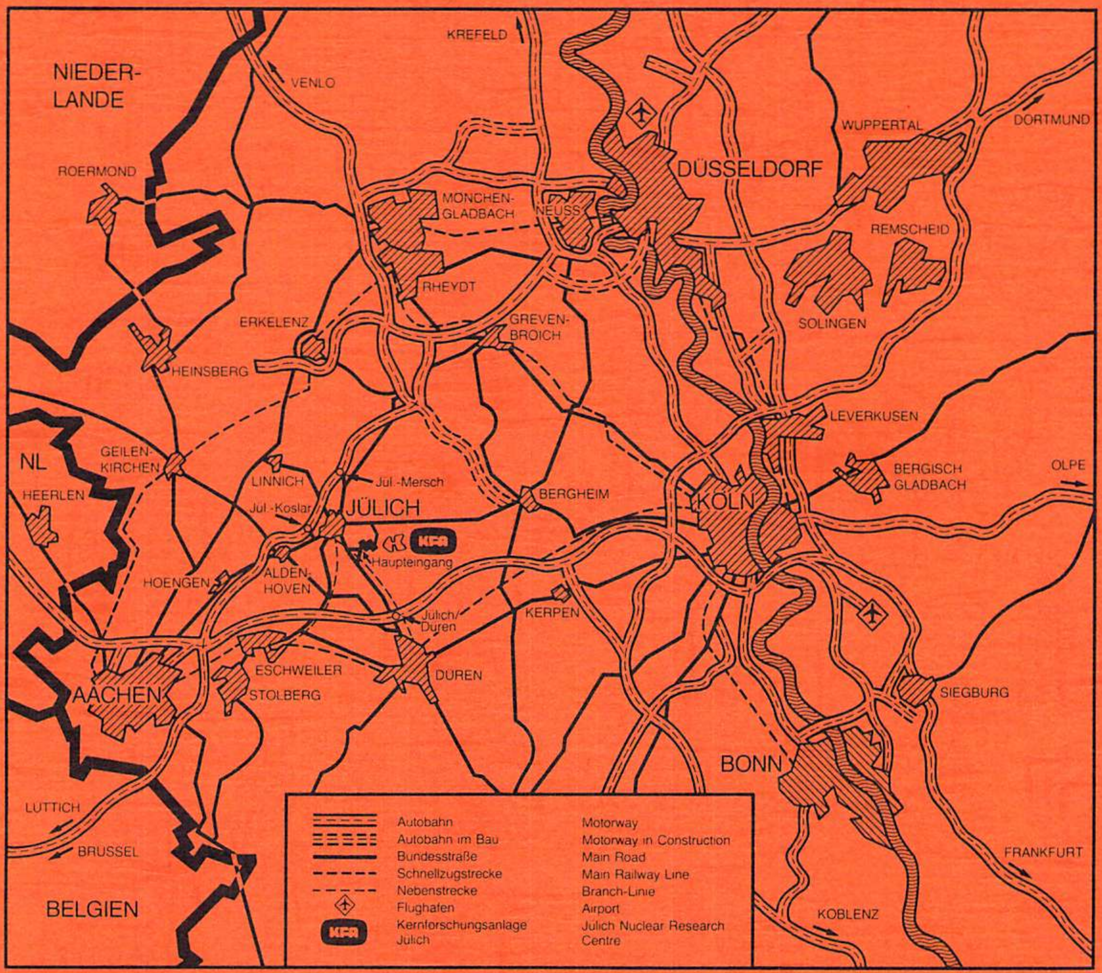
KERNFORSCHUNGSANLAGE JÜLICH GmbH
Projektleitung Energieforschung
International Energy Agency IEA

Implementing Agreement for Co-Operation in the Development of Large Scale Wind Energy Conversion Systems

8th Meeting of Experts-
Safety Assurance and Quality Control of LS WECS During Assembly, Erection and Acceptance Testing

Organised by
Project Management for Energy Research (PLE)
of the Nuclear Research Establishment Jülich (KFA)
on behalf of the
Federal Minister of Research and Technology,
the Fluid Mechanics Department
of the Technical University of Denmark and
the National Swedish Board for Energy
Source Development

Jül - Spez - 203
April 1983
ISSN 0343-7639



Als Manuskript gedruckt

Spezielle Berichte der Kernforschungsanlage Jülich – Nr. 203

Projektleitung Energieforschung Jül - Spez - 203

Zu beziehen durch: ZENTRALBIBLIOTHEK der Kernforschungsanlage Jülich GmbH
Postfach 1913 · D-5170 Jülich (Bundesrepublik Deutschland)
Telefon: 02461/610 · Telex: 833556 kfa d

Implementing Agreement for Co-Operation in the Development of Large Scale Wind Energy Conversion Systems

8th Meeting of Experts-
Safety Assurance and Quality Control of LS WECS During Assembly, Erection and Acceptance Testing

Stockholm, May 26–27 1982

Organised by
Project Management for Energy Research (PLE)
of the Nuclear Research Establishment Jülich (KFA)
on behalf of the
Federal Minister of Research and Technology,
the Fluid Mechanics Department
of the Technical University of Denmark and
the National Swedish Board for Energy
Source Development

Scientific Coordination:
L. Möller (PLE-KFA Jülich)
M. Petersen (Techn. Univ. of Denmark)
R. Windheim (PLE-KFA Jülich)

C O N T E N T S

THE SWEDISH PROTOTYPE NÄSUDDEN

Safety assurance and quality control during assembly, erection and acceptance testing.

Contribution by G.Svensson - Swedish State Power Board

Introduction

The Swedish State Power Board (SSPB) is a public utility responsible for almost half of the Swedish electrical energy production. (44 TWh/year)

In the Swedish Wind Energy Program the SSPB represents the National Swedish Board for Energy Source Development (NE) during the design, manufacturing, erection and evaluation of one of the two LS WECS that NE has ordered.

The project we are participating in, is the one built by
OH 1 KAMEWA in cooperation with MBB-VFW in FRG. The unit is
OH 2 located at Näsudden on the Island of Gotland.

The order was placed with KAMEWA during the second half of 1979.

OH 3 The project status is that the tower has been cast, manufacturing of blades and machinery is completed. Shop tests have been performed and erection is scheduled to June and July this year. The first rotation will take place during the autumn.

General description of the unit

OH 4 The prototype is a horizontal axis, two bladed, upwind machine. The rotor diameter is 75 m and the center of the hub is 77 m above the ground level.

Rated power is 2 MW at a windspeed of 12.5 m/s.

Cut-in and cut-out wind speeds are 6 and 21 m/s respectively and the turbine rotates at 25 rpm.

Energy production is estimated to 6 GWh/year and the design life is 30 years.

Blades

The blade is designed by MBB-VFW in Bremen and the steel work has been done by AG Weser, a shipyard, also in Bremen.

OH 5 The blade is designed with a load carrying box of welded steel with internal ribs.

The upper and lower side of the box is part of the aerodynamic profile and the nose and trailing edges of the profile are formed by GRP-panels screwed to the steel box.

OH 6 The profile is a NACA 64-4XX and the twist is 15^{0}.

The material for the steel box is a water-quenched, fine grain steel, NAXTRA 56, with a yield strength of 550 N/mm2.

The box is welded in two halves and bolted together.

The total weight of one blade is in the order of 20 tons.

Hub, nacelle and machinery

OH 7 The turbine has full pitch blades and the blades with bearings are bolted to a rigid hub. The hub is a cylinder formed by welded steel plates.

The nacelle is a load carrying shell design. The primary shaft, bolted to the hub has a tilt of 10^{0}. One of the bearings for the main shaft is close to the hub and the other is within the gear box. The first bearing is the one taking the thrust load.

The gear box has two planetary stages and the final stage is a bevel-gear with an angle of 100^{0}. The step-up ratio is 60 which means that the secondary shaft is rotating at 1500 rpm.

The arrangement with a bevel-gear makes it possible to arrange the generator in the lower part of the nacelle, below the yaw bearing. The generator is fixed to the non-rotating parts and thus there is no need for slip-rings and the size of the nacelle can be reduced, which is of importance for transport and handling.

On the secondary shaft there is a parking brake and also a shear coupling.

As it is an upwind turbine the yaw angle is governed by two hydraulic motors, acting on the yaw bearing. When the correct yaw angle is found the nacelle is held by six disc brakes.

The hydraulic pitch change mechanism is inside the hub.

Tower

The tower is a prestressed, conical concrete tower on a concrete foundation.

The diameter of the foundation is 22.3 m. The diameter at the base of the tower is 10.4 m and at top 4.5 m. The wall thickness is 400 mm.

In the bottom of the tower there are three floors with rooms for electrical equipment, data acquisition system, control room and a room for the personnel.

OH 8 The weight of the tower is 1500 tons and the foundation 1900 tons.

Electrical system

The generator is an asynchronous generator with a rated output of 2.4 MW. The power is transmitted by cables to the ground level where in the bottom of the tower the switchgear, generator breaker, control and protection equipment is located. Outside the tower is the transformer, transforming the voltage (6 kV) to the level of the utility grid, 30 kV.

Control system

The control system is based on Programmable Controller (PC-system). There are two such units, one in the nacelle and one in the control room in the base of the tower.

For the communication between the systems, optical fibers are used in order to reduce the risk for electrical disturbances.

The PC-system makes it easy to monitor the status of all different components in the unit.

Safety assurance and quality control during assembly, erection and acceptance.

Safety assurance and quality control is a wide subject and I will not go into all details that have been discussed and performed during this project but I will mention only some areas that can be of a more general interest.

The contract between NE and KAMEWA is based on a turn key delivery. The contractor shall thus perform and be responsible for the quality control and verification according to the technical specification and verification program.

The detailed programs are made by the contractor for approval by the customer. The customer has of course the right to participate during the tests and also at his own expense perform tests himself if found necessary and if it is not affecting the contractors work.

The following presentation will be based on the different subsystems, previously described, as far as possible.

Blades

The blade is probably the most difficult and sensitive part of a Wind Power Plant.

OH 9 As the load carrying part of the blade is made of welded steel, fatigue is a major design factor.

The allowable stress levels are according to the Swedish Structural Welding Code and the crack inspection shall be 100 %.

As each inspection method has its own advantages and disadvantages,certain welds have been inspected by as well ultrasonic as X-ray as with magnetic particles, each to an extent of 100 %.

The reference level is based on crack propagation calculations.

As previously mentioned the steel box is made in two halves, which makes it possible to have good access to all welds as well as a good corrosion protection can be applied before the two halves are bolted together.

The geometrical shape has been checked by templates and before drilling the final size of the holes the two halves can be adjusted according the specified tolerances.

To avoid problems with different weight of the two blades, due to tolerances of the plate thicknesses,each plate has been cut into two identical pieces, one for each blade.

After applying the GRP-panels weight and center of gravity was measured and compared with calculated values.

The dynamic properties of a single blade was determined by fixing the blade in a rig and excite the three lowest flapwise eigenfrequencies, the two lowest lead-lag frequencies and the first torsional frequency.

In order to verify the calculations, a static test was performed in the same rig as for the dynamic test. The load applied, except for the centrifugal load, was corresponding to the maximum static design load. Stresses and deflections were measured during the test.

After the static test critical areas have been crack in-spectected and the geometrical shape is checked.

Several of the strain gauges will be used later on during the evaluation phase and to be sure that the sealing compound withstands the contrifugal loads, tests have been performed in a centrifuge.

Hub, nacelle and machinery

OH 10 The quality standard for the material and welding follows the "Regulations for Steel Structures" and the "Swedish Structural Welding Code".

As well as for the blades the welds in the hub have been crack inspected to 100 %.

Special efforts have been made to make sure that the impact strength is high enough at temperatures down to -30°C.

The major components in the nacelle and hub as the gear box, blade bearings and yaw bearings have been inspected and tested in front of an independent control organization as Det Norske Veritas, on behalf of KAMEWA.

Most of the other components as the hydraulic equipment, sensors etc has individually been tested at KAMEWA before the assembly.

In order to reduce the amount of work on site, an extensive shop test has been performed during the last months at KAMEWA. The complete nacelle with hub has been tested according to a detailed program.

All different subsystems have been tested together with the control system. The different modes of operation has been simulated and failure modes have been investigated as well as the emergency feathering system.

A spin test has been performed during almost 50 hours with the yaw and pitch change mechanisms activated.

To make sure that all components withstands an overspeed situation the spin motor has run with 20 % overspeed. This also gave an opportunity to check the overspeed detectors.

The blades were simulated by attached weights to the blade bearing in order to learn the behavior of the pitch change system.

The eigenfrequency of the pitch change mechanism was also measured in order to verify the assumptions in the stability calculations.

The shop test has given a lot of valuable information regarding the behavior of the system and has also made it possible to make necessary modifications with good access to a well equipped workshop.

Preliminary inspection by Swedish authorities regarding safety for personnel has taken place. A final inspection will take place before the unit is formally delivered.

Tower and foundation

OH 11 The quality control for the tower has been performed according to the Swedish code "Regulations for Concrete Structures".

The design for the tower and also for the nacelle includes the load case "lost blade". Which mean that if one blade is lost, the nacelle must not be dislocated from the tower and the tower must not turn over.

There are provisions made for injection of concrete into the ground if a pitching of the tower should occur.

As part of the dynamic testing program the three lowest eigenfrequencies and the first torsional frequency, for the tower without nacelle and blade, has been measured.

Before first rotation there will be a dynamic test for the complete system performed at site,in order to verify the dynamic calculations.

Electrical system

OH 12 The electrical equipment is of a conventional type and standard procedures are used for verification and quality control.

Control system

OH 12 During the shop-test the PC-systems have been tested and debugged. The verification of correct behaviour at malfunctions has been performed.

Procedures for testing the sensitivity to electrical disturbances and lightning strokes are presently under discussion.

Acceptance testing

OH 13-14 During the acceptance phase the contract specifies that the following tests and investigations shall be performed.

Conclusion

I will strongly point out that the procedures discussed here refer to a prototype where the uncertainties and number of questions are many. If there in the future will be a serial production the procedures will most likely be different. I think it is important not to establish a practice too early, because once accepted it is very hard to change.

On redundancy in the process systems of large scale wecs.

P. Christiansen - ELSAM

BACKGROUND.

One of the activities of the Danish wind energy programme has been to build and operate the two Nibe turbines in order to gain practical experience with the problems involved. Fig. 1.

The status of the turbines today are as follows:

Nibe A	In automatic unmanned operation.	
	One week service interval.	
	Operating hours	1468
	Production MWh	302.2
Nibe B	Under commissioning.	
	Operating hours	948
	Production MWh	186.5

DEVELOPMENT PROJECT.

As a continuation we are at present working with systems design for an upscaled Nibe-B. Fig. 2.

H_H = 60 m
D = 60 m
Generator rating: 1450 kW
Pitch control for power regulation.
Upwind, active yaw system.

The size is 2.3 × Nibe-B with respect to generator size and 1.5 × Nibe-B with respect to blade length.

This increase in size tends to complicate the design, since the demand for auxiliary systems for the main components rises sharply with the rated output.

NIBE EMERGENCY STOP STORY.

Now let us look at the 2400 hours we have accumulated on the Nibe turbines and concentrate on the Emergency Stops (ES), we have had. Fig. 3.

2 ES Caused by computer malfunction within the first 200 hours.
After correction: None.

2 ES Caused by a silted servovalve within the first 150 hours.
After cleaning: None.

7 ES Caused by voltage drops or black-outs on the grid. Events evenly distributed throughout the operating time.

These facts point to the following conclusions, of which the first is rather obvious:

- The classical bathtube-curve can be applied to a wind turbine.

- The dominating number of emergency stops is caused by external events (i.e. from the grid).

ON REDUNDANCY.

Now, on redundancy: Redundancy can mainly be applied for two reasons.

1. To increase availability of a plant.

2. To increase reliability of a safety system.

For a wind turbine cluster only ≠ 2 needs to be taken into consideration, as the number of turbines in the cluster provides a very high level of redundancy resulting in a very high availability compared with the uncertainty caused by the wind. The picture is the same seen from a service point of view, since the amount of repair rises with the amount of equipment and with systems complexity, and since redundant systems should be checked periodically to assure that they are actually functional.

DESIGN PHILOSOPHY.

This leads to the following design guidelines:

- An emergency stop shall not be regarded as an extreme event, but be regarded as a normal way to stop the turbine should something fail.

- The safety of the turbine shall be obtained by checking that critical process variables (for example gear lube oil flow) are inside the operating limits. If not, emergency stop should be the result.

  Components (bearings for example) shall, by a conservative design, be secured loads and operating conditions so that failures have a very low probability.

  If the condition of components is supervised (temperature or vibration), alarm conditions shall result in a normal stop procedure.

HARDWARE IMPLEMENTATION.

The above described principles can be implemented as follows:

- All normal operating systems are made without other redundancy or back-up than that required to start, operate, and stop the turbine when all systems are working as intended. Fig. 4.

- The turbine shall be equipped with a safety system with the following features:

  - One hydraulic safety cylinder with gas accumulator for each blade. Fig. 5.

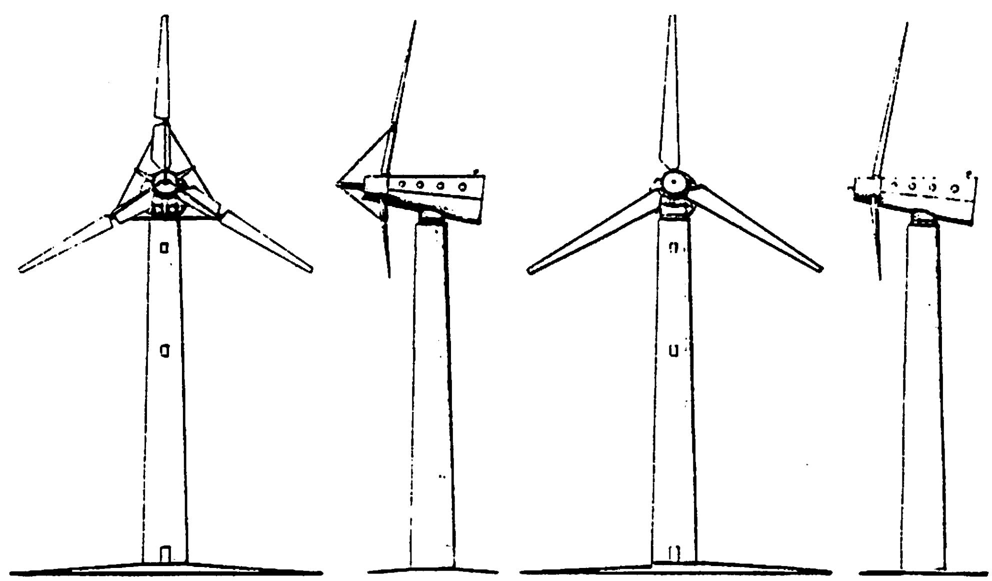
  - A "one of two" failsafe relay circuit with transducers initiating an emergency stop should a failure occur that threatens the turbine or one of its main components. Fig. 6.

  - A protective relay system for the generator with redundant short-circuit relays and a "one of two" trip circuit with one or other form of redundancy for the generator circuit-breaker. Fig. 7.

CONCLUSION.

The design principles described above follow the ideas from the Nibe turbines closely, but are augmented with respect to the attitude to redundancy in auxiliary and normal operating systems.

We hope that a future project will enable us to try these ideas in practice.



møIle A

møIle B

De to Nibe møller
set forfra og fra siden.

Fig. 1

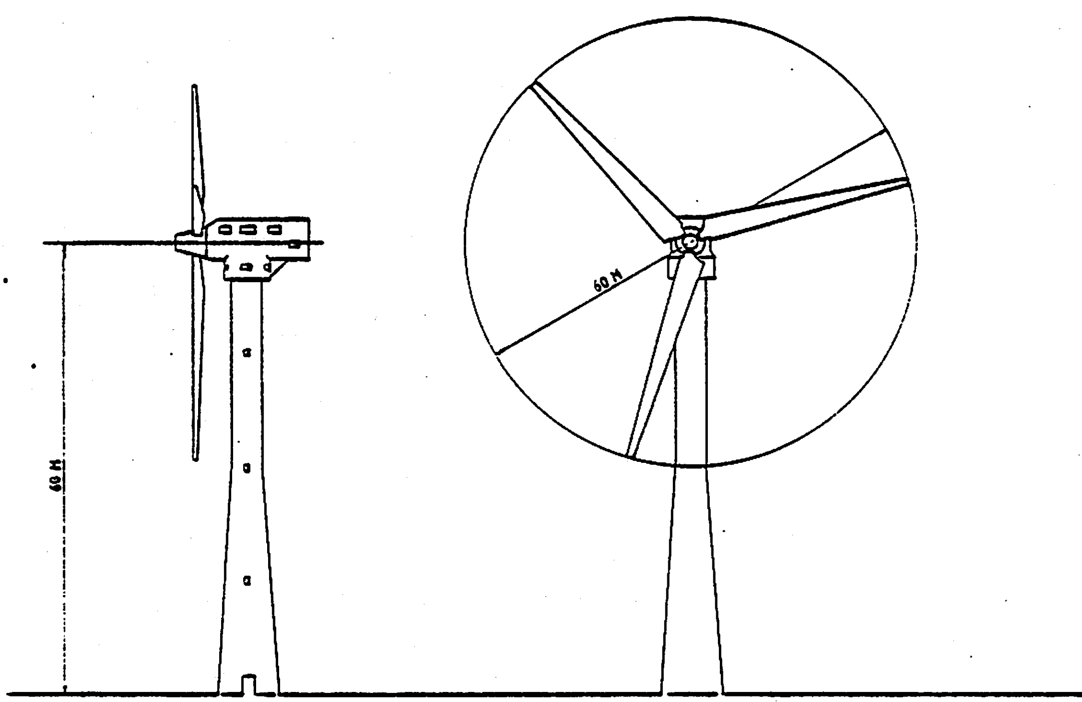


Fig. 2

EMERGENCY STOPS.

NIBE A	27.03.80	SILTED SERVOVALVE	X
	29.04.80	EARTH FAULT RELAY	
	4.05.80	SILTED SERVOVALVE	X
	30.08.80	VOLTAGE DROP ON GRID	
	7.10.80	VOLTAGE DROP ON GRID	
	8.10.80	VOLTAGE DROP ON GRID	
NIBE B	19.02.81	VOLTAGE DROP ON GRID	
	9.03.81	COMPUTER WATCH-DOG	X
	23.03.81	COMPUTER WATCH-DOG	X
	30.03.81	VOLTAGE DROP ON GRID	
	4.05.81.	VOLTAGE DROP ON GRID	

TOTAL 11

7 CAUSED BY EXTERNAL EVENTS

4 CAUSED BY INITAL FAILURES, NOT SEEN AGAIN AFTER CLEANING OR REPAIR.

Fig. 3

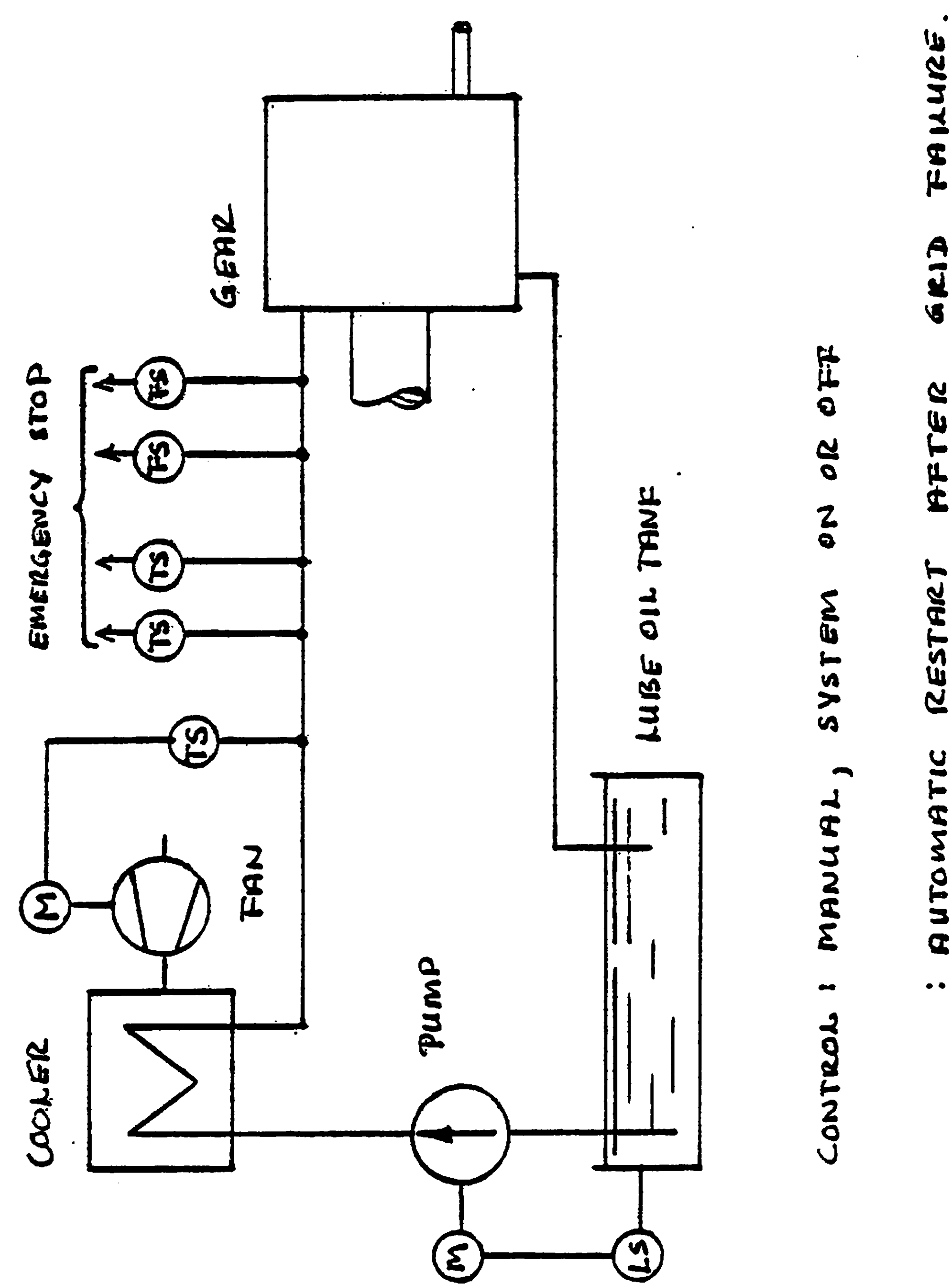

COOLER
M
FAN
TS
TS
TS
TS
TS
EMERGENCY STOP
GEAR
PUMP
M
LS
LUBE OIL TANK
CONTROL : MANUAL, SYSTEM ON OR OFF
: AUTOMATIC RESTART AFTER GRID FAILURE.

Fig. 4

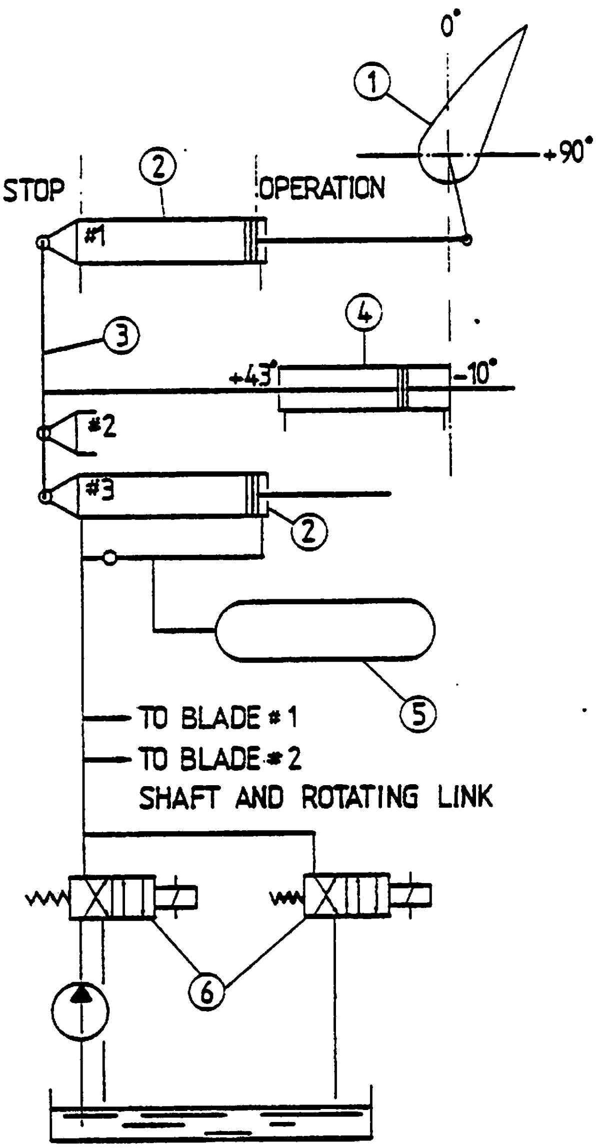

0°
1
+90°
STOP
2
OPERATION
#1
3
4
+43°
-10°
#2
#3
2
5
TO BLADE # 1
TO BLADE # 2
SHAFT AND ROTATING LINK
6

Fig. 5

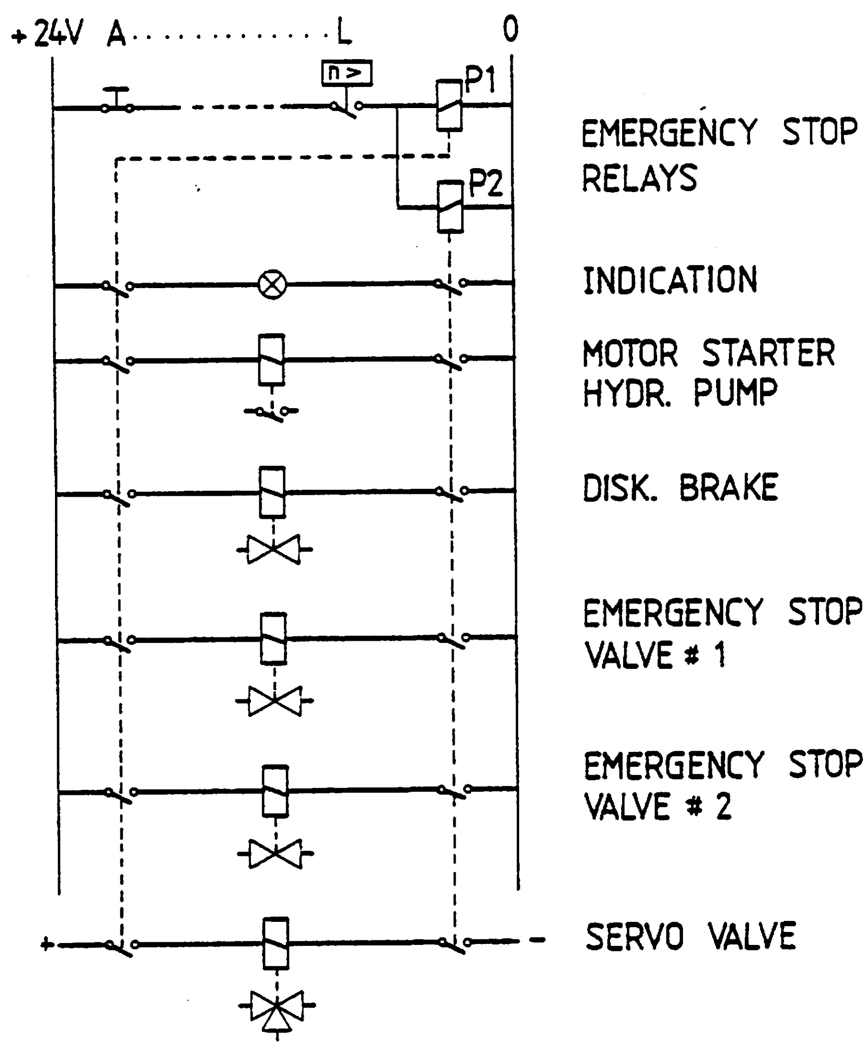
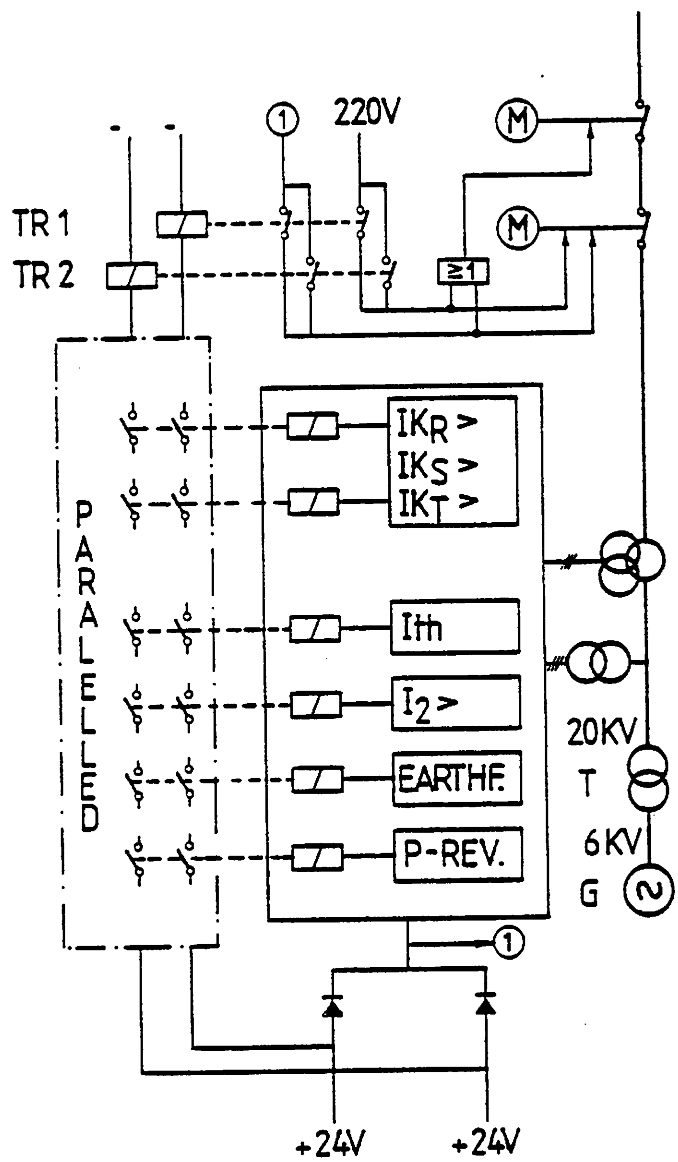

+24V A L
0
n >
P1
P2
EMERGENCY STOP
RELAYS
INDICATION
MOTOR STARTER
HYDR. PUMP
DISK. BRAKE
EMERGENCY STOP
VALVE # 1
EMERGENCY STOP
VALVE # 2
+
SERVO VALVE

Fig. 6



1
220V
M
M
TR 1
TR 2
≥1
PARALELLED
IKR >
IKS >
IKT >
Ith
I2 >
EARTHF.
P-REV.
20KV
T
6KV
G
1
+24V
+24V

Fig. 7

Standard Procedures, Glossary and Requirements

P.B. Simpson - participant representing
WIND ENERGY GROUP (UK)

ABSTRACT

Discussion of Quality Assurance of wind turbine generators should be based on an appreciation of the standard procedures that are now adopted in numerous fields for the application of quality assurance principles.

This contribution therefore represents a summary of the basic terminology and requirements of quality assurance, making reference to the principle British Standards Institution Publications relating to the subject.

QUALITY ASSURANCE

British Standards Institution Publications

BS 4778	:	1979 Glossary of General Terms used in Quality Assurance
BS 4891	:	1972 A Guide to Quality Assurance
BS 5750	:	Quality Systems
1979	:	Part 1 Specification for Design, Manufacture and Installation
		Part 2 Specification for Manufacture and Installation
		Part 3 Specification for Final Inspection and Test
1981	:	Part 4 Guide to the use of BS 5750 Part 1
		Part 5 Guide to the use of BS 5750 Part 2
		Part 6 Guide to the use of BS 5750 Part 3
BS 5760	:	Reliability of Systems Equipment and Components
1979	:	Part 1 Guide to Reliability Programme Management
1981	:	Part 2 Guide to Assessment of Reliability
BS 5781	:	Measurement and Calibration Systems
1979	:	Part 1 Specification for System Requirements
1981	:	Part 2 Guide to the use of BS 5781 : Part 1
PD 6112	:	Guide to the Preparation of Specifications
PD 6452	:	Guide to Inspection Procedures

QUALITY ASSURANCE

BS 5750 : Part I : 1979 Quality Systems

Specification for design, manufacture and installation

- specifies the quality system to be applied when the technical requirements of materiel and/or services are specified principally in terms of the performance required, or where design has not been established

- in these circumstances the supplier is frequently responsible for design, development, manufacture, installation work and field trials, any of which activities may require the use of new techniques

"materiel" : equipment, stores, supplies and spares that form the subject of a contract

CONCEPT OF QUALITY

'Quality' used for three distinct purposes

(a) Comparative sense or degree of excellence

GRADE	When applied to a material or product, an indication of the degree of refinement
	When applied to a service the diversity of functions or facilities provided

(b) Quantative sense

QUALITY LEVEL	A general indication of the extent of departure from the ideal
	(usually a numerical value indicating degree of conformity or non-conformity, as in sampling inspection)

(c) Fitness for purpose sense

QUALITY	Relates the evaluation of a product or service to its ability to satisfy a given need

In the quality assurance field the word 'quality' is used in the 'fitness for purpose' sense.

QUALITY ASSURANCE

Definition of Basic Terms

(according to BS 4778 : 1979)

QUALITY ASSURANCE	All activities and functions concerned with the attainment of quality.
QUALITY	The totality of features and characteristics of a product or service that bear on its ability to satisfy a given need
QUALITY CONTROL	The operational techniques and activities that sustain the product or service quality to specified requirements, also the use of such techniques and activities

GENERAL PRINCIPLES OF QUALITY ASSURANCE

NEED has to be **recognised** and **stated**

CRITERIA have to be **specified, defined** and **communicated**

MEANS have to be **devised, proposed** and **feasibility demonstrated**

ARRANGEMENTS for supply have to be **devised, established** and **communicated**

WAYS AND MEANS have to be **devised, established, communicated, provided** and **maintained**

METHODS have to be **devised, established** and **communicated**

SUCCESS depends on **proper aims, resources, facilities** and **proper use**

MEANS OF QUALITY ASSURANCE

Ensure adequate DEFINITION and COMMUNICATION of OBJECTIVES

Therefore establish Quality Assurance PROGRAMME

This provides basis for REVIEW and EVALUATION upon basis of feedback

Precise SPECIFICATION is required

Provision of goods or services in accordance with specification require COMMUNICATION to ensure

1) that supplier KNOWS what is required

2) that he is CAPABLE of doing what is required

3) that he UNDERSTANDS his RESPONSIBILITIES

4) that he UNDERTAKES to meet his RESPONSIBILITIES

5) that supplier can be SEEN to have met his responsibilities

PRINCIPAL TOOLS OF QUALITY ASSURANCE

QUALITY SYSTEM	required to ensure and demonstrate that material or services conform to the specified requirements Includes quality management objectives, policies, organisation and procedures to demonstrate compliance with the requirements of BS 5750.
QUALITY PROGRAMME	a documented set of activities, resources and events serving to implement the quality system of an organisation
alternatively :	overall management and procedures for the execution of a specific contract or project
QUALITY PLAN	a document derived from the quality programme setting out the specific quality practices, resources and activities relevant to a particular contract or project
alternatively :	a document setting out the specific quality practices and procedures relevant to a particular material, part or component
QUALITY MANUAL	a document setting out the general quality policies and practices of an organisation
QUALITY AUDIT	an activity to determine, through investigation, the adequacy of and adherence to established procedures, instructions, codes, standards and other contractual requirements and the effectiveness of implementation

PRINCIPAL TOOLS OF QUALITY ASSURANCE (Cont'd)

QUALITY SURVEILLANCE	the overseeing of a supplier quality control organisation and methods
PRIMARY SPECIFICATION	describes primary purpose and gives essential guidance concerning grade, performance, conditions of use, reliability, maintenance, etc.
FUNCTIONAL SPECIFICATION	describes in detail the characteristics with regard to intended capability
INSTALLATION AND USE SPECIFICATIONS	documents that describe in detail the procedure for installing and the method of bringing into use, operating, controlling and adjusting
TEST SPECIFICATION	describes in detail the methods of conducting tests including, if necessary, the criteria for assessing the result
ACCEPTANCE SPECIFICATION	describes in detail the criteria for acceptance
CERTIFICATION	the authoritative act of documenting compliance with requirements

PROBLEM PREVENTION FOR LARGE WIND ENERGY CONVERTERS.
THE USE OF CONSTRUCTIVE DESIGN TO ENSURE QUALITY.

M. Schwarte GST / Krupp

General Objectives

All of us here, I am sure, are of the opinion that wind will be a future source of energy. By this I do not only mean its use as electrical energy for the general public but also its use on a wider scale for various different purposes. The possible uses of wind power stations are, after all, manifold. The quality of the wind power station is, however, of paramount importance in every case. Under the heading quality we understand the following: Operational efficiency, minimal maintenance requirements and a long service life. To put it tritely largewind energy converters are only economical when they actually function with wind. In general, then, quality is of great significance to operational efficiency. In actual fact, quality as just defined is probably of greater importance than the optimal efficiency of such a station. Moreover, the customer is right to demand quality of wind power stations as this is, nowadays, just one of many possible energy sources open to him.

Wind energy is just one of many energy bases. The customer will always favour the type of plant that can offer the desired type of energy at the most economical price. In the Third World and Threshold Countries demands for the availability of energy are perhaps not quite so high as in industrial countries.

Here one is happy to be able to take advantage of the high-grade type of energy produced by a wind power station. Nevertheless economics are also of importance.

In the case of Third World and Threshold Countries there seem to be two barriers to cross:
Firstly, there is an exceptionally high initial investment which is not always seen in relation to the rather low running costs and the fact that dependence on oil is reduced. Calculations do, in fact, show that this type of energy is cheaper per kilowatt/hour than others.

Secondly, wind energy converters are seen as a technological regression in such countries. The principal of the windmill is, after all, over 1,000 years old.

Thus, then, we have the challenge faced by the builders of wind energy converters. On the one hand the manufacturing costs of such stations are compared with those of other types of energy plants. Here prices of 3,000.- DM per kilowatt of installed performance volume have to be considered even though comparisons are not necessarily of much value. On the other hand the demands of today's customer have to bė met with an impressive level of technology.

Designers of such wind energy converters have to satisfy all these requirements in order that the significance of WEC's is generally recognised.

Thanks to the research contracts offered by the German Federal Ministry for Research and Technology (c. Growian and a number of accompanying studies) and existing WEC's in many other countries we now know where the technological limits probably lie. More definite information will be available in a few years time when large WEC's have been tried and tested. However we can already estimate in what areas the most efficient and economical solutions will lie and derive starting points for work on future WEC's from this. This will, in turn, satisfy the customer's demand for quality.

What preventive measures can be taken in respect of quality ensurance before construction is actually started on?

The choice of the optimal size for good performance

Disputes over the optimal size of WEC's will probably never end. However, one can already say that size is limited by the demands made for quality.

The limits set on the optimal size for good performance depend on the prinip or system used. (single blade or multi-blade rotor, converter or concentrator etc.)

This means that if we want to build WEC's which produce several MW, new systems will have to be developed that not only guarantee technological sense but are also economically viable.

Future planning should commence with WEC's of a size to satisfy the customer's present quality requirements. This will make sure of a market for wind energy. The important points for the customer are that the annual electricity production from a WEC be as high as possible and that the costs for this production are minimal. One can only build a market for large WEC's when the performance: cost ratio appears favourable. When a market has been established and wind energy has become part of the energy programme, one can start to think of pushing a wind energy system to its limits. In other words, choosing the right performance capacity for the relative system is of real significance when considering quality ensurance.

Quality Ensurance and Tower Design

Here the question to ask is: What are the tower's main functions? They are:

1. The tower is responsible for keeping the operational level of the nacelle at its most economical.

2. The tower has to transfer to the ground the reaction energy produced in the nacelle.

These are the most obvious major functions. All other functions are subsidiary and can be carried out by other components e.g. the lift does not have to be positioned in the tower. It could also be allowed to swing down freely from the nacelle. That is if it cannot actually be done without altogether.

When designing the tower one should, at first, concentrate on these main functions in order to develop an economical and high-quality concept. One must not, of course, neglect other provisos such as swing behaviour and general safety requirements. Up until now tower height has always been seen in a predefined relation to the diameter of the rotor and this fact should be looked into and thought about. The first main function of the tower, given above, shows us, that there is no direct connection between the rotor diameter and the height of the tower but rather that the former calls for a minimum height. Important parameters when considering the height of the tower and the required level of performance are building costs in relation to an optimal exploitation of performance capacity.

This means that the tower's height can alter considerably depending on the amount of available wind and the design of the WEC. When one takes all this into account it becomes obvious that, in the future, the height of the tower will definitely not be calculated in relation to the rotor diameter as, for example, 100 m hub height to 100 m rotor diameter. This new way of looking at things gives one a feeling for the tower height which will offer an exonomically optimal solution when taking quality ensurance into account. Aesthetics are not of importance here, as protection of the environment groups will have as much against a 120 m high tower as against an 80 m tower. Disputes with such groups should be avoided by designing and finishing the tower to merge with the countryside.

Quality Ensurance and the Design of the nacelle

Here we must also ask ourselves about the major functions of which the nacelle has two.

1. Housing of the aggregates necessary for the production of electricity.

2. Creation of the connection between hub and tower in order that the reaction energy be transfered.

The problems caused by these two major functions should be gone into here. Problem areas here are, amongst others, guaranteeing a straight-line arrangement of the aggregates, assembly and construction of the nacelle dimensions and weight as well as rigidity, stability and safety.

What do the designers have to keep in mind in order to minimise the effects of such problems? If one wants to guarantee a straight-line arrangement of the aggregates they should all be mounted in a one-piece machine bed. This can only be achieved when the manufactured capacity and performance ability of the WEC's allow it. In short, one has to adapt the manufactured capacity and disign the construction accordingly. One other requirement not to be forgotten is that the nacelle should be pre-produced in the factory with as many of the important aggregates already in it. This minimises assembly problems at the building site. Difficulties that do crop up at the building site can be avoided by previous assembly in the factory. Other advantages are that work carried out in factory is not dependant on the weather and, of course, that it is considerably cheaper. Demands for pre-assembly also make sense when one thinks of exporting large WEC's to Third World and Threshold Countries. We still have to look into whether or not it is possible to ship and transport complete nacelle thereby keeping building costs down to a minimum. Problems with assembly work must be avoided abroad as they are usually very costly, both in terms of cash and the cost of expert personell who can deal with them. Thus we aim for quality ensurance by adapting the nacelle to the above needs, even though this does have a direct influence on the max. performance size of a WEC.

The other problems which arise out of the second major function (rigidity, stability and safety of the nacelle) are also directly connected with the performance size. Financial considerations put a limit on construction, especially when the objectives are minimal weight and dimensions with the necessary rigidity and safety.

However, minimal weight and dimensions are not only important for transportation and assembly as the weight directly influences the tower design. For financial reasons the heavier the nacelle the lower the tower must be. This in turn means lowering the possible performance level.

For this very reason, the task of the nacelle should be limited to the two major functions mentioned. Subsidiary functions, such as accomodating the heavy duty crane, should be kept to a minimum. Aggregates that do not really belong to the nacelle should be housed in the tower or on the ground. The facing should only serve as a protection against the damp. In this case one can also minimise the weight and expense of the facing.

Our opinion is that it is easier to build good quality, high-performance nacelle if one only demands the presence of the absolutely necessary functions.

In other words a functions analysis, i.e. a singling out of unnecessary functions, is another preventive measure one can take to ensure quality. This, of course, applies to other building components of the WEC and not just to the nacelle.

Blade adjustment is perhaps the next point to be considered and here, also. we must ask ourselves what the main function is. We arrive at:

- To aid controllability of the WEC.

This formulation itself shows us that blade adjustment is not always absolutely necessary. It is well known that small systems do do without it. There are, after all, a number of other control possiblities. One must, then, see to it that blade adjustment only fulfills this function, i.e. only has a supportive function in many designs. The next question to ask is: Is it necessary to make the whole blade adjustable or perhaps only the blade ends? This means that the control function is transfered from the whole blades to their ends. Depending on the type of WEC it can actually be unnecessary to make the rotor blades totally adjustable. In actual fact, one should look at WEC design in more detail and try to discover which functions are superfluous as superfluity means unnecessary expense and no improvement in quality.

The design of the rotor blade should be looked at in a similar way. What are its functions? The main function is the reception of wind energy for conversion into rotational energy. Here, though, one must ask the question: Is this a function of the whole rotor blade or should one divide the blade into segments which carry out different tasks? What is the main function at the hub section of the blade? The conversion of wind energy into rotational energy or perhaps the achievement of a defined blade length which allows the largest possible rotor diameter. If the second function is the most important one, then this must have a direct influence on the design. Otherwise this section of the blade fulfills no necessary function and thus means superfluous expense.

The reduction of unnecessary building costs usually means the avoidance of problem areas. In the case of the rotor blade a reduction in building costs means a reduction in weight which, in turn, has a positive influence on the design of the hub and thus on the nacelle and finally on the tower and so we have a sort of chain reaction, with one assembly component influencing the other.

Looking at functions in this way means being able to find the solution to certain problem areas more easily. One significant problem is the long-term vibratory fatigue limit which must be seen in connection with progressive crack formation which is likely to occur when one intends cross-seams in the rotor blade. One preventive measure towards quality ensurance is, thus, the avoidance and/or drastic reduction of cross-seams in the rotor blade. This is certainly only possible when the total length of the rotor blade is adapted to such demands. However, the length of the rotor blade determines performance and, consequently, one way of preventing progressive crack formation is the choice of the right performance size. Here, of course, one must take the concept of the rotor blades into account.

From that what has been said it is clear that, at the beginning of constructional design work on large WEC's, one must ask the question: Can we really realise the given performance size and service life values? For example, when the avoidance of progressive crack formation represents impossible demands and the design team is unable to alter the fact due to given sizes, then, one could possibly try to correct the initial sizing. The design process must be one of adjustment that will always be able to question the initial parameter in order to guarantee the quality of the WEC. The adjustability of this construction process can, then, also be seen as a preventive measure one can take to ensure quality.

In conclusion we can say that quality guarantee with regard to operating efficiency, low maintenance requirement and high service life already starts in the construction design phase.

It is determined here whether the fixed quality requirements of a WEC can realy be fulfilled. For this reason, it will be necessary to attach increasing importance to the constructive design at the beginning of the construction phase in order to guarantee the quality of large WEC's.

Safety Assurance and Quality Control of G R O W I A N

H. Zwahr

Große Windenergieanlage Bau- und Betriebsgesellschaft mbH

1. Introduction

The GROWIAN-concept has been described extensively in literature /1,2/, at conferences /3/ and at meetings like this /4/. The present status of the project is as follows:

- The foundation of the tower was completed last autumn.

- The first section of the tower was delivered and erected in March (Fig. 1) after a long and severe winter, which made any earlier continuation of work on the site impossible.

- The middle section of the nacelle (6 m wide, approximately 15 m long and 8 m high, Fig. 2) was lifted over the base of the tower at the beginning of April (Fig. 3).

- Construction of the tower continued after a protective roof had been set up over the nacelle to shield it against falling parts. The tower has now reached almost its designed height of 96,5 m (Fig. 4).

- The teetering hub (Fig. 5) and the front part of the nacelle have just been delivered to the site.

Construction goes on almost on schedule, so all participating in this project are hopeful that the nacelle complete with hub and rotor can be hoisted to the top of the tower this autumn.

2. Safety assurance and quality control of GROWIAN

There have been two sides to cope with this aspect of the GROWIAN project: construction according to certain safety standards and production with a quality control system on one side and a supervisory group acting on behalf of the licensing authorities on the other side.

What steps have been taken to secure a save erection and operation of this LS-WEC during construction and production?

2.1 Design and component specifications

The main components and design criteria of GROWIAN are described in detailed specifications, which determine

- the standards to be followed,
- the requirements a component has to fulfill,
- other design criteria to be used and
- the way a component is integrated into the system.

There are more than 50 specifications, which were originally written during the time the feasibility study was carried out and were later reviewed according to the progress made in design and construction.

Special attention was given to the load conditions unter which the GROWIAN system is expected to operate. A set of five different meteorological configurations (wind, duration) during construction, hoisting of the nacelle and operation of the windmill was agreed upon.

2.2 Quality control

A high quality standard is obtained by an elaborate quality control system. Each contractor or sub-contractor had to work out his quality control system which was subject to authorization by the system engineer (M.A.N.-NT). It had to contain calculations, drawings, plans for each step in production, assembling and tests to ascertain the proper function of each part. Only after these plans had been approved fabrication was allowed to start.

Should any change be necessary during the design or production stage, this was first subject to approval by the system engineer in case other systems were affected by this change.

2.3 Protection against corrosion

Much attention was given to the protection of all materials against corrosion in regard of the highly aggressive atmosphere GROWIAN will be operatingin near the coast. Experience of the GROWIAN company and her associates operating power plants along the shore of the North Sea was a valuable asset in developing a system of galvanizing and coating to assure up tc 20 years of protection against corrosion.

2.4 Lightning Protection

Large-Scale Wind Energy Converters are especially endangered to be struck by lightning because of their height and because they are usually located in level terrain. The problems encountered have been described by D. Jaeger /5/. Basically the same solutions to protect the structure and the electric and electronic gear will be applied on GROWIAN. The main features are:

- a wire mesh integrated into the GFC (Glass Fiber Compound) covering of the rotor blades connected to the spar,

- the hatches on top of the nacelle, which are made of GFC as well, are also equipped with a wire mesh,

- the blade bearings are bridged by bonding strips, other bearings, especially the rotor bearing, by slip rings. Heavily loaded bearings like the azimuth bearing don't need a bridging device as is well known from cranes.

- the tower as well as the bracings are connected to an earth grounding system,

- arresters or Zener diodes are used on all electronic cables when considered necessary. The shielding of cables is connected to the grounding system as well.

GROWIAN is connected to the grid via a radial line with several customers connected to it. When GROWIAN or the line are hit by lightning, short interruptions in the current can occur leading to changes in the direction of current flow in the grid radial line. In order to avoid any trouble with customers, GROWIAN will therefore probably be shut down when thunderstorms are imminent.

2.5 Protection of the electric equipment

The power generating equipment of GROWIAN has been described by H. Mühlöcker at a previous meeting /6/. The double-fed asynchronous generator with its control monitoring devices is - as far as the protection of the system is concerned - conventional. Protection is provided against

- unbalanced load,
- stator overload,

- transformer-generator differential,
- rotor earth fault,
- overload,
- overvoltage,
- frequency deviations, and
- overcurrent

by a single-channel electronic control system, giving trip commands to the circuit breakers to isolate only the faulted part of the equipment. Thus selectivity is guaranteed for a save operation of the power generating equipment.

2.6 Protection against system failures

GROWIAN consists of many components, miscellaneous systems and sub-systems, which will all be monitored and controlled by a computer. In order to prevent a failure of the wind turbine, possible faults in any of its components have been catalogued. Then criteria were defined which of these faults would lead to a normal shut-down or an emergency shut-down. An emergency stop is brought about first by electrical means. If these fail, the hydraulic emergency system is actuated. If any failure occurs, the appropriate procedure for shut-down is selected by the computer and a message is given to the operator in charge. After a shut-down the wind turbine can only be restarted after the cause for the failure has been eliminated.

3. Supervisory and control instances

The design of GROWIAN by the system engineer M.A.N.-NT, the construction and production of its components by M.A.N. as well as by many other contractors and sub-contractors have been subject to control and supervision by several institutions.

3.1 Germanischer Lloyd

The licensing authority, the board of works in Heide, Schleswig-Holstein, delegated the task of examinating the GROWIAN design for safety and quality to the Germanischer Lloyd. This company, well known in the field of ship-classification, was quite familiar with the GROWIAN-concept, because it had already evaluated the feasibility study of M.A.N. in 1979.

The task of the Germanischer Lloyd was to eliminate any hazard to staff and the public by the wind turbine during operation and standstill. It was assumed that during the construction period and during a standstill GROWIAN should be handled like any ordinary construction with the appropriate standards and safety regulations to be applied. Besides this, provisions had to be foreseen to eliminate an unwanted start during standstill or while servicing jobs are carried out.

During operation the greatest danger lies in the rotating parts. It must be possible to transfer the rotor into an uncritical status under all circumstances. To assure this, two ways are open to the Germanischer Lloyd: demand of constructional changes if considered necessary or administrative procedures, for example limiting operation at certain wind speeds or weather conditions.

Drawings and calculations of - among others - nacelle, teetering hub, blade drive, bearings, planetary gear, couplings, emergency breaks were checked and production supervised. Supervision will go on during the construction and putting into service of GROWIAN.

It may be mentioned at this point that the Germanischer Lloyd has been very cooperative in fulfilling its job, being firm when vital issues of safety are concerned but always taking into account that GROWIAN is a prototype machine.

3.2 Other control instances

The building regulations of Schleswig-Holstein demand the statical calculation to be examined by an approved engineer. The tower of GROWIAN was considered to fall under this regulation. As the Germanischer Lloyd doesn't have official approval to perform this task, an appropriate engineering office was engaged by the licensing authorities.

The ground of the site Kaiser-Wilhelm-Koog is very problematic, the land having been reclaimed from the sea just a few decades ago. Because of this a ground expert was consulted and test drillings were carried out. This ground expertise together with the static and dynamic loads approved by the Germanischer Lloyd delivered the boundary conditions to ascertain the statical calculation of the tower.

Last but not least there was the GROWIAN company for the construction and operation of the wind turbine, which in collaboration with its associated partners acted more or less like a consultant to the system engineer - as far as safety and quality control is concerned - checking drawings and specifications, thereby paying attention mainly to operational and handling aspects. Electrics and electronics are their specialty, so examination and approval of these systems were delegated to one of the associates, the Hamburgische Electricitäts-Werke.

4. Construction supervision, commissioning

All those parties mentioned before will supervise their respective part during construction in the factories as well as during erection on site. The experts of the Germanischer Lloyd have inspected the fabrication and tests on materials and components. Delegates of the GROWIAN company have taken part at preliminary tests of components and inspected the quality of corrosion resistance measures.

The same is going on right now on the construction site and will be done during the six-weeks commissioning of the wind turbine, a procedure which is customary in power plant construction.

5. Operation of GROWIAN

GROWIAN has been designed to be operated fully automatically. Nevertheless a staff of four to five is planned to service the plant during the first three years of operation. Check patrols will be performed regularly and there will always be one of the staff in a stand-by position being informed via telephone (automatic) in case of a shut-down during unsupervised operation.

This relatively large staff is considered necessary because an extensive measuring program will be carried out simultaneously. Two meteorological towers are erected right now, each 170 m high and equipped with 11 measuring stations at different heights. This measuring program, intended to give further insight into the design and performance of large wind energy converters, will be performed within a separete research program, also sponsored by the government of the Federal Republic of Germany.

Intensive cooperation of the GROWIAN staff will be necessary to carry out this program successfully. For example GROWIAN will have to be operated under manual control to perform out-of-design operating conditions within the measuring program. Experienced personnel is needed for that task, keeping in mind the safety of GROWIAN and the staff on the site.

6. References

/ 1 / Mitschel, H.: Die Großwindanlage GROWIAN - eine moderne Windenergieanlage in Norddeutschland. Forschung in der Kraftwerkstechnik 1980, 1980, p. 23 - 30.

/ 2 / Hau, E.: Große Windkraftanlagen - Technologie und Projekte, Sonderdruck M.A.N., 2. Aufl., München 1981.

/ 3 / Windheim, R.: Wind Energy R&D-Program of the Federal Republic of Germany and Current Wind Energy Projects. Fifth Biennial Conference and Workshop on Wind Energy Conversion Systems, Washington D.C., October 5 - 7, 1981.

/ 4 / Helm, S.: Erection and Maintenance of GROWIAN. 6th IEA-Expert Meeting, Aalborg, April 1981.

/ 5 / Jaeger, D.: Design Provisions for Wind Energy Systems Lightning Protection and EMC. 5th IEA-Expert Meeting, 1980.

/ 6 / Mühlöcker, H.: Power System Operation of a GROWIAN. 2nd Meeting of Experts, July 1979.

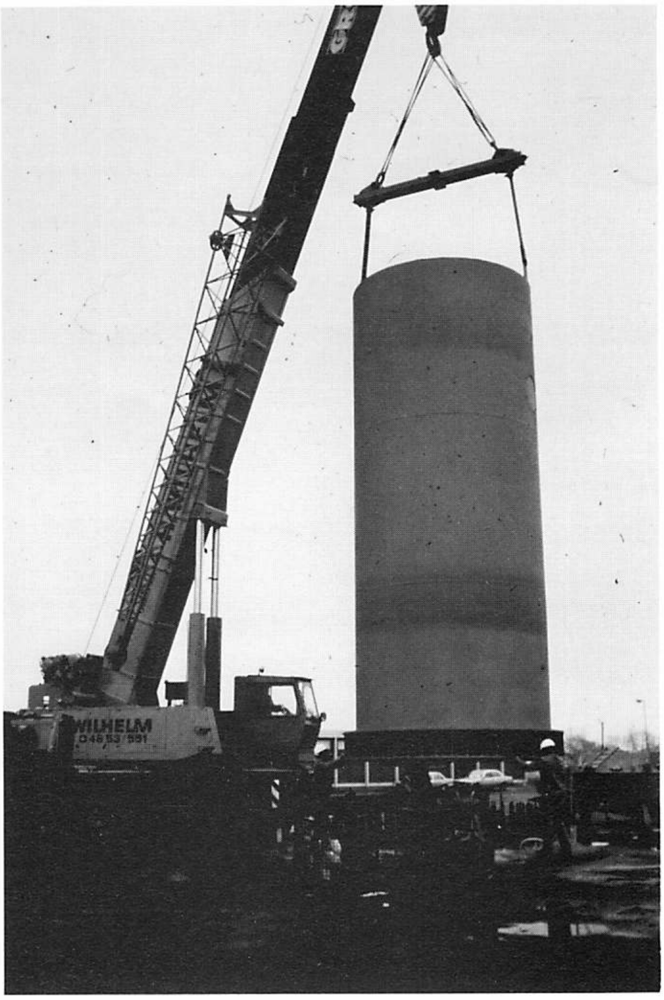


Fig. 1: Erection of first section of tower

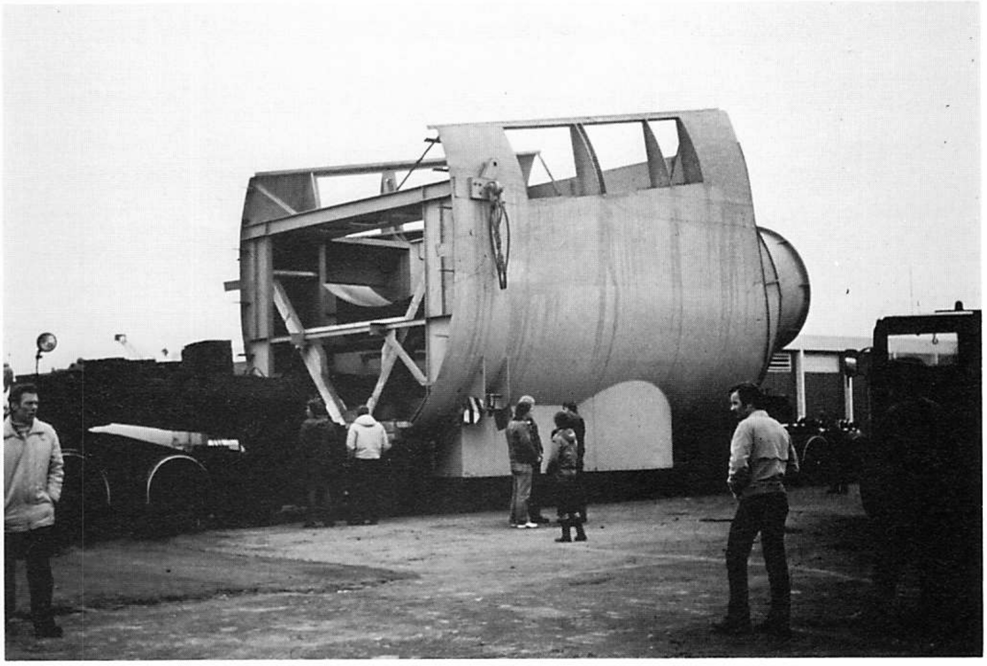


Fig. 2: Middle section of nacelle after delivery to the site

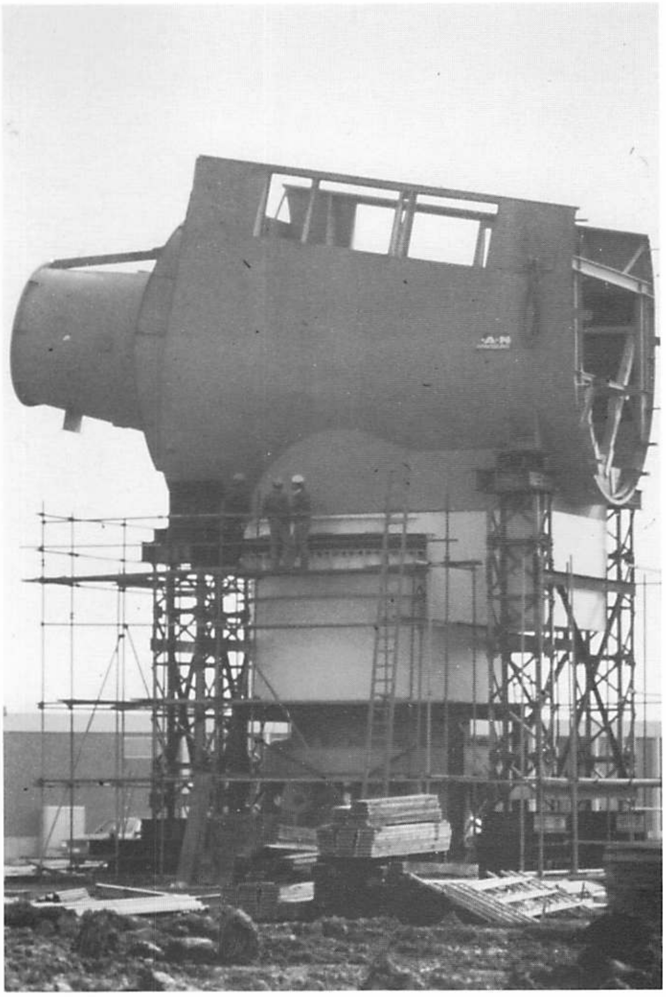


Fig. 3: Middle section of nacelle lifted over the base of the tower

Fig. 4: GROWIAN-tower, height 96,5 m

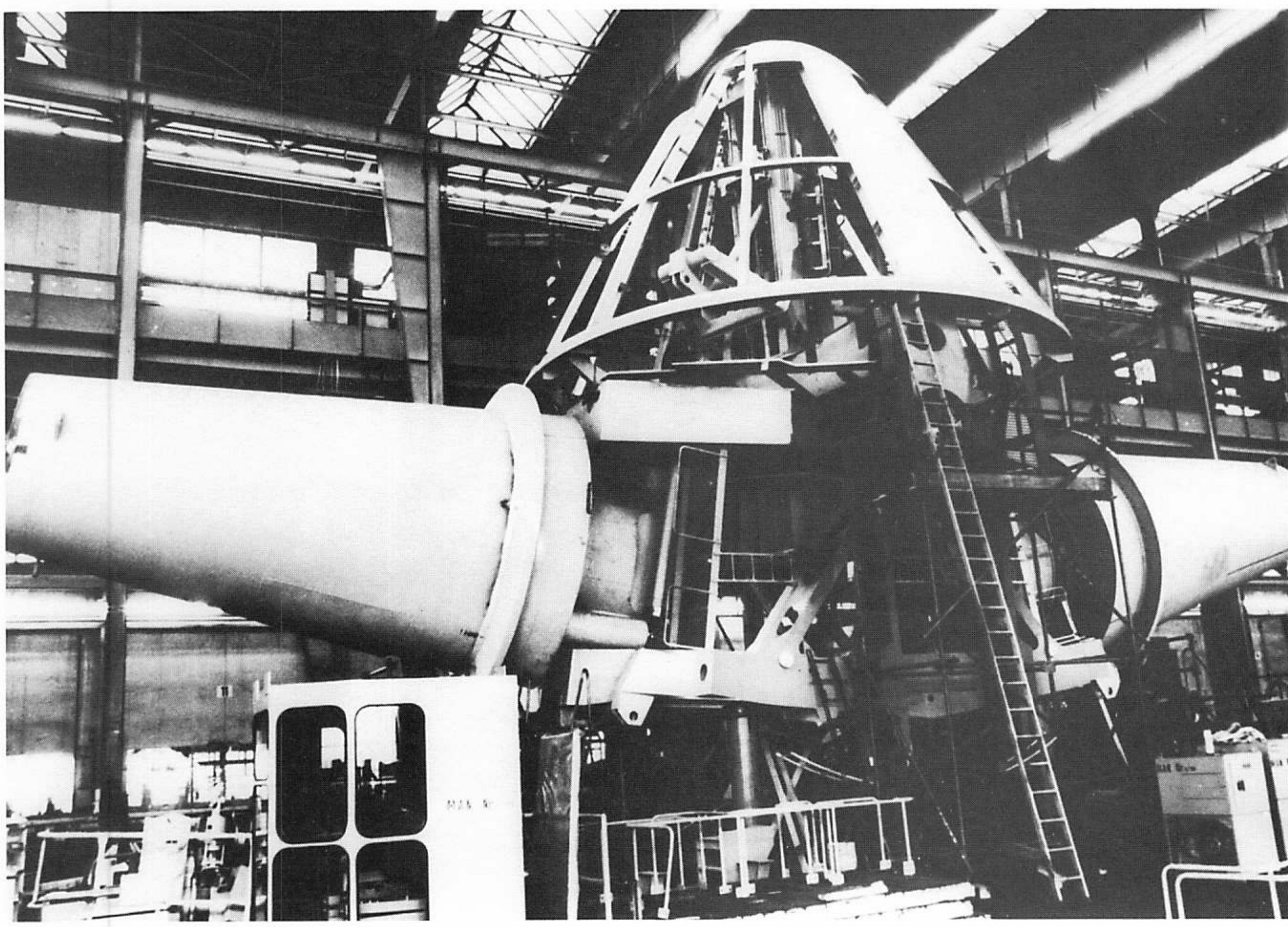


Fig. 5: Teetering hub during work-shop assembly

LIST OF PARTICIPANTS

Peter Christiansen	ELSAM 7000 Fredericia DENMARK
Staffan Engström	National Swedish Board for Energy Source Development Box 11 03 16312 Spanga SWEDEN
Anders Erecsson	Gullspang Power Co. Box 16 43 70116 Örebro SWEDEN
Erich Hau	MAN - Neue Technologie Dachauer Str. 667 8000 München 50 GERMANY
Ove Hermansson	KaMeWa AB Box 10 10 68101 Kristinehamn SWEDEN
Mats Johansson	KaMeWa AB Box 10 10 68101 Kristinehamn SWEDEN
Lars Möller	KFA Jülich GmbH - PLE Box 19 13 5170 Jülich GERMANY
B. Maribo Pedersen	Technical University of Copenhagen Building 404 2800 Lyngby DENMARK

M. Schwarte

GST - Gesellschaft für
Systemtechnik
Am Westbahnhof 2
4300 Essen 1

GERMANY

Peter Simpson

Wind Energy Group
Greenford House
309 Ruislip Road East
Greenford
Middlesex UB6 9BQ

GREAT BRITAIN

Göran Svensson

Swedish State Power Board
Civil Engineering Dep. BKI
16287 Vällingby

SWEDEN

Heiner Zwahr

GROWIAN - Company
Oberseering 12
2000 Hamburg

GERMANY