# Chapter 9
# Greece

## 9.1 NATIONAL POLICY

### Strategy

Greece is one of the European countries possessing high wind energy potential. In spite of this, the deployment of wind energy technology has been slow. During the last two years, with enforcement of the Law 2773/99 (Liberalisation of the Electricity Market – Regulation of Energy Policy Issues and Other Provisions), the development of the wind energy technology has been speeded up.

Besides, it is among the aims of the government to substitute expensive imported fuel, currently used for electricity production in a large part of the Greek territory, by exploiting the country's wind potential. Government support for wind energy exploitation is part of its policy concerning renewable energy sources.

During 2002, the Regulatory Authority for Energy (RAE) approved an important number of applications for power production from wind energy, of 595 megawatts (MW) total installed capacity. More analytically, 407 MW have been approved for the interconnecting system of the mainland while 188 MW have been approved for the islands Evia, Andros, and Tinos, which are characterized by high wind potential. Especially for the area of Evia there is a great investment interest, although it is problematic, since the high wind power potential cannot be absorbed by the existing poor electrical infrastructure. Recently, with the approval of a study for the development of electrical energy transportation system and the involvement of a project for the development of high voltage electrical grid, 550 MW of installed wind capacity is planned to be accepted for installation in this region.

According to Law 2773/99, the Hellenic Transmission System Operator (HTSO) uses the wind energy produced in priority during generation unit dispatching. The price paid to the producer is a percentage of the tariff paid by the medium- and low-voltage consumers, the same as defined by the older Law 2244/94 in power until the Law 2773/99 came in effect. The difference is that the Minister of Development is allowed to ask the producers from renewable sources for a discount on this price.

### Progress Towards National Targets

A significant progress towards the development and growth of the wind energy sector has been achieved during past years in Greece. The installed capacity of wind turbines reached 355.4 MW at the end of 2002, fulfilling the target of 350 MW set by the Greek Ministry for Development. It is worthwhile to mention that in 1995 the total installed capacity was only 29 MW.
The Greek Ministry for Development set a new target for wind energy of more than 1,500 MW installed capacity for 2010, following European Union (EU) directions.

The new Law 2773/99, introducing electricity market liberalization, maintains support of energy from renewable sources in the framework of the competitive market, yet the effect of the liberalization on the development of the wind energy is not obvious.

**Figure 9.1 Nine-megawatt wind park at Skopies-Zarakes, Evia (Source: ROKAS AIO-LIKI ZARAKES)**

## 9.2 COMMERCIAL IMPLEMENTATION

### Installed Capacity

In total, 70 WECS having an installed capacity of about 57.4 MW, concerning 10 separate projects, have been connected to the electricity supply network in 2002, bringing the total installed wind energy capacity to 355.4 MW (685 machines). The distribution of the installed wind energy capacity around Greece for the year 2002 is shown in Figure 9.2.

### Rates and Trends in Deployment

Development of wind energy within the last 10 years is shown in Figure 9.3, where the total installed capacity per year is depicted.

### Contribution to National Energy Demand

The energy produced from wind turbines during 2002 was approximately 650 GWh, while the energy produced in 2001, 2000, 1999, 1998 and 1997 was 756 GWh, 460 GWh, 160 GWh, 71 GWh, and 38 GWh, respectively. Total energy consumption in the country is on the order of 50 terawatt-hours (TWh), so the energy produced from wind turbines accounts for about 1.5% of the energy demand. For 2010 total energy consumption in the country is expected to reach 72 TWh. Figure 9.4 shows the electricity produced from wind turbines for the last ten years and the corresponding capacity factor.

## 9.3 MARKET DEVELOPMENT AND STIMULATION

### Main Support Initiatives and Market Stimulation Incentives

Support for the development of wind energy projects was provided under the Operational Program Competitiveness (OPC). The Center for Renewable Energy Sources (CRES) acts as an intermediate agent in charge of the

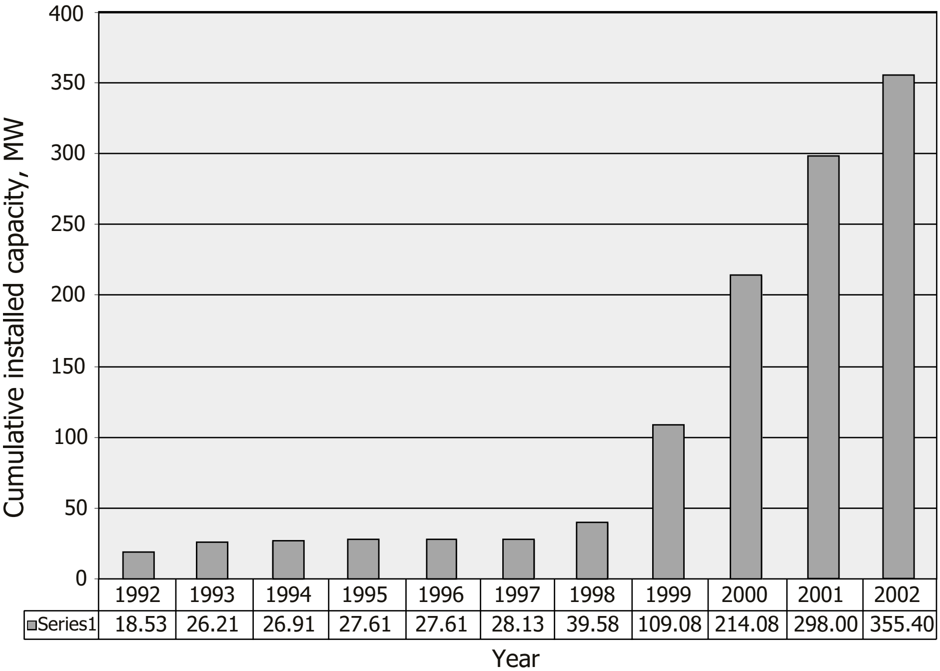

**Figure 9.2 Distribution of installed wind energy capacity around Greece in 2002**

administration and management of projects included in Measure 2.1, Action 2.1.3 of the OPC. More specifically, CRES is the thematic intermediate agent responsible for the administration and management of all wind energy projects to be realized on the mainland and these with nominal capacity greater than 5 MW to be realized on the islands of Greece. The relevant budget is up to 650 million Euros (€).

According to the OPC, wind projects may be subsidized by 30% of the cost. An installation permit is necessary in order to finance a project. The eligible cost for financing a wind farm is up to 900 € per kilowatt (kW) without including the cost for the connection to the electrical grid. During 2002, 85 applications of 846.5 MW were submitted, of which 38 applications of 418.2 MW were approved. However, only four projects of 12.5 MW were finally contracted.

**Unit Cost Reduction**

No data are available.




| | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Series1 | 18.53 | 26.21 | 26.91 | 27.61 | 27.61 | 28.13 | 39.58 | 109.08 | 214.08 | 298.00 | 355.40 |

**Figure 9.3 Cumulative installed wind capacity in Greece**

## 9.4 DEPLOYMENT AND CONSTRAINTS

### Wind Turbines Deployed

The average capacity of the wind turbines installed in 2002 was 814 kW, while the average capacity of all the wind turbines operating in the country is 518 kW. The market share per manufacturer is depicted in Figures 9.5 and 9.6.

### Operational Experience

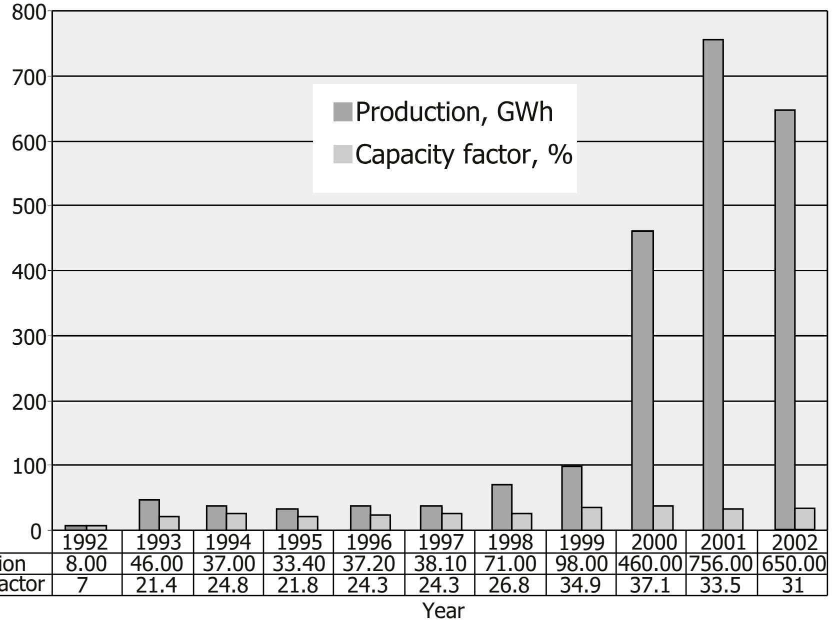
Due to the relative short period of operation of most of the wind energy projects, limited malfunctions have been reported since their commissioning. However, CRES has developed and continuously updates a database with related information for the operation and performance of all the wind parks around Greece.

### Main Constraints on Market Development

Complicated procedures for acquiring generation authorization and an electrical network that is inadequate to absorb the energy produced remain the two main constraints for the installation of new wind farms.

### Trends in Investment

The total cost of wind power projects depends on the type of wind turbine, its size, and accessibility, and varies between 970 €/kW and 1,170 €/kW. Cost of generated wind power could be assumed to be between 0.026 €/kWh and 0.047 €/kWh, depending on the site and project cost. The typical interest rate for financing wind energy projects is on the order of 7% to 8%.




| Year | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Production | 8.00 | 46.00 | 37.00 | 33.40 | 37.20 | 38.10 | 71.00 | 98.00 | 460.00 | 756.00 | 650.00 |
| Capacity factor | 7 | 21.4 | 24.8 | 21.8 | 24.3 | 24.3 | 26.8 | 34.9 | 37.1 | 33.5 | 31 |

**Figure 9.4 Electricity produced and capacity factor for wind turbines in Greece**

## Trends in Unit Costs of Generation

The power generation system in Greece is divided into two categories: the so-called interconnected system of the mainland and the autonomous power plants of the islands. In today's liberalized electricity market, as well as before, a single charging price exists in both systems, depending on the identity of the consumer and the voltage class.

The following selling tariffs for low and medium voltage have been valid since July 2002.

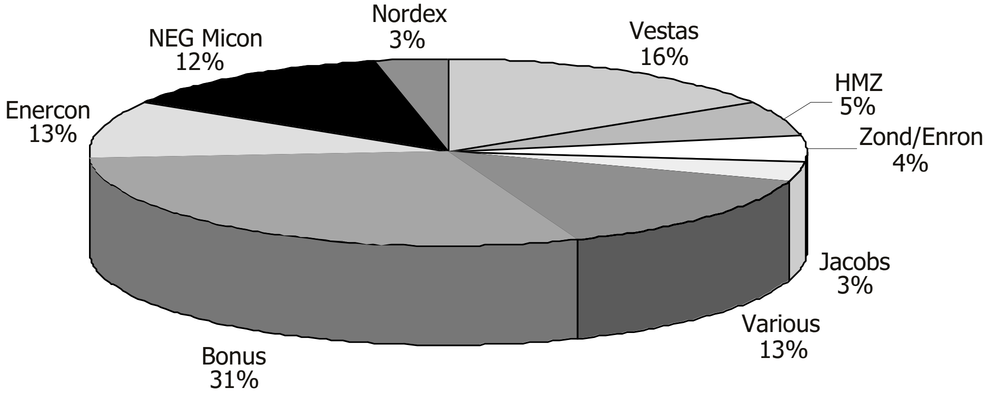



**Figure 9.5 Market share of wind turbine manufacturers (as a percentage of number of wind turbines)**

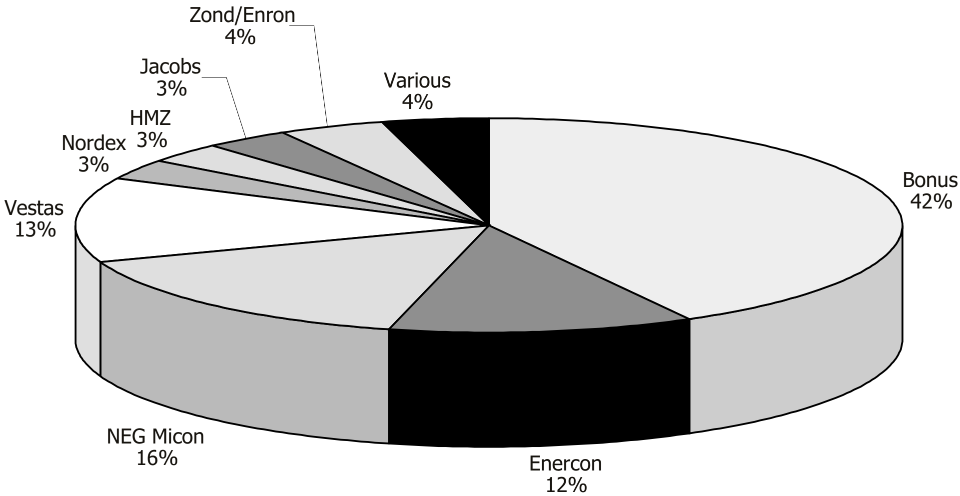



**Figure 9.6 Market share of wind turbine manufacturers (as a percentage of installed capacity of wind turbines)**

- Low voltage: 0.08643 €/kWh
- Medium voltage: 0.06991 €/kWh and 3.2305 €/kW (peak power value)

The purchase prices defined by HTSO for renewable energies are based on the actual selling price.

For the interconnected grid, the tariffs have two components: energy and power (capacity credit). The energy component is set at 90% of the medium-voltage tariffs, i.e., 0.06292 €/kWh, while the power component is set at 50% of the respective PPC's power charge, i.e., 1.61525 €/kW x P/2 where P is the maximum measured power production over the billing period. For the autonomous island grids, the tariff is set at 90% of the low-voltage tariffs, i.e., 0.07779 €/kWh. The Ministry of Development has the right to ask the producers for discount on these prices.

## 9.5 INDUSTRY

### Manufacturing

Concerning the Greek wind industry, there is no significant development except for a couple of small wind turbine manufacturers in a typical range of 1.0 kW to 5.0 kW. However, an important involvement by the Greek steel industry, manufacturing the tubular towers of the wind turbines, has been considered. A Greek company that has been involved in blade manufacturing has not yet managed to commercialize its products.

### Certification

In Greece, installation permission is required for the installation of a wind turbine of more than 20 kW installed capacity. With the new law entitled "Procedures for the Installation and Production Permits," a type approval certificate along with a power quality certificate for each wind park is needed.

The Center for Renewable Energy Sources is, by law, the certifying authority for wind turbines in Greece and is responsible for issuing the two certificates just mentioned.

Until now, CRES has been accepting type certificates and reports of the measurements of the power quality issued by authorized institutions (such as Germanischer Lloyds and

DNV or any other organization accredited according to EN45011 for certifying wind turbines) according to the following standards and criteria.

- Germanischer Lloyds Regulations
- Danish standards and criteria
- Dutch standards and criteria
- IEC 61400-1 standard

Additionally, CRES's Wind Energy Department participates in the standardization work carried out by the Hellenic Organization for Standardisation (ELOT) in the framework of European and international organizations, working on certification procedures and standards to be followed nationwide, taking into account the climatic characteristics of Greece.

In 2002, active involvement in the conduct of IEC TC-88, CLC/BTTF83-2 and its working groups was continued.

**9.6 GOVERNMENT-SPONSORED R,D&D**

**Priorities and New R&D Developments**

The Ministry for Development promotes all research and development (R&D) activities in the country including applied and basic R&D as well as demonstration projects. Key areas of R&D in the field of wind energy are wind assessment and characterization, standards and certification, development of wind turbines, aerodynamics, structural loads, blade testing, noise, power quality, wind desalination, and integration in autonomous power systems. There is limited activity in Greece concerning MW-size wind turbines or offshore deployment.

A project for the development of a 450-kW wind turbine was initiated within the framework of the EPET-II National Programme in 1995. The project was aiming at both the development of a 450-kW variable-speed, stall-regulated wind turbine and the development of blade manufacturing technology. The assembly of the prototype concluded in 2000. It was installed at the test site at the beginning of May 2001, and the connection to the electrical grid was completed at the end of 2002. The measurement equipment for the commissioning tests has been installed, and the tests are planned to take place during 2003.

CRES is the national organization for the promotion of renewable energies in Greece, mainly involved in applied R&D in the fields of aerodynamics, structural loads, noise, power quality, variable speed, wind desalination, standards and certification, and wind assessment and integration. CRES has developed and operates a laboratory with advanced blade testing facilities for static, dynamic, or fatigue testing of blades up to 25 meters (m) long. The blade testing laboratory has been accredited under the terms of ISO/IEC 17025:2000 standard.

CRES wind-diesel hybrid laboratory system, which simulates small autonomous grid operation common in the islands of the Aegean Sea, is effectively used in optimizing the integration of the renewable energies in such systems. Also, CRES in co-operation with the Greek market has designed and developed a pilot autonomous hybrid (W/T, PV) reverse osmosis system for seawater desalination, within the National Programme PAVET, of the Greek Ministry for Development, Third Framework Programme, for further research on technologies coupling. The system has been installed at CRES Wind Park at Lavrio, Attiki.

Several research projects were running or initiated at CRES during 2002, cofunded by DGXII and GSRT (the Greek Secretariat for Research and Technology) aiming at the following goals.

- Characterizing the main features of complex or mountainous sites (most sites favorable for wind energy development are of such topography) and identifying the crucial parameters affecting both the power performance and the loading of different types of wind turbines operating in such environments. In that direction, new techniques are under development for power-curve measurement of wind turbines operating in complex terrain and developing wind turbines for installation in hostile environments with poor infrastructure
- Improving the damping characteristics of wind turbine blades
- Developing new techniques for power quality measurement and assessment
- Contributing know-how to wind turbine standardization procedures
- Developing blade-testing techniques within the in-house experimental facility
- Understanding generic aerodynamic performance of wind turbine blades through computational fluid dynamics (CFD) techniques
- Developing cost-effective micro-siting techniques for complex terrain topographies

Basic R&D on wind energy is mainly performed at the country's technical universities. The National Technical University of Athens (NTUA) is actively involved in two research areas concerning wind energy, namely in rotor aerodynamics and wind energy integration in the electrical grid. The Fluids Section of the Mechanical Engineering Department of the NTUA is active in the fields of wind modeling, rotor aerodynamics, load calculation, fatigue analysis, noise, and wind farm design. Work conducted during 2002 concerned applied research on rotor aerodynamics for wind turbines.

More specifically, in terms of prediction/ design codes, NTUA participated in a European Community (EC)-funded benchmark exercise concerning the verification of design tools for wind turbines. In this activity, NTUA upgraded the free-wake model GENUVP developed in house into a complete aeroelastic tool. In particular, a new hybrid wake model was implemented allowing the simulation of complete 10-minute time series with turbulent wind inflow. The code was successfully validated against measured data.

The new viscous-inviscid interaction model for airfoils FOIL2W was validated against wind tunnel measurements in cases of light as well as deep stall for pitching airfoils.

In terms of design, NTUA further developed the computational procedures concerning the optimum design of airfoil sections and complete blades for stall-regulated machines. The family of airfoils designed has improved polars especially as regards roughness sensitivity and stall behavior. Application of this procedure was carried out for MW-scaled machines within a CEU-funded project. Extension of the optimization procedure to the case of pitch and variable-speed machines has been initiated, aiming at an improved design of the new very large offshore machines.

The Electrical Engineering Department of NTUA has been actively involved in the field of wind energy since the beginning of the 1980s, participating in R&D projects sponsored by the EU and other institutions and co-operating with universities and research centers from many European countries.

In 2002 the Electric Power Division of NTUA continued its research on issues related to technical constraints and problems in the integration of wind power into the electrical grids, the management and control of isolated power systems with increased wind power penetration, power quality of wind turbines and wind parks, and the design of electrical components for variable-speed machines.

The technical constraints and problems in the integration of wind power into the electrical grids have been investigated in various regions of Greece, where the transmission system is weak and there is high interest in related wind projects because of favorable wind conditions. Steady-state voltages, voltage variations, and power quality issues have been investigated. Besides work on the interconnected system, emphasis has been placed on the secure integration of increased shares of wind energy in island systems.

The work on MORE CARE, the advanced control system comprising load and wind power forecasting, unit commitment, and economic dispatch and on-line dynamic security assessment modules integrated within a friendly person-machine interface, has been continued. The advanced control system has been installed on Crete and is currently under evaluation, with promising preliminary results. In addition, various control systems of variable-speed wind turbines have been studied. A specialized code for the simulation of the effect of most common wind turbine types on the steady-state and dynamic performance of weak grids has been developed. This tool allows the convenient study of relevant power quality problems.

Dispersed renewable generation is gaining considerable attention, and research in this area has continued, focusing mostly on technical issues related to the integration and control of such units, their impact on the operation of the distribution grids, and the planning of distribution networks in areas with high potential for dispersed generation. Particular emphasis is placed on the development of MicroGrids comprising low-voltage grids with increased dispersed generation.

Work has been performed on the control of variable-speed wind turbines in order to reduce mechanical stresses and achieve a more "grid-friendly" operation (improved power quality and controlled power factor for voltage support of weak grids).

Design of electrical generators and converters for wind turbine applications is in progress, including permanent magnet synchronous generators with state-of-the-art electronic converters suitable for small wind turbines.

Power quality issues related with the grid-connected operation of wind turbines (slow and fast voltage variations, flicker, and harmonics) are a central research area, and a lot of work has been performed on the elaboration of connection guidelines.

The Applied Mechanics Section of the Department of Mechanical Engineering and Aeronautics, University of Patras (UP), has focused since 1990 on educational and R&D activities involving composite materials and structures. Emphasis is given to anisotropic material property characterization, structural design, and dynamics of composite rotor blades of wind turbines. Experience has been acquired by participating in several national and EC-funded research projects.

The University of Patras has successfully completed structural designs for a series of GRP rotor blades ranging from 4.5 m to 20 m, verification of which was performed by full-scale static, fatigue, and modal tests at a CRES blade-testing laboratory.

In the framework of the JOULE-III program, UP as subcontractor to CRES has participated in and successfully completed several projects, such as "AEGIS-Acoustic Emission Proof Testing and Damage Assessment of W/T Blades" and "ADAPTURB: Adaptation of Existing Wind Turbines for Operation on High Wind Speed Complex Terrain Sites; kWh Cost Reduction." During 2002, UP contributed to the following three research projects funded by EC.

- "DAMPBLADE: Wind Turbine Rotor Blades for Enhanced Aeroelastic Stability and Fatigue Life Using Passively Damped Composites"
- "MEGAWIND: Development of a MW Scale Wind Turbine for High Wind Complex Terrain Sites"
- "OPTIMAT BLADES: Reliable Optimal Use of Materials for Wind Turbine Rotor Blades"

In DAMPBLADE, UP is contributing with experimental characterization of anisotropic damping properties, development of a dedicated FEM code for efficient damping modeling of composite structures, and, finally, design of a 20-m GRP rotor blade optimally damped. In the MEGAWIND project, UP has accomplished the structural design of a modular (split) 30-m blade, which will be verified by full-scale testing at CRES of a prototype under development by Geobiologiki SA. In the OPTIMAT BLADES project, UP is a task group leader in investigating blade material behavior under complex stress states in which the effect of multi-axial static and cyclic loading on strength and life of composite laminates is to be assessed. Results will be available in the form of design guidelines for rotor blade manufacturers.

Other research activities of the Applied Mechanics Section are: (a) development of finite element formulations and dedicated code accounting for selective nonlinear lamina behavior, e.g. in shear, in the laminate, modeling of property degradation due to damage accumulation so as to predict life of large rotor blades under spectrum loading; (b) probabilistic methods in the design of composite structures; (c) residual strength and fatigue damage characterization of composite materials using wave propagation techniques; (d) smart composites and structures, and (e) structural damping, passive and active vibration control.

## 9.7 DEMONSTRATION

The main demonstration programs in wind energy currently under way in Greece are financed within the framework of the Thermie program of the EU and the National Operational Program of Energy. The following demonstration projects were ongoing in 2002.

1. Large advanced autonomous wind/diesel/battery power supply system in Kythnos (THERMIE program).

The aim of this project is the demonstration of the technical feasibility of the integration of a very high penetration of wind energy in large supply systems. This large modular system for the island of Kythnos is designed for the combination of diesel generator sets, battery storage, rotating phase shifter, five small wind energy converters, and one additional large wind energy converter. This large wind energy converter with a power output of 500 kW will supply a great portion of the power demand. It will be the first time that such a high portion of more than 50% of the energy demand is realized by wind turbines, and due to this the diesel generators can be totally stopped when the power output of the wind turbines is sufficient.

The wind turbine was erected in mid-1998 and the commissioning was completed during 2000. High wind penetration reaching even 100% has been achieved, while the system is still in trial operation.

Furthermore the already existing PV system with a nominal power of 100 kW, as well as the existing five energy converters of type Aeroman (with 33-kW rated capacity each) will be integrated into the wind/diesel/battery system. The project is being carried out from PPC and SMA.

Following are the most important advantages achieved during the system's operation.

- Demand under specific conditions can be covered totally by RES
- Great reliability of the system
- Improvement of grid stability and consequently the quality of the power supply
- Decrease in the operational cost of the diesel gensets.

2. CRES 3.1-MW wind farm in complex terrain (National Operational Program of Energy).

CRES's demonstration wind farm is located just near the Wind Turbine Test Station in Lavrio. The purpose of the project is to study the effects of complex topography on the performance of the wind turbines as well as of the overall wind farm. It consists of five different medium-sized wind turbines with distinguished design aspects: a 500-kW gearless synchronous multipole wind turbine generator Enercon E40, a 750-kW stall-regulated induction wind turbine NEG Micon 750/48, a 660-kW pitch-regulated induction wind turbine Vestas V47, and two variable-speed-stall AC/DC/AC wind turbine generators of 500 kW and 600 kW each, both developed in Greece and manufactured by PYRKAL S/A.

The first three machines were erected in 2000 and the electrical infrastructure and commissioning were completed in January 2001. Since then the three machines have been in continuous operation. The two variable-speed-stall generators manufactured by PYRKAL S/A have been installed. Their electrical infrastructure and commissioning are under way.

Among the five HAWTs, three are commercially available machines and the other two are Greek prototypes. The last ones use an advanced variable-speed technique (OPSC®: Opti Power Speed Control) together with stall-designed blades. The electricity is fed to the grid via an active line inverter. The other three commercial turbines are a stall-controlled turbine with an asynchronous generator, a pitch-controlled turbine also with an asynchronous generator, and a pitch-controlled, variable-speed, direct-drive turbine with a synchronous generator. Finally, the wind farm comprises two meteorological masts (100 m and 40 m), which are used to measure the reference wind conditions.

To investigate how the different design concepts perform at this specific complex-terrain wind park, it was necessary to develop one single monitoring program that continuously stores, in a common way, the operation of each turbine. This was realized using a home-developed software, based on the communication protocol, which was provided by each turbine manufacturer. Similarly, the total produced power, fed to the 20-kilovolt (kV) grid, is monitored at the main circuit breaker of the wind park.

A feature of the monitoring software worth noting is its ability to periodically update the contents of an Internet site, presenting the latest operational data of the wind park. Figure 9.7 presents the typical contribution of each turbine to the total power. Finally, the monthly production of the year 2002 is shown in Figure 9.8.

No offshore wind farms were installed.

Authors: E. Tzen , K. Rossis, and P. Vionis, CRES, Greece.

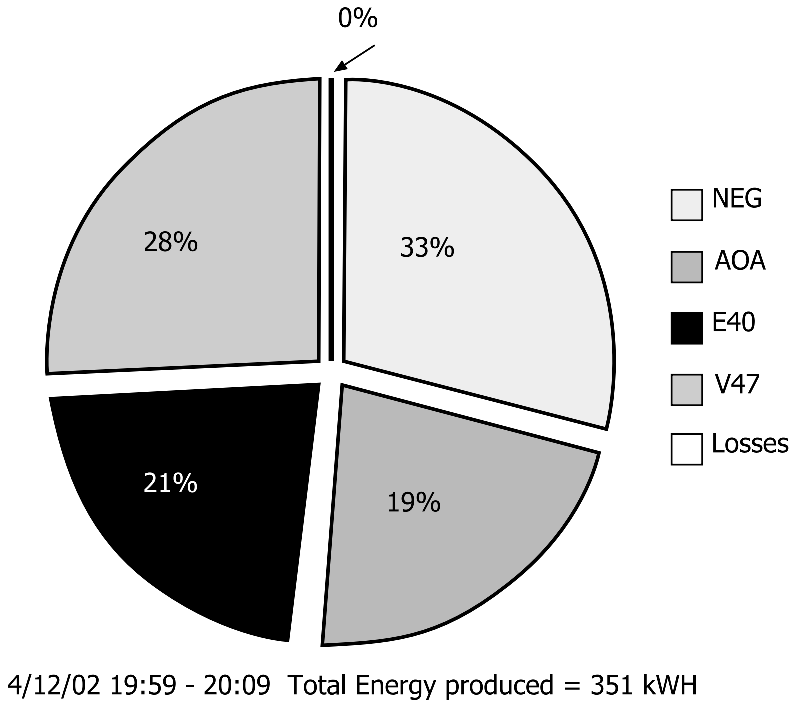



**Figure 9.7 Typical contribution of each turbine to total power**

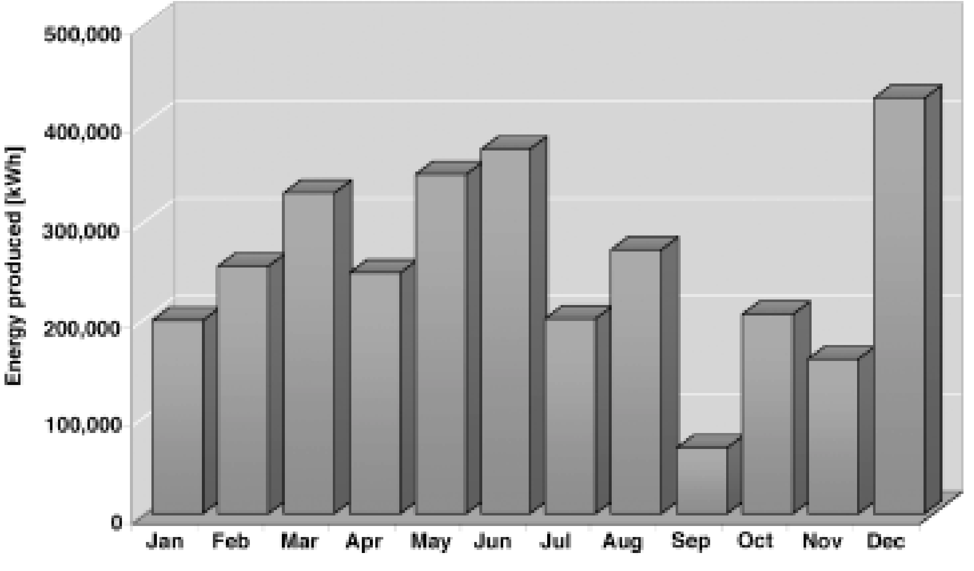



**Figure 9.8 Monthly production of CRES wind park in 2002**