Arnold Schwarzenegger
*Governor*

# REVIEW OF INTERNATIONAL EXPERIENCE INTEGRATING VARIABLE RENEWABLE ENERGY GENERATION

## APPENDIX D: SPAIN

PIER PROJECT REPORT

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Public Interest Energy Research Program

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# Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission) conducts public interest research, development, and demonstration (RD&D) projects to benefit the electricity and natural gas ratepayers in California.

The PIER program strives to conduct the most promising public interest energy research by partnering with RD&D organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural /Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

*Review of International Experience Integrating Variable Renewable Energy Generation, Appendix D: Spain* is the final report for a subtask of Task 3 for the PIER Intermittency Analysis Project (IAP), contract number 500-02-004, work authorization number MR-017, conducted by the IAP team comprised of the California Wind Energy Collaborative, Exeter Associates, BEW Engineering, Davis Power Consulting, and GE Energy Consulting (with assistance from AWS Truewind, National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL), and Rumla Consulting). The information from this project contributes to PIER's Renewable Energy Technologies program.

For more information on the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/pier or contact the Energy Commission at (916) 654-5164.

# Table of Contents

Acknowledgments ..... i
Preface ..... ii
List of Tables ..... iii
List of Figures ..... iii
Abstract ..... iv
1.0 Spain's Electricity Profile ..... 1
2.0 Organization of the Spanish Transmission System ..... 4
3.0 Energy Policies Promoting Renewable Resources ..... 7
4.0 Wind Resources ..... 10
5.0 Current Market for Wind Development ..... 12
6.0 Impact of Wind Power on the Grid ..... 14
References ..... 21

# List of Tables

Table 1. Spain's major electricity companies ..... 2
Table 2. Interconnection capacity with Spanish transmission network ..... 5
Table 3. Net international energy exchanges by Spain, 2000-2004 ..... 5
Table 4. Feed-in premium tariff for renewable technologies (Euro cents/kWh) ..... 7
Table 5. Wind power tariff options (March 2004) (Euro cents/kWh) ..... 8
Table 6. Spanish government proposals to limit regional wind development ..... 12
Table 7. Transmission interconnection requests for wind projects ..... 15
Table 8. Reactive complement as a percentage of the TMR ..... 18

# List of Figures

Figure 1. Electricity generation and capacity by source in Spain, 2005 ..... 1
Figure 2. Installed wind capacity in Spain ..... 10

# Abstract

This report summarizes the experience in Spain through 2006 with integrating variable renewable energy generation, primarily wind generation, and discusses potential operating and mitigation strategies for incorporating variable renewable energy generation. Initially, wind development in consisted of smaller but numerous wind projects interconnected to the distribution grid, in contrast with larger, utility-scale wind projects interconnected to the transmission grid in the United States. The differences between other countries and the United States are starting to narrow as development of variable renewable energy generation (e.g. wind and solar) increases and as wind development takes place in more countries. In addition, as more utility-scale wind projects emerge, more countries are relying on common strategies, such as grid codes, to help integrate variable renewable energy generation. This report is a part of the Intermittency Analysis Project (IAP), a comprehensive project aimed at assessing the impact of increasing penetration of variable renewable energy generation in California. A review of the international experience will provide perspective and insight to the IAP analysis team on various techniques for managing intermittency.

**Keywords:** ancillary services, grid, ramp, renewable energy, reserves, telemetering, transmission, wind forecasting

# 1.0 Spain's Electricity Profile

Nearly all of the electricity consumed in Spain is generated domestically, with less than 1% imported from outside the country. As indicated in Figure 1, fossil fuels generate approximately 54% of the electricity produced in Spain, with nuclear contributing about 21%, wind 7%, hydroelectric facilities over 10 MW about 7%, and other renewables making up about 11% of the total amount of electricity generated (Ceña 2006a).

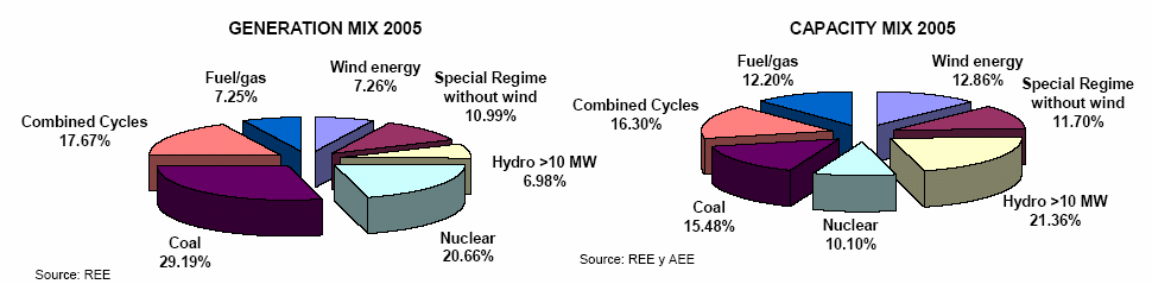


**Figure 1. Electricity generation and capacity by source in Spain, 2005**

Source: Ceña, Alberto. "Large Scale Integration of Wind Energy." Presented before the European Wind Energy Association. Large Scale Integration of Wind Energy, Brussels, Belgium, November 7-8, 2006. Available at http://www.ewea.org/index.php?id=490.

The demand for electricity in Spain has been steadily increasing at an average annual rate of 5.3% for the past ten years. Driven by strong economic growth, electricity demand has been difficult to keep up with, leading to several major blackouts attributed to extreme weather, supply shortages, or transmission grid malfunctions. Spain's heavy reliance on hydroelectric power (25% of total installed capacity) and the fluctuation of water availability contribute to supply constraints (International Energy Agency 2005b). Further contributing to supply shortages and blackouts were the natural gas shortages in the winter of 2004–2005.

One of the first European countries to initiate electricity market liberalization policies, Spain privatized and unbundled the transmission system in 1985 and passed the European Union's Electricity Sector Act by Royal Decree in 1997. The Red Elèctricia de España (REE) is the Spanish transmission operator, with 28.5% ownership by the Spanish government, 8% by each of the four major utilities, and 60.5% owned under private ownership and traded on the Spanish stock exchange. The Compania Operadora del Mercado Espanol de Electricidad, S.A. (OMEL) was created by the Spanish government to manage the business side of the electricity market, establish a spot market, operate the futures market, and assure the timely settlement of payments. Thus, REE was placed in charge of the technical operations and OMEL the economic functions of the market.

Spain has five major electricity companies, all of which operate both regulated and deregulated business enterprises: Endesa, Iberdrola, Union Fenosa, Hidroelectrica del Cantábrico, and Enel Viesgo. The relative sizes of the utilities (including their subsidiaries and affiliate companies operating in Spain) are listed in Table 1.

**Table 1. Spain's major electricity companies**

| Company | Distribution Size (No. of customers) | Capacity (MW) |
|---|---|---|
| Endesa | 10,500,000 | 21,602 |
| Iberdrola | 9,000,000 | 25,237 |
| Union Fenosa | 3,000,000 | 5,796 |
| Hidroelectrica del Cantabrico | 578,000 | 2,566 |
| Enel Viesgo | 600,000 | 2,365 |

Information provided on each of the company's webpages: Endesa – www.endesa.es; Iberdrola – www.iberdrola.es; Union Fenosa – www.unionfenosa.es; Hidroelectrica del Cantabrico – www.h-c.es; Enel Viesgo – www.viesgo.es

There are 21 companies operating as electricity producers in Spain under what is termed the "ordinary regime." Generators under the ordinary regime sell their production on the wholesale market and receive compensation for the electricity sold, plus a capacity payment and costs of transition (CTC) payments. As of 2003, the average capacity payment was €4.808/Megawatt-hour (MWh). An additional 150 electricity producers operate under what is considered the "special regime" open to companies specialized in the production of energy from renewable energy sources, waste, or cogeneration (Operadora 2004). Up until 2004, electricity sold under the special regime was purchased by the network operator at a fixed price that included a premium based on the technology or fuel. There was a reduction in the wind premium in 2003 that contributed to sluggish development of wind projects throughout 2003. The regulation was modified in 2004 under Royal Decree 436/2004, discussed in greater detail below under the section Energy Policies Promoting Renewable Energy. Generation classified under the special regime is dominated by cogeneration and wind power technologies.

The Spanish Electricity Market is organized as a sequence of markets: the day-ahead market, several intra-day markets that operate close to real time, and the ancillary services market. Participation in these markets is not compulsory, as participants are allowed to enter into physical, bilateral contracts outside the market structure. However, most transactions are carried out in the daily market. Available production units that are not linked to a bilateral contract participate as sellers. The price to be received or paid by the participants is set according to a uniform-price auction. Therefore, irrespective of individual bids, the market-clearing price is set equal to the highest accepted supply bid, or the "System Marginal Price" (Crampes and Fabra 2004). Buyers on the daily market include regulated distributors, retailers, resellers, qualified consumers and external agents registered as buyers. According to the OMEL Annual Report, 241,224 Gigawatt-hours (GWh) were traded on the market in 2004 for a total value of 8,340 million euros or an average annual cost of 3.457 Euro cents/kilowatt-hours (kWh). This represents an increase of 5.5% in the amount of electricity traded in the market at an average cost 1.9% higher than the previous year (Operadora 2004).

OMEL operates the market as one zone and does not provide location specific pricing for transactions. Without transparent locational pricing signals, congestion in the market is not reflected in electricity prices. As described above, the Spanish electricity market functions with the aid of two separate organizations: the market operator, OMEL, and the system operator, REE. The market operator receives the bidding of generation and demand for each hour on the day-ahead market and clears the market according to economic criteria. The system operator is responsible for the secure operation of the power system and owns the transmission system. One of the main tasks of the system operator consists of solving the power system constraints that arise after the economic market has been cleared. Power system constraints are solved by re-dispatching units, e.g., increasing and decreasing the generation of connected units, or connecting off-line units.

Furthermore, after every intra-day market session, REE manages any deviations in real time using ancillary services and deviation management. The purpose of ancillary services and deviation management is to ensure that energy is supplied under established conditions of quality, reliability and security, and that production and demand are balanced at all times. The system operator, REE, incorporates regulating band ancillary services in the viable daily schedule after the daily market sessions have been held. The final "wholesale" price of electricity comprises the market clearing prices, the cost of ancillary services and the capacity payment.

# 2.0 Organization of the Spanish Transmission System

The transmission grid includes approximately 16,547 km of 400-kV lines and 11,284 km of lines rated 220-kV or lower (International Energy Agency 2005b). REE has been the main transmission owner since it was created in 1985, owning 99% of the transmission grid. Over the past several years, REE has purchased the transmission lines of Endesa, Union Fenosa and Iberdrola, and is finalizing negotiations with Hidro Cantabríco for the remaining transmission assets.

REE is a private firm regulated by the National Energy Commission (Comisión Nacional de Energía or CNE). Royal Decree (RD) 1955/2000 guarantees access to the transmission system. Other relevant orders include RD 2819/1998, which defines the economic scope of transmission and distribution activities in order to guarantee a high degree of service quality; and RD 1164/2001, which fixes the tariff rules for access to the networks of transmission and distribution of electricity (Crampes and Fabra 2004). Further resolutions issued by the Secretary General for Energy address the specific conditions and operating parameters governing the interconnection and operation of the grid.

As the System Operator, REE Performs the following functions:

- Receives information from producers regarding available energy;
- Generates demand projects based on information from distributors, marketers, consumers, and internal resources;
- Analyzes technical constraints;
- Evaluates the need for reserves;
- Establishes hourly generating program for each one of the systems;
- Plans the development of the transmission grid; and
- Manages interconnection requests and access to the grid (Red Elèctricia de España, 2005c).

Spain has 16 high-voltage transmission interconnections with France, Portugal, Morroco, and Andorra (See Table 2). However, unlike Germany and Denmark, Spain's interconnection to the rest of Europe is relatively weak, with roughly 2,500 MW of cross-border capacity. Therefore, most supply-demand balancing is done internally.

In November 2001, the Spanish and Portuguese governments signed a protocol creating the Iberian Electricity Market (Mercado Ibérico de Electricidade - MIBEL), a common electricity market for the Iberian Peninsula. The agreement included provisions for increased transmission capacity between Spain and Portugal, and the use of a common market operator, OMEL, to manage trades. Following the construction of two new transmission lines, there are now four 400-kV and three 220-kW lines running between the two countries. Spain exports power to Portugal, and transmission capacity has often been congested in the past. Generally, Spain imports electricity from France and exports it to Portugal, Andorra and Morocco.

**Table 2. Interconnection capacity with Spanish transmission network**

| | Interconnection Capacity (MW) | | Interconnectors | | | | |
|---|---|---|---|---|---|---|---|
| **Country** | **Import** | **Export** | **Total** | **110kV** | **132kV** | **220kV** | **400kV** |
| France | 1000-1400 | 750-1000 | 6 | 1 | 1 | 2 | 2 |
| Andorra | - | | 1 | 1 | | | |
| Portugal | 600-850 | 750-1050 | 8 | | 1 | 3 | 4 |
| Morocco | 350-550 | 300-400 | 1 | | | | 1 |
| Total | 1950-2800 | 1800-2450 | 16 | 2 | 2 | 5 | 7 |

Source: Craig, Dr. Lucy (2005). "Large-Scale Integration of Wind Power into Power Systems—The Spanish Experience". Proceedings of the Fifth International Workshop on Large-Scale Integration of Wind Power and Transmission Networks for Offshore Wind Farms, April 7-8, 2005, Glasgow, Scotland.

Presently, electricity trade between Spain and France is done contractually and does not incorporate economic criteria, nor is it coordinated between the two transmission operators. The contracts represent 550 Megawatts (MW) of import capacity with France at peak demand periods. There are plans to establish economically-based allocations of transmission capacity, whereby power exchanges would flow from the low price area to the high price area. A pilot project in conjunction with capacity additions are planned for the near term.

In 2004, international exchanges amounted to 2,939 GWh exported, or 1.2% of annual electricity production. Spain was a net exporter of power in 2004 for the first time since 1997 (Table 3). The amount of electricity exported and imported can change dramatically from year to year, depending on particularly the amount of available hydropower, but has shown a steady growth over 30 years.

**Table 3. Net international energy exchanges by Spain, 2000–2004**

| Year | France | Portugal | Andorra | Morocco | TOTAL |
|---|---|---|---|---|---|
| 2000 | 7,907 | -931 | -111 | -2,263 | 4,441 |
| 2001 | 5,552 | -265 | -249 | -1,780 | 3,258 |
| 2002 | 8,835 | -1,899 | -292 | -1,315 | 5,329 |
| 2003 | 5,785 | -2,794 | -270 | -1,457 | 1,264 |
| 2004 | 5,174 | -6,254 | -287 | -1,572 | -2,939 |

Source: Craig, Dr. Lucy (2005). "Large-Scale Integration of Wind Power into Power Systems— The Spanish Experience". *Proceedings of the Fifth International Workshop on Large-Scale Integration of Wind Power and Transmission Networks for Offshore Wind Farms,* April 7-8, 2005, Glasgow, Scotland.

Plans to expand and improve the transmission grid include the addition of 271 km of high voltage power lines and 123 substations, as well as seven new transformers. Grid development work will focus mainly on connecting combined cycle plants and wind power projects, and providing service in support of the development of the high-speed train network (Red Elèctricia de España 2005a). Specifically, a partnership between the REE, local government officials, and wind developers is expected to strengthen the transmission system in Andalucia to allow for up to 4,000 MW of wind power to come on-line over then next several years.

In 2004 and 2005, the Andalucian government was granted transmission connection concessions from REE for nearly 4,000 MW. The Andalucian government holds the cessions and awards them as part of the permitting process. The concessions are the result of a significant effort on the part of the Andalucian government and local distribution companies working together with REE to create a grid zoning plan. The Andalucian government also requires wind developers to work together to identify and pay for network upgrades prior to awarding any concessions. Developers have pledged €60,000 for each megawatt under development for transmission interconnection and upgrades. The Andalucia region boasts significant wind resources, but a poorly developed infrastructure connecting potential projects to the transmission system (McGovern 2005c). Recent interconnection activity has accelerated, though, and 2,400 MW of interconnections for wind has been processed, clearing the way for rapid growth of wind power in the region.

# 3.0 Energy Policies Promoting Renewable Resources

In 1999, Spain established the *Plan for the Promotion of Renewable Energy in Spain* with the goal of meeting 12% of the total energy supply and 29% of electricity with renewables by 2010. Since the plan was issued, renewables have advanced significantly; however, the growth in total energy demand dampens the total impact of renewables and, thus, the market share is only half of the amount anticipated in the *Plan*. The strongest growth in renewable energy comes from the wind sector, which is already at 70% of the *Plan*'s goal for installed capacity of 13,000 MW by 2010. In 2004, the Spanish government raised the renewable energy target to 20 GW by 2010.

Under the special regime, renewable generators sell their output to the network operator, REE, under a fixed price or feed-in tariff that is set annually by the government. The government has the ability to change the amount of the premium in an annual review to support particular technologies, or to reduce support for them. Table 4 below provides the feed-in tariffs for eligible resources under the special regime for the years 2001–2004.

**Table 4. Feed-in premium tariff for renewable technologies (Euro cents/kWh)**

| Technology | 2001 | 2002 | 2003 | 2004 |
|---|---|---|---|---|
| Solar PV < 5 kWp | 36.0607 | 36.0607 | 36.0607 | 36.0607 |
| Solar PV > 5 kWp | 18.0304 | 18.0304 | 18.0304 | 18.0304 |
| Wind | 2.8788 | 2.8969 | 2.6640 | 2.6640 |
| Mini Hydro <10 MW | 2.9870 | 3.0051 | 2.9464 | 2.9464 |
| Hydro 10-50 MW | 2.9870 | 3.0051 | 2.9464 | 2.9464 |
| Primary Biomass | 2.7707 | 2.7887 | 3.3250 | 3.3250 |
| Secondary Biomass | 2.5603 | 2.5783 | 2.5136 | 2.5136 |

Source: International Energy Agency. *Energy Policies of Spain, 2005 Review*. Paris: International Energy Agency 2005.

The decrease in the feed-in tariff in 2003 and 2004 led to sluggish growth in the wind power sector in 2003. However, RD 436/2004 passed in March 2004, established alternative methodologies for selling power under the Special Regime. Following RD 436/2004, the owner of a renewable generator can choose to sell their power under one of three pricing options:

1. Special Regime Transition: continuation of the current subsidy as set annually according to market prices and the average reference tariff, available until January 2007;
2. Fixed Tariff Option: Bilateral sales to distributors with a subsidy of 90% of the average reference tariff (ART) for the first three years, 85% of the ART for the next ten years, and 80% of the ART through the life of the project;

3. Market Sales Option: negotiated market price, plus a subsidy of 40% of the ART, and an incentive for taking part in the market set at 10% of the ART (Asociación Empresarial Eólica 2005).
4. Producers may participate in either system; however, they must stay with the system they choose, special regime or market-based, for a minimum of one year. Table 5 estimates the three tariff options under RD 436/2004.

**Table 5. Wind power tariff options (March 2004) (Euro cents/kWh)**

| Technology | Market Rate | Fixed Rate | Special Regime Transition |
|---|---|---|---|
| Market Price | 3.1 | | |
| Reference Price | | | 3.77 |
| Fixed Tariff | | 6.58 | |
| Production Incentive | 3.65 | | 2.75 |
| Power Guarantee | 0.48 | | |
| Imbalance Penalties | -0.12 | -0.15 | -0.15 |
| Scheduling | -0.05 | -0.05 | -0.05 |
| Market Agent | -0.08 | | |
| Total Earnings | 6.98 | 6.38 | 6.32 |

Source: Michael McGovern, "Spain's Tariff Options: Moving Towards Market Realities." *Windpower Monthly* (May 2004): 32.

Despite what appear to be favorable economics supporting the market rate, wind power generators were skeptical of the new alternatives and largely stayed with the special regime system in 2004. After further cuts in the production incentive in December 2004, there was increased interest in the new tariff options in 2005. Several companies switched to the market rate in 2005, mainly because of the increase of the pool price, although wind power producers were required to schedule power alongside conventional resources in the power pool. This proved to be a sound economic move as wind farm owners were paid on average 8.661 Euro cents/kWh last year, 30% more than expected. A combination of high wholesale prices and subsidies led to the high prices (McGovern 2005f). Therefore, 91% of the wind capacity in Spain trades on the day-ahead market (McGovern 2006b).

In summer 2006, Spain's legislature passed RD 7/2006 effectively ending the existing production incentives for wind power created by law in 1997. Significantly, the production incentive payment is no longer linked to the ART for existing and future wind generation facilities, effective as of the end of 2006. RD 7/2007 requires that replacement regulation, including new incentives, be established by January 1, 2007. However, no specific criteria or guidance are provided for the design of new incentives. In addition, changes to the law may also remove the guaranteed minimum payment, fixed at 80% of the ART, for existing and future wind generation facilities. The Spanish government initiated the change after wholesale prices increased because of higher natural gas prices and lower-than-expected hydro production. Spain's electricity suppliers were legally

prevented from passing cost increases to customers and built up a deficit of 3.8 billion Euros. Of that, payments for wind accounted for 320 million Euros, or 8.4% of the total. The wind industry in Spain proposed a new incentive package for wind developers that both protects existing contracts by grand fathering certain incentives to existing generators that may have long term supply contracts but reduces incentive payments going forward on a sliding scale that is largely based on the wholesale power price (McGovern 2006a).

The Spanish electricity market also includes a market for renewable energy certificates (RECs). However, any producer that is already taking advantage of a subsidy or feed-in tariff is prohibited from unbundling the environmental attributes of green power for the sale of RECs. However, producers selling their output into the market, as opposed to the fixed rate or special regime, may be able to sell the associated RECs as a separate product.

Although this profile of Spain is primarily focused on wind, Spain will likely see a surge of concentrated solar power (CSP) projects beginning in 2007. The feed-in law provides two options for the first 200 MW of CSP projects in operation by 2010. For the first option, CSP generators receive a fixed tariff of 300% of the reference price (€ 0.21/kWh) during the first 25 years after start-up and 240% of the reference price (€ 0.17/kWh) thereafter. Under the second option, solar thermal electricity generators selling their electricity on the free market may receive 250% of the reference price during the first 25 years after their start-up and 200% thereafter, plus an incentive of 10% (International Energy Agency, Global Renewables Policies Database). The length and stability of the incentive set off a race to be the first 200 MW of CSP projects. Up to 795 MW of parabolic trough and power tower projects are planned for southern Spain, with two 50-MW projects are under development currently (Western Governors Association 2006). In August 2005, Spain raised the 200 MW target to 500 MW target (Solar Paces 2006).

# 4.0 Wind Resources

Spain has sufficient wind resources to exceed 30,000 MW of installed capacity, without consideration of offshore facilities (Asociación Empresarial Eólica 2005). Large shares of wind production take place in the North (Navarra, Aragon, La Rioja) and the Northwest (Galicia) with a national average operating capacity of 26% (Red Elèctricia de España 2005b). At the end of 2006, Spain had the second greatest amount of installed wind power capacity in the world. Germany was first with 20,622 MW and the United States was third with 11,603 MW of installed capacity. In 2006, approximately 1,600 MW was brought on-line in Spain, bringing total installed capacity to over 11,000 MW (Figure 3). RD 436/2004 created greater regulatory certainty and assured more stable returns on investment thereby encouraging developers to move ahead with projects that had been on hold in the previous year.

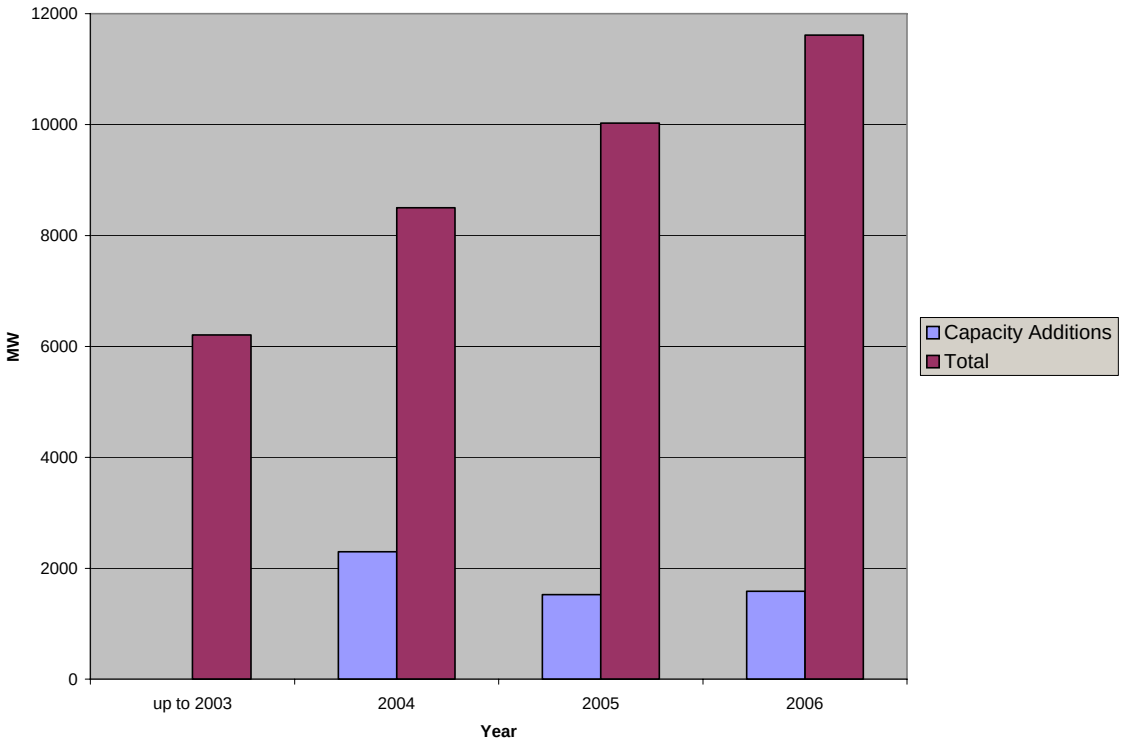


**Figure 2. Installed wind capacity in Spain**

Sources: Asociación Empresarial Eólica. "Installed Power Base 2005." http://www.aeeolica.org/english/html/installed_figures_2005.html. (accessed February 9, 2006).

Global Wind Energy Council. "Global Wind Energy Markets Continue To Boom – 2006 Another Record Year." 2007. http://www.gwec.net/uploads/media/07-02_PR_Global_Statistics_2006.pdf. (accessed February 8, 2007)

Among the manufacturers, Gamesa is the undisputed leader, as has produced almost two-thirds of all turbines installed in Spain. Gamesa benefits from regulations that require developers to use a minimum amount of Spanish-made wind power technologies. Next in line comes Vestas and Ecotècnia, currently incorporated within the Corporación Mondragón group (McGovern 2005e).

# 5.0 Current Market for Wind Development

Following the development of the new tariff structure in March 2004, creating what was considered a viable market for wind developers, investor confidence in wind projects has been very high. Furthermore, the new Spanish leadership, which came to power in 2004, raised the 13,000 MW cap on wind capacity in Spain, creating a new target of 20,000 MW by 2010. Further incentivizing the development of wind power projects is the national allocation plan for carbon emissions, established to help meet Spain's greenhouse gas reduction goals under the Kyoto Protocol.

However, despite the 20,000 MW target established by the central government, 2010 targets set by individual state governments would amount to a total of nearly 40,000 MW nation-wide. Grid operator REE advises that Spain can take no more than 20.2 GW of wind power by 2010 without compromising the security and reliability of the grid. This concern prompted the Spanish government to propose caps for the amount of wind power that can be developed in each region by 2010. Targets in some regions were cut by as much as 80% (Table 6) (McGovern 2006b).

**Table 6. Spanish government proposals to limit regional wind development**

| Region | Online (Qtr. 2006) | Regional Govt. Target 2010 | Central Govt. Cap 2010 | Target/Cap Difference % |
|---|---|---|---|---|
| Andalucia | 478 | 4,000 | 2,074 | -48.15 |
| Aragon | 1,488 | 4,000 | 2,577 | -33.58 |
| Asturias | 162 | 950 | 438 | -53.90 |
| Cantabria | 0 | 300 | 122 | -59.40 |
| Castile-La Mancha | 1,932 | 6,500 | 3,239 | -50.17 |
| Castile & Leon | 1,958 | 6,438 | 4,871 | -24.34 |
| Catalonia | 225 | 3,016 | 585 | -80.61 |
| Extremadura | 0 | 400 | 104 | -74.00 |
| Galicia | 2,429 | 6,500 | 3,757 | -42.20 |
| Madrid | 0 | 200 | 106 | -47.00 |
| Murcia | 55 | 850 | 207 | -75.65 |
| Navarra | 881 | 1,536 | 1,284 | -16.41 |
| Rioja | 419 | 665 | 594 | -10.68 |
| Valencia | 50 | 3,500 | 1,759 | -49.75 |
| Basque County | 145 | 624 | 270 | -56.73 |
| Total | 10,222 | 39,479 | 21,987 | -44.31 |

* The 2010 cap to be adjusted in 2008 in favor of best regional performers 2006-2008. Combined cap will remain at 21.987 MW.

Source: McGovern, Michael. "Government Brakes Speeding Market." *Windpower Monthly* (July 2006): 34.

Spain's largest energy companies are also the major developers of wind projects. Iberdrola has 32% of the market share and has established a target of 5,500 MW on-line by 2008. Endesa owns 8% of wind facilities in Spain and has established a target of 2,500 MW by 2009. Energía Hidroleléctrica de Navarra, bought in 2005 by Acciona, is the largest independent wind power developer with 11% of the installed capacity (McGovern 2006c).

The regions with sizeable wind markets have encouraged more development by raising targets and permitting plants as soon as grid improvements allow. Developers offering land-lease offers to municipalities and communities have become a valuable source of income for many rural areas. However, REE's concerns regarding the cumulative impact of more wind power on the grid have slowed their approval of connection permits considerably and the central government's recent statement regarding regional caps and limits to wind development may further deter investments. This is particularly true in those regions that already have a significant amount of wind capacity, namely Aragon and Castile & Leon which, despite having additional sites available, may have to limit the number of new facilities. Furthermore, the regional caps proposed by the central government may jeopardize grid improvement plans that were designed for a larger investment in wind power. Nevertheless, REE is requesting that some regional governments establish new control centers at the main grid points of their system, along with centralized grid point control for all regions (McGovern 2005b).

# 6.0 Impact of Wind Power on the Grid

With the increase in the national wind energy target to 20,000 MW, market participants and regulators have been seeking policies and regulations to both encourage wind development and support grid stability. The system operator is concerned with the reliability of the grid and potential problems from an intermittent resource. The wind developers are seeking appropriate price signals to stimulate investment in wind projects.

Wind developers seeking to sell their output on the wholesale market in Spain must arrange for interconnection to the transmission system. RD 1955/2000 and Resolution 3419 issued February 11, 2005, govern the procedures through which facilities must apply for interconnection. Facilities to be connected at greater than 100-kV must request access from REE, even if a local distribution utility owns the node to which access is connected. If access is requested through a distribution system, the developer will apply for interconnection to the local utility managing the distribution system who will subsequently request access for any additional load that will occur from the local distribution system to the transmission system as a result of the project. REE maintains a list of interconnection requests from potential wind projects. Table 7 provides the current amount of capacity under consideration for interconnection by province.

There are two impacts to REE from a new wind facility. First, under current regulations, REE will have to purchase the output of any facility operating under the special regime. Second, REE will manage the technical operation of the grid, including management of imbalances or voltage reductions that may result from unexpected wind conditions. REE is very conservative when considering the availability of wind supplies to meet projected demand, and REE does not include wind power in its programming, scheduling only conventional production as if the wind power does not exist. Therefore, if wind fails to produce, it has no impact on balancing the grid. If wind generation is available, the excess thermal energy that was scheduled either goes on standby or shuts down completely. However, as a greater number of facilities move off of the special regime tariff and sell their electricity directly under market prices, the wind producers are required to predict and schedule their output. Under RD 436/2004, wind producers using the market tariff already schedule their load on the wholesale market, buying and selling excess power as needed to smooth out any imbalances. Those participating under the fixed tariff rate are required to forecast and schedule their projected electricity supplies beginning January 2006. Wind forecasting must be conducted 30 hours in advance of the day-ahead market, i.e., up to 54 hours ahead of the last hour for the day-ahead market. Forecasts can be adjusted between one and six hours of the actual hour (Craig 2005). However, whether or not REE uses this information for operating the grid remains to be seen (McGovern 2005d).

**Table 7. Transmission interconnection requests for wind projects**

| Province (*) | Requests Received (MW) | Requests Answered (MW) | Requests Waiting for Response, Documentation Complete (MW) | Requests Waiting for Response, Documentation Incomplete (MW) |
|---|---|---|---|---|
| Andalusia | 7.739 | 5.836 | 1.857 | 45 |
| Aragón | 3.566 | 1.047 | 2.432 | 87 |
| Asturias | 605 | 534 | 71 | 0 |
| Cantabria | 174 | 174 | 0 | 0 |
| Castilla La Mancha | 3.874 | 3.752 | 0 | 122 |
| Castilla y León | 8.299 | 7.799 | 160 | 340 |
| Cataluña | 1.996 | 961 | 93 | 942 |
| Extremadura | 0 | 0 | 0 | 0 |
| Galicia | 2.925 | 2.773 | 3 | 149 |
| Madrid | 232 | 0 | 0 | 0232 |
| Murcia | 637 | 140 | 40 | 456 |
| Navarra | 551 | 502 | 0 | 049 |
| País Vasco | 310 | 200 | 110 | 0 |
| Rioja, La | 587 | 587 | 0 | 0 |
| C. Valenciana | 2.218 | 2.218 | 0 | 0 |
| Total | 33.712 | 26.525 | 4.766 | 2.422 |

Source: Red Elèctricia de España, Accesso a la Red de Transporte de Nueva Generación de Régimen Especial (1 Diciembre, 2005) http://www.ree.es/. (accessed on December 27, 2005).

Thus far, Spain has not made any regulations requiring additional reserves for wind power projects. Experience in the Spanish wind market shows that the short-term variations from predicted or scheduled load are not so great or numerous as to require additional secondary reserves (Eriksen et al. 2005). Furthermore, because REE does not schedule wind power alongside conventional resources but instead curtails thermal resources as needed to compensate for wind power that is available, the issue of long-term reserves has not been tested. With the increased number of wind projects using market rates, this issue may be revisited. The Spanish government is taking steps to mitigate imbalances created from greater penetration of wind power in the market. Regulations adopted in 2005 provide penalties for deviations greater than 20% from the day-ahead, 24-hour production forecast. Additionally, there are incentives available for deviations less than 10% from the rolling four-hour forecast (Miller and Lyons 2005).

Concerning wind forecasting, Spain has two ongoing efforts to improve forecasts, data collection and improved modeling techniques and telemetering. The Asociación Empresarial Eólica (AEE) is engaged with industry stakeholders and REE in a forecasting exercise to analyze the results of six different wind forecasting models applied to seven

plants. The models selected are actual forecasting models employed by six different companies. The seven wind projects were selected based on site topography and turbine design and each facility will use all six models compiling data for a full year. Preliminary results from the first three months (September – November 2004) indicate that the average hourly forecasting error in each of the wind plants was approximately 60%. This is far beyond the allowable margin of error stipulated in the fixed tariff. An important observation in the study indicates the value of aggregating multiple wind projects for scheduling as a mechanism to even out the imbalances. In particular, the initial results indicate that it is best to group plants in different wind basins (Asociación Empresarial Eólica 2005).

AEE provided an update that stated the mean absolute production error was 25%—still higher than the allowable margin of error—and that cannot be reduced any further with today's prediction tools. Greater accuracy in the metrological input data, and real-time production and wind data, is necessary to improve wind forecasting accuracy. AEE confirmed its earlier finding that aggregating wind projects reduces forecast error. Other results included that wind speeds were more important in determining forecast error than terrain, and that intra-day forecasts need data refreshing to improve forecast accuracy (Ceña 2006b).

The second ongoing effort to minimize system imbalances and variations from load forecasts is the telemetering of wind farm output. REE has worked with wind power project owners and developers to install telemetering equipment at wind facilities that collects production data and aggregates the data across the entire wind industry, comparing actual production to forecasted production. The telemetering is used to help manage and monitor real time market activity as well as for data collection to aid in future forecasts. The wind power output measurements, pictured in Figure 4, generate real time information on wind power being produced by telemetered wind producers. It covers a period of 30 hours, including the end of the previous day and the beginning of the next day, and is updated every three minutes for publication on the internet. The data includes information from all of the wind farms monitored by REE via telemetering, approximately 7,800 MW, or 81% of the total wind power installed in the Spanish mainland system (Red Elèctricia de España 2005a).

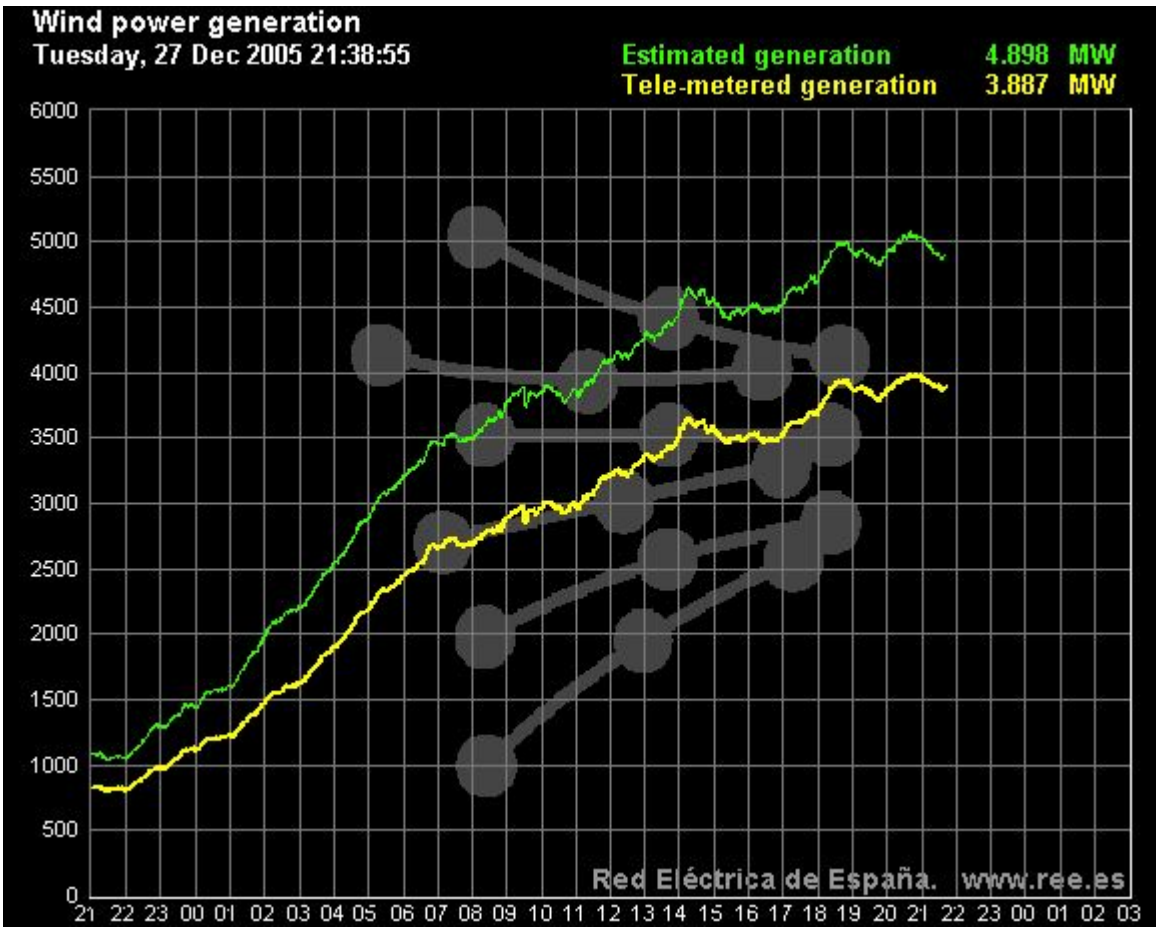


**Figure 3. Projected and real time wind power production**

Source : Red Elèctricia de España, available www.ree.es.

In December 2005, Spain required wind projects over 10 MW to be associated with a control center by the end of 2006 that will communicate directly with REE. The end of 2006 deadline was extended one year. Once implemented, REE will be able to control wind generation by sending orders from REE's control system to the wind generator's control center.

In addition to the concerns associated with the predictability of wind power, REE is also concerned with grid stability issues associated with voltage reductions and reactive power. These are legitimate concerns; however, many of the grid stability issues are addressed by new technologies available to wind developers. Furthermore, Spain has two advantages over other countries: the first is that the dominant market position of Gamesa has led to relatively homogenous turbine technologies that synchronize well, and make dynamic modeling and problem solving easier; secondly, the slower market development in Spain means that the majority of wind project have been built during the last four years with modern technologies. Most of the wind turbines in Spain use variable speed turbines that include a doubly-fed induction generator and pitch control. These technologies provide a wider range of dynamic speed control and minimize frequency fluctuations (Eriksen et al. 2005).

Furthermore, regulations established in 1985 require that all wind turbines automatically trip off-line if the grid voltage drops below 85% of the required voltage. However, most wind projects have operated with a power factor near unity in order to receive incentive payments. Under older legislation, wind operators could receive incentive payments for reactive power between 0.9 inductive and unity, determined as a monthly mean. The incentive payments varied from zero at a power factor of 0.9 to 4% at a unitary (100%) power factor. Penalties were levied at power factors below 0.9. In addition, as discussed below, Spain adopted a grid code for wind in October 2006 that requires wind turbines to stay on-line if voltage drops to 80% of nominal voltage for up to 500 milliseconds, among other provisions.

Under RD 436/2004, the incentive payment for reactive power may be positive or negative, as determined by the actual power factor and the time of day. The payment is a percentage of the ART and varies from –4% for a power factor of less than 0.95 at peak and flat rate periods to an 8% bonus for a power factor of less than 0.95 inductive in valley periods or less than 0.95 capacitive in peak rate periods (Table 8).

**Table 8. Reactive complement as a percentage of the TMR**

| | COS PHI | PEAK | FLAT | VALLEY |
|---|---|---|---|---|
| | <0.95 | -4 | -4 | 8 |
| | <0.96 and <0.95 | -30 | 6 | |
| INDUCTIVE | <0.97 and ≥0.96 | -2 | 0 | 4 |
| | <0.98 and ≥0.97 | -1 | 0 | 2 |
| | <1.00 and ≥0.98 | 0 | 2 | 0 |
| | 1.00 | 0 | 4 | 0 |
| | <1.00 and ≥0.98 | 0 | 2 | 0 |
| | <0.98 and ≥0.97 | 2 | 0 | - |
| CAPACITIVE | <0.97 and ≥0.96 | 4 | 0 | -2 |
| | <0.96 and ≥0.95 | 6 | 0 | -3 |
| | <0.95 | 8 | -4 | -4 |

Source: Craig, Dr. Lucy (2005). "Large-Scale Integration of Wind Power into Power Systems—The Spanish Experience". Proceedings of the Fifth International Workshop on Large-Scale Integration of Wind Power and Transmission Networks for Offshore Wind Farms, April 7-8, 2005, Glasgow, Scotland

To maximize the incentive payments and avoid the penalties, variable speed turbines incorporate control equipment at each turbine. Operators of fixed speed turbines typically operate a bank of capacitors at the substation. So far, it appears that the fixed turbines have had less flexibility in meeting the reactive power standards and are not as likely to qualify for the full incentive payments.

An additional incentive payment of 5% of the fixed tariff is available for up to four years for wind projects that can continue operating through network voltage drops at the interconnection point (Craig 2005). In October 2006, Spain adopted a grid code that requires wind turbines to stay operating if voltage drops to 20% of nominal voltage lasting

up to 500 milliseconds, followed by a ramp up to 80% of nominal voltage in another 500 milliseconds and a more gradual recovery to 95% of nominal voltage 15 seconds from the occurrence of the grid fault (Fernández 2006). Reportedly, the provisions would require all wind generators to be equipped with emergency override-control by the grid operator if wind generation exceeds demand (McGovern 2006c).

In the past, REE curtailed wind output if wind power penetration exceeds 12% of demand. REE derived this penetration level through system studies of the Spanish grid and its international connections, particularly the interconnection to France. REE's study was conducted in 2002 and found that the grid functioned adequately at peak with a peak demand of 36,500 and with 10,000 MW of wind, or 27% of demand. System problems emerged during minimum demand periods at 25,000 MW, with the maximum wind penetration at 5,000 MW if wind projects can stay connected at low voltage up to one second, or 3,000 MW if wind projects are disconnected within 0.5 seconds. The 3,000 MW represents 12% at minimum demand. At higher levels of wind power or at shorter grid disconnect times, REE determined that the interconnection with France would be lost. At peak times, REE believed that 20% could be met by wind, or 13,000 MW, assuming that REE can curtail wind production during periods of minimum demand (Craig 2005). With the government's 20 GW goal, the belief is that wind projects will have to meet new grid security requirements and procedures in order for that 20 GW goal to be reached (McGovern 2006c).

Several assumptions that drove REE's 2002 study results should be considered:

- The wind turbine designs reflected what was in the industry in early 2002. Wind turbine designs have changed considerably since then, with more doubly-fed induction generators and some synchronous generators becoming operational.
- The geographic spread of wind capacity in Spain is more distributed than what REE assumed.
- REE did not submit the generator models used in its studies to the wind industry for review until relatively recently, and discussion between RES and the wind industry regarding the models is ongoing.

Under its interconnection agreements with wind project, REE can curtail wind production if system conditions require such action. REE said it would first curtail or disconnect wind projects that do not have fault ride-through capability. Curtailment was relatively infrequent up to 2003. One occurrence was in the Galicia region in northwestern Spain, which has limited connection to the transmission grid and in periods of high rainfall, cannot handle the hydro and wind generation. Losses for wind operators from curtailment in the region have been up to 12% of annual output.

Curtailment in 2004 occurred more often and generally whenever wind generation exceeded 12% of demand, particularly during valley hours on weekends. The wind industry disagrees with the legal and technical criteria for curtailment, and curtailment criteria will likely be re-examined, especially given the government's goal of reaching 20

GW from renewables instead of 13 GW (Craig 2005). In 2005, however, curtailment reportedly occurred relatively less frequently. In addition, it appears that REE's limit of 12% wind has been relaxed, as there have been periods of wind penetration considerably higher than 12%–the highest half-hourly penetration has been 24% of total demand (Craig 2006).

In addition to the regulations for voltage control, REE has indicated to both developers and the officials within the autonomous regions of Spain that those regions with a high penetration of wind power may not receive additional concessions for connection to the transmission grid without sufficient upgrades to the grid. As mentioned above, the region of Andalucia has already taken steps to prepare their local distribution systems for an influx of wind projects and requires developer to contribute to the cost of grid improvements. Subsequently, Andalucia was awarded concessions for nearly 4,000 MW of wind. Another approach that has met with approval by REE is that of the private company Iberdrola. In response to REE's concerns, Iberdrola created a Center for Operations of Renewable Energy (CORE) in Castile-La Mancha, where it already has nearly 1,000 MW on-line. CORE enables Iberdrola to monitor a wide range of parameters at the grid connection and has enabled Iberdrola to respond quickly to voltage fluctuations as well as requests from REE for curtailment. The use of the control center eases REE's concerns regarding grid stability and, as a result, Iberdrola has been issued new grid access for 200 MW of new projects in a region with 1,600 MW already on-line. REE has recommended that other regions with large amounts of wind power also establish local control centers (McGovern 2005b).

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