Convocatoria de ayudas de Proyectos de Investigación Fundamental no orientada

TECHNICAL ANNEX FOR TYPE A or B PROJECTS

1. SUMMARY OF THE PROPOSAL (the summary must be also filled in Spanish)

PROJECT TITLE:

Short- and Medium-Term Multimarket Optimal Electricity Generation Planning with Risk and Environmental Constraints.

PRINCIPAL INVESTIGATOR: F.-Javier Heredia Cervera

SUMMARY
(brief and precise, outlining only the most relevant topics and the proposed objectives):

The GNOM research group of the UPC team has been continuously participating in research projects founded by the MEC-CICYT since 1999, always in the field of the optimal electricity generation planning. In the last two projects, project DPI 2002-03330 and DPI2005-09117-C02-01 (in progress at present) we have formulated and implemented mathematical models and algorithms for the optimization the of electric power generation planning in the short (one week) and in the medium term (one year) of a generation company operating in a competitive market. The radical changes occurred in the Spanish energy market regulation during the last three years with the starting of the MIBEL (Iberian Electricity Market) forces the existing models to be adapted to the knew operating rules and opportunities. The project here proposed aims at several new features:

- The joined optimization of the “multimarket” nature of the MIBEL organization, with a portfolio of markets (futures, day-ahead, reserve, intradiary, VPP,…) and physical bilateral contracts, both in medium and short term planning.
- The inclusion of “environmental constraints” in the optimization models, through the precisely formulation of the emissions permits in such a way that each emission technology (wind, solar, hydraulics, combined-cycle, thermal) will be used in the optimal way.
- Several stochastic variables, as energy prices in the different energy markets, fuel price, natural inflows, etc must be precisely modelled in order to be able to formulate accurate stochastic programming models with risk o solve the optimal multimarket risk and environmental constrained offer problem.
- The different market problems were solved separately in previous projects. The multimarket model proposed in this project aims to optimize simultaneously al these related markets, posing new optimization challenges that must be undertaken both with commercial optimization software and, whenever necessary, with specialized interior point and dual decomposition algorithms for mixed nonlinear optimization which will be also developed within this project.
- Finally, due to the applied orientation of the fundamental research of this project, both the models and the algorithms developed should be validated with the help of the real data provided with the two EPOs of the project, Unión Fenosa and Gas Natural, two of the most prominent electrical utilities of the Spanish electricity market.

TITULO DEL PROYECTO:
Short- and Medium-Term Multimarket Optimal Electricity Generation Planning with Risk and Environmental Constraints.

RESUMEN (breve y preciso, exponiendo sólo los aspectos más relevantes y los objetivos propuestos):

El grupo de investigación GNOM de la UPC ha venido desarrollando ininterrumpidamente proyectos de investigación en optimización de la generación eléctrica dentro de los sucesivos Planes Nacionales desde el año 1999. Dentro de los dos últimos proyectos (DPI 2002-03330 y DPI2005-09117-C02-01, este último todavía activo) se han desarrollado diversos modelos y métodos de optimización para la planificación de generación eléctrica en el corto plazo (hasta una semana) y medio plazo (hasta un año) de una compañía productora de electricidad que opera en mercados eléctricos competitivos. Los profundos cambios de modelo y normativa que se han producido en España con la puesta en marcha del Mercado Ibérico de Energía Eléctrica (MIBEL) hacen precisa la adaptación de los modelos y algoritmos matemáticos ya obtenidos por el grupo a las nuevas restricciones y oportunidades que brinda la nueva regulación. El proyecto que presentamos aspira a investigar las siguientes nuevas características:

- La optimización conjunta de la naturaleza "multi-mercado" en que se ha organizado el MIBEL, y otros mercados extranjeros, con una cartera tanto de mercados (derivados físicos y financieros, mercados diarios, mercados de reserve, intradiarios, subastas de plantas virtuales VPP, etc) como de contratos bilaterales físicos, tanto en medio como en corto plazo.
- La aparición de forma explícita en los modelos de optimización de "restricciones medioambientales", a través de la precisa formulación de los derechos de emission de forma que las compañías generadoras puedan decidir la generación de las diferentes tecnologías (solar, eólica, hidráulica, térmica, nuclear y ciclo combinado) de forma optima.
- Existen diversas variables aleatorias, como el precio de la energía en los diferentes mercados, el precio de los combustibles, las aportaciones hidráulicas, etc, que deben modelizarse con precisión para ser capaces de formular modelos de optimización estocásticas fiables, que incorporen medidas de riesgo, y que permitan resolver problemas reales de optimización de la oferta con restricciones medioambientales.
- A diferencia de los proyectos anteriores, donde tan solo se analizaban y resolvían los mercados de forma separada, en este proyecto aspiramos a formular y resolver modelos multimarket donde se optimicen de forma conjunta diversos mercados i/o nominaciones de contratos bilaterales. Esto llevará a la aparición de nuevos problemas de optimización de gran escala que deberán ser resueltos, ya sea mediante el software de optimización comercial o, probablemente, mediante el desarrollo de algoritmos específicos de optimización de gran escala, especialmente métodos de punto interior y métodos de descomposición duales.
- Finalmente, debido al interés práctico de la investigación básica que se desarrollará en este proyecto, será necesario validar tanto los modelos matemáticos como los algoritmos desarrollados mediante la ayuda de los datos de sistemas de producción reales proporcionados por los dos EPO del proyecto, Unión Fenosa y Gas Natural, dos de los principales operadores del mercado ibérico de energía eléctrica.

2. INTRODUCTION
(maximum **5** pages)

- The introduction should include: the aims of the project; the background and the state of the art of the scientific knowledge, including the essential references; the most relevant national and international groups working in the same or related topics.

Project Purposes:

This research project aims to develop mathematical models and algorithms to optimize the complex decision making process faced by a generation company who wants to maximize its own benefit when operating in a liberalized electricity multimarket framework, as it is the MIBEL in Spain and Portugal. Through this models and algorithms we will try to extend and improve the fundamental scientific knowledge, of one of the most relevant production planning problem, with economical and environmental nation-wide impact. Based (a) on the evolution of the national and international behaviour and regulation rules of the electricity markets, (b) on our conversations with the EPO of the current project, and with other Spanish electrical utilities, and (c) on the most recent scientific results published in the area, we would like to improve and extend the models developed under the current project DPI2005-09117-C02-01, in the following ways:

- **Multimarket modellization**. Liberalized electricity market are nowadays very sophisticated energy- and financial-transaction multimarkets where, around the "main" electricity market, the so called "day-ahead market", there exists a portfolio of other financial and physical markets (futures and forwards contracts, virtual plant auctions, bilateral contracts, regulation market, intradiary markets, international connection capacity auctions,…) some of them concurrent, some of them sequential. We would advance in the formulation of short- and medium-term mathematical programming models for the joined optimization of all this concurrent and sequential markets. It is also relevant, In the medium-term optimization, to perform simulations to determine the type of market behaviour in the Spanish electricity market: equilibrium, cartel, or mixed cartel-equilibrium
- **Modellization of environmental issues.** A generation company operating in such a complex market cannot optimize its medium and short term generation planning decisions (basically, its offers to each of the beforehand mentioned markets) without taking into account the increasingly importance of the environmental issues: both the costs of the pollutants emissions (cost of CO_2 emission rights, NO_x bubble) and the impact of the emission-free (wind-power an hydro-generation) and low-emission technologies (combined cycle). The models proposed in the electrical market optimization area (as the ones developed at present at the GNOM projects) usually consider just the thermal and hydro units. It is our aim to extend these mathematical models to accommodate wind-power and combined-cycle generation units.
- **Stochasticity**. Several of the fundamental parameters of the optimization models are stochastic variables: spot price, natural inflows, fuel price, wind power generation. The modellization of those uncertainties will be undertaken with the help of *stochastic programming techniques*. We would like to improve the confidence of the stochastic optimization models previously developed (a) through an appropriate modellization of the stochastic variables through time series analysis, (b) through the design and implementation of specifically tailored scenario tree generation and reduction techniques and (c) hedging with the derivatives electricity market against the risk of profit loss. Finally, *probabilistic constraints* could be used to suitably formulate several energy balance constraints where some of the energy incomes are functions of stochastic variables.
- **Optimization.** The *deterministic equivalent* optimization problems associated to the stochastic programming models described in the previous paragraphs use to be *large scale nonlinear continuous, or mixed, mathematical programming problems*. These problems will be optimized in a first attempt, with general purpose commercial optimization software (mainly CPLEX, MINOS, Knitro,…). Whenever necessary, we will develop specialised optimization tools: *interior point* techniques for the solution of the maximization of the market surplus; warmstartings and global optimization procedures, as the use of a reverse-convex constraint are to be employed; dual and

decomposition methods in the presence of binary variables associated to the thermal and combined-cycle generation units management; nonlinear network optimization to treat the hydro-generation replicated network.

- **Solution analysis.** The modellization and optimization hypothesis of the proposed research project must be verified through computational tests performed with the data provided with the electrical utilities that participates as "EPO". With the help of the EPO, we will create a set of test cases with which we will validate the proposed models and optimization methods.

Background:

The main results already obtained, or that are more likely to be achieved by the end of the current project DPI2005-09117-C02-01 are summarized in the following items:

Medium-term generation planning:

We term the *pure-pool basic block* the formulation of the medium-term power planning in a pure pool (with market auction only) as a convex quadratic optimization problem [Nabona04], and its solution using the GP heuristic [Pagès07] and warm starting [Pagès07b]. We term the *mixed-system basic block* the formulation of the medium-term power planning in a mixed pool, with market auction plus physical bilateral contracts, as a DC (difference of convex functions) optimization problem [Pagès08] tranformed to a convex optimization with a reverse convex constraint, and its solution using the GPb heuristic. In both basic blocks the GenCos profits are calculated with a linear market-price function w.r.t. the load duration with endogenous variation of the market-price with use of hydro generation and generation by other technologies, and satisfaction of demand through the matching of load-duration curves following the Bloom and Gallant formulation, and we reach the Nash-Cournot equilibrium [Tesser08b] through the NIRA algorithm [Nikaido55, Contreras04], and avoiding the creation of an exponential number of load-matching constraints through the GP and GPb heuristics. In the mixed-market basic block, the maximization of market-price function of load duration is only for the expected generations accepted by the M.O. of all the units, but the generation costs of units to be subtracted refer to the matching of both the market LDC and the bilateral contract LDC, which leads to a DC objective function. For risk-averse GenCos the efficient frontier can be obtained using the CVaR measure [Tesser 08].

When dealing with a mixed marked of pool plus bilateral contracts (BCs) the fundamental block is the maximization of profits with respect to the part of the units' expected generations that are bids accepted by the Market Operator, while the rest of the expected generations are match the BCs [Pagès 08]. The objective function of this problem is the difference of two convex functions (DC), and special techniques are necessary to find an acceptable optimizer. A new heuristic has been developed during the second half of the current DPI2005-09117-C02-01 MEC project to avoid having to generate an inordinate number of LMCs while matching the market and the BC loads [Pagès08b]. The special technique employed to deal with the DC objective function is to transform the problem to one with a convex objective function and an additional reverse convex constraint. With this fundamental block for the mixed market, stochasticity (through scenario trees), market equilibrium and risk aversion by GenCos can be taken into account.

Wind-power in the medium term will be considered by decomposing it into a pseudo thermal unit with a given outage probability of about 10% plus a totally random generation represented by a uniform reduction of the LDC [Eager07].

Given the new rules introduced in the Spanish market in 2006-2007, forward markets become relevant. Contracting policies for the various instruments available (futures and options on virtual power plants) have to be considered in the medium-term planning as instruments of hedging the price risk. Furthermore risk averse policies must be taken into account for hedging uncertainties (fuel and emission permit prices, renewable generation, as wind and solar power, and hydro inflows) [Tanlapco02]. For this reason, models for the forward price of energy must be used in order to take contracting decisions. The determination of forward prices can be done either trough exogenous reduced form models [Lucia02] or by computing endogenously the equilibrium on the forward markets [Buhler07].

Short-term generation planning:

In the short-term planning for a price-maker, the model in [Nabona07] will be extended. The extensions will include the satisfaction of the physical bilateral contract load and of the spinning-reserve band limits. A joint optimization of the profits from the daily energy and of the secondary market will lead to a unit commitment solution representing the best planning for the GenCo participating in both markets and having to honor a bilateral contract load.

A quadratic mixed integer stochastic model for a price-taker GENCO was developed [Corchero06] at the beginning of the current DPI2005-09117-C02-01 MEC project, following the first and incomplete official documentation about the Iberian Futures Market. The uncertainty of the market price was modelled through a discretization of the spot price represented by a scenario tree with equiprobable scenarios. This model allows the GENCO to select the contracts that are going to be physically delivered ant the unit commitment for the day after tomorrow, the economic dispatch of the futures contracts for tomorrow, and the optimal instrumental bid.

The new rules of electrical energy production market operation of the peninsular system, for the diary and intra-diary market from the July 2007, bring new challenges in the modeling and solution of the production market operation (see [omel]). The presence of new mechanisms to balance the competition of the production market, such as: physical futures contracts, bilateral contracts of the virtual power plan and bilateral contracts between electricity distributors for the supply of energy to captive customers in the production market, with the national bilateral contracts, are being currently modeled by our research group.

The model in [Corchero06] was adapted accordingly to the new MIBEL rules [Corchero07]. In this first approach only the futures contracts were considered. The model was a two-stage stochastic mixed integer quadratic model with a 24h optimization horizon. This model allows a price-taker GENCO to decide the unit commitment, the economic dispatch of the physical futures contracts and the optimal bid observing the MIBEL regulation. The stochasticity of the spot price is represented by a reduced scenario tree. Both models were solved with real data of a Spanish GENCO and market prices. Nowadays, we are working in the improvement of this model including bilateral contracts.

In the scope of the treatment of the stochasticity, there has been applied the techniques presented in [Hoyland01] and [Gröwe-Kuska03] to the Electricity Market Spanish prices in two Graduate Thesis, [Roso07] and [Vila07]. In [Vila07] a scenario tree is build by a non-linear optimization model where both prices and probabilities can be decision variables. In [Roso07] a scenario tree is obtained reducing an existing tree by a heuristic method. The results of both works have been successfully applied in the stochastic optimization problems for the short-term generation problem, and a final report is been written for publication.

The deterministic equivalent problem associated with all those stochastic optimization models are large scale mixed nonlinear problems, which are hard to solve via direct methods (Branch&Bound) with the available commercial software (CPLEX). The experience of the group with specialized dual decomposition techniques (Radar Multiplier methods, [Beltran02], [Beltran05]) will be applied to solve such a complex problems.

All this models have been solved with real data obtained from the EPO and from public data of the market and system operator. The largest model solved included all thermal units of the EPO with a detailed quadratic cost function; it has a 48 interval horizon and the stochastic model was solved with a 20 scenario tree.

State of the art:

Medium-term generation planning:

Medium-term generation planning considers the programming of power generation by each generation unit during each subperiod (of length one week to three months) over a horizon of one to two years. This programming must be adapted to the competitive environment of electricity markets where generation companies (GenCos) try to maximize their profits, defined as the revenues from the market minus the generation costs.

The Spanish electricity market can be considered to be an oligopoly because there are four to five price-maker participants and a host of small price-taker GenCos. The type of planning that a price-maker GenCo should envisage must be one that takes into account the rest of participants in the pool, which jointly with the specific GenCo (SGC) considered matches the pool load, and this research project addresses the medium-term planning as seen by a price-maker GenCo.

There are three main approaches: the direct solution of the analytic complementarity conditions of the market equilibrium, the equilibrium methods based on conjectural methods, and the methods based on the use of a predicted exogenous and endogenous market-price function with respect to the load duration.

The analytic complementarity conditions require many simplifications on the generators bids and lead to a mixed complementarity problem (MCP) expressing the first order optimality conditions of equilibrium [Hobbs01]. Solving this problem for large cases is practical only when demand elasticity and constraints are linear, and cost functions are linear or quadratic.

Special mention should be made of the variant of conjectural variation presented in [Barquin04, Reneses06] and further extended in [Barquin06] and [Centeno07] for uncertainty in the demand and inflows. In them, the generator supply function is assumed to be linear with constant and known slope for every supplier and for every period and load level considered, and these coefficients can be estimated from historical records. The basic equilibrium conditions are shown to coincide with the first order conditions of an optimization problem having the generations as variables and with a special objective function and subject only to the load balance constraint. Technical and operational constraints are then added to this optimization problem to solve realistic medium-term planning problems. (It is there stated that solving the problem having added to it other technical and operational constraints on generations produces the equilibrium generations subject to the same technical and operational constraints.)

Finally, the methods based on the use of a predicted exogenous and endogenous market-price function, which have been developed by the research team of this project [Nabona04, Pages07,Tesser08], offer several important advantages over the two other procedures: they do not require the limiting assumptions on the GenCos of having a constant and known capacity of changing the market price with their generation at every subperiod of the optimization horizon, and they have no limit in the type of operational constraints that can be taken into account. In this procedure the medium-term load is considered as a load-duration curve (LDC) and its matching, taking into account the random outages of generation units, is done using the Bloom and Gallant formulation [Bloom&Gallant94]. A linear market-price function in terms of the load duration is predicted for each subperiod of the problem horizon based on historical records of market prices, loads, and generations. An endogenous variation of the parameters of this linear market-price function with hydro generation and generation by other technologies is also employed [Pagès06, Tesser08], and equilibrium is obtained using the NIRA algorithm [Nikaido55, Contreras04] and risk of profit loss aversion by the participating GenCos is taken into account using CVaR constraints [Palmquist99]. Given the uncertain nature of many of the variables that determine the profits of the GenCos, risk aversion policies and forward contracting decisions have to be determined: we mention the article of [Eichhorn06] because it can be considered the state of the art both in the scenario reduction techniques used come up with computable scenario trees, and for the consideration of coherent, multi-period risk measures. As for the hedging against risk with futures, there are the works of [Bessembinder 02], and [Buhler07], where the participant consider a mean/variance utility.

Regarding the oligopolistic mixed electricity markets with pool and bilateral contracts (BCs), as the Spanish market is since July 2006, the presence of BCs further complicate the modelling of the profit maximization by GenCos as they have to match the LDC of its own BCs jointly with the LDC of the market load, which requires sharing the generation time of each unit between the BC LDC and the market LDC [Pagès08].

Short-term generation planning:

Works that address bidding strategies in deregulated markets consider either “price-taker” market participants or “price-maker” participants. The bids of price-takers do not influence the market clearing prices because they are small players. On the other hand, price-makers are powerful enough to influence the market clearing prices. Most articles take the viewpoint of a single producer in a market with no competition among the participants. That is, the producer under study develops his bidding strategy while the others bid as usual. Only a few works integrate competition to obtain more realistic models.

GenCos in short-term planning must decide which bids to submit to the Market Operator compatible with a certain unit commitment of their units, which satisfies the operating conditions of minimum service and down times. In the process of determining the offer bids, the market price is a key point, which can be approched in two ways. One is to consider the SGC a price-taker company, and then the market price must be forecasted and supplied as data to the model. The other way is to consider the SGC a price-maker company, being then the price the result of an optimization process.

For an SGC owing a portfolio of units capable of altering market-clearing prices, a procedure has been proposed in [DelaTorre02] for which it is necessary to know the price quota curve of the SGC for each hour. With this procedure, a maximum-profit linear unit-commitment problem for the SGC units can be set up and solved over a planning horizon. From its solution market prices for each hour are estimated and generation bids can be established. While this model addresses only a SGC, in [Nabona 07] the model is thought to include all the units of the pool and enforcing the matching of the market load of the whole system. This idea was developed in [Li 99], where a bidding strategy for multi-round auctions based on a two-level optimization procedure was proposed.

Another method considering the units of the SGC plus a unit commitment is that in [Conejo02], which relies on the prediction of a residual demand function (also called price-quota curve) for each hour, expressing the change in market price due to the generation of the SGC. From these, a nonlinear and discontinuous mixed-integer optimization problem is formulated to maximize the SGC profit.

Combined cycle (CC) units represent the majority of new generating unit installations across the globe. For example, in the Peninsular system the installed capacity of CC units in the 2002 was the 5.24% of the installed total capacity, in the 2007 is the 24.38% (see [ree]). The reason of this growth is that the CC units feature distinct advantages for power generation such as high efficiency (a 20%–30% improvement over that of traditional thermal plants), fast response, shorter installation time, abundance of gas, and environmental friendliness [Kehlhofer91]. The short-term scheduling of CC units could represent a complicated optimization problem because CC units could have multiple operating configurations based on the number and the status of combustion turbine and steam turbine [Lu04].

The new regulations of the MIBEL, which start-up last July 2007, attempt to reduce the influence of the dominant operators through financial tools in order to increase the competition in the market. This kind of regulations wants to converge in the perfect market which is integrated by all price-taker operators. Because of those reasons and the fact that it is very difficult to model the influence of a price-maker operator in the clearing price, the majority of the publications are focus on price takers generation companies. General considerations about the bidding process in these electricity markets can be found in [Anderson02], [Anderson03], [Neame03].

In the context of thermal units, the authors in [Conejo02a] propose a mixed integer programming model to optimize the production schedule of a single unit. A simple strategy is introduced to convert the production schedule into real bids. The strategy consists in bidding very low when the unit must produce electricity and very high, otherwise. Although this approach works well in the presence of good price forecasts, additional benefits can be obtained in a volatile price environment by considering more flexible bidding strategies. In [Conejo02b] and [He02], bids are optimized in a context where competition among producers is taken into account through a Nash equilibrium model.

In the last years there has been many works focused on the short-term generation planning in deregulated markets but only a few obtains the bid curve for the company. The procedure presented in [Bakirtzis07] develops a mixed integer linear model to obtain the bidding strategy for an electricity producer in a day-ahead market with step-wise offers. The model takes into account both the producer constraints and the system operator market clearing problem. Both offer quantities and price are decision variables of the model. For this approach it is necessary to know the offers of the competitors, which is a very hard condition.

As an alternative in [Ugedo06] the residual-demand curve is used for avoid this uncertainty of the demand and the competitors' offers this approach, this curve represents the influence of the company in the clearing price. This work presents a stochastic model to obtain the distribution of the generation of a company among the day-ahead market and the ancillary services markets with the characteristics of the Spanish energy markets. The model obtains the bidding curve for each unit and market.

Another approach is presented in [Li07] who models the risk associated to the price uncertainty by risk-constraints. This work obtains a bidding strategy for the day-ahead market and the ancillary service market for a generation company with stochastic unit commitment.

Some interesting multi-market works are [Plazas05] and [Triki05]. In [Plazas05], the authors develop a sequential bidding strategy for thermal units in three spot markets using stochastic programming. Basically, offers are submitted to the first market and, depending on the result, offers are then submitted to the second market and, finally, to the third market. The authors consider a price-mover setting for the last market, which complicates the matter. Also, bids for all periods of the planning horizon must be submitted at once. In [Triki05], the authors present a mixed integer stochastic optimization model for scheduling thermal units. In this model, production plans are optimized in the presence of stochastic Market Clearing Price, but without considering bids explicitly. Thus, an ad hoc bidding strategy, like the one mentioned earlier, must be used.

Although there are a lot of publications in the area of the emissions permits, there are only a few works that include them in the short-term generation planning. Most of the publications are about the emissions trading or the long-term planning but not about the influence in the short-term strategies. [Linares06] presents, among other models, the optimization of the generation of each company taking into account the impact of the European emissions trading in Spain.

National and International Groups:

There are two important groups in Spain working on short- and medium-term planning. The first one is in the Department of Electrical Engineering of the University of Castilla-La Mancha, led by Prof. A.J. Conejo. Its recent production includes a risk-constrained stochastic programming framework [Carrion07a] to decide which forward contracts the retailer should sign and at which price it must sell electricity so that its expected profit is maximized at a given risk level. In [Carrion07b] provides a technique based on stochastic programming to optimally solve the electricity procurement problem faced by a large consumer. Supply sources include bilateral contracts, a limited amount of self-production and the pool. In [Gabriel06] analyzes the problem of setting up contracts on both the supplier and end-user sides to maximize profits while maintaining an acceptable level of settlement risk. In [Bouffard05a] and [Bouffard05b] is formulates and tested a stochastic security-constrained multi-period electricity market clearing problem with unit commitment. In [Conejo05] proposes a technique to forecast day-ahead electricity prices based on the wavelet transform and ARIMA models. The group of professor Conejo has published some models with high relationship with the ones we have presented and, in the last years, they have studied new techniques for Spanish market price forecasting that will be very useful for our approaches. This results are described, among others, in [Plazas05] and [Conejo05].

The second active group in this field is in the Instituto de Investigación Tecnológica, at the Universidad Ponticia de Comillas, led by Prof. A. Ramos, and where Drs. J. Barquín, E. Centeno, J. Reneses and Prof. M. Rivier are active. In [Centeno07] they present a model to address generation companies' medium-term strategic analysis based on a conjectured price-response market equilibrium representation that assumes a single node system. In [Reneses06] they analyzes the coordination between medium-term generation planning and short-term operation in electricity markets. This group has also developed some models of multimarket optimization, [Franco03] and [Ugedo06].

Among the international groups with interest in medium-term planning there is that led by Prof. Werner Römisch of the Mathematisch-Naturwissenschaftliche Fakultät at the Humboldt-Universität zu Berlin. We can mention also the research group of the Electrical and Computer Engineering Department at Illinois Institute of Technology led by Prof. Mohamed Shahidehpour, as well as also the research group of the Electrical and Computer Engineering Department at McGill University in led by Prof. Francisco Galiana.

The research team that is submitting this Project, which is part of the GNOM (Group on Numerical Optimization and Modelling) in the Dept. of Statistics and Operations Research at Univ. Politècnica de Catalunya, has also been active since 1996 in short- and medium-term power planning.

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3. OBJETIVES

(maximum **2** pages)

- **3.1** Describe the reasons to present this proposal and the **initial hypothesis** which support its objectives (maximum **20** lines)

Liberalized electricity markets are nowadays very sophisticated energy- and financial-transaction multimarkets where, around the "main" electricity market, the so called "day-ahead market", there exists a portfolio of other financial and physical markets and bilateral contracts. A generation company operating in such a complex market can no longer optimize its medium and short term generation planning decisions without taking into account (a) the financial and physical relation between those markets and (b) the increasingly importance of the environmental issues: both the costs of the pollutants emissions (cost of CO_2 emission permits, NO_x bubble) and the impact of the emission-free (wind-power an hydro-generation) and low-emission technologies (combined cycle). Our **initial hypothesis** is that all this issues must, and can, be incorporated in the mathematical models to improve the global operation of an electric utility which operates in the MIBEL energy production market. Of course, the joined consideration of the multimarket en environmental nature of the problem posses several complex mathematical challenges: firstly, the stochastic nature of the most relevant data in the problems forces the application of stochastic programming techniques and risk considerations. Secondly, the complex real cases to be solved are modelled as a family of large scale optimization problems (continuous quadratic, mixed nonlinear,…) that must be treated not only with the best available commercial software but usually, when this commercial software fails, with specially developed interior point and dual decomposition methods. Finally all these optimization models and algorithms must be validated using the real data of the generation systems (Programming Units, "Unidades de Programación" following the MIBEL terminology) owned by the electrical utilities acting as EPO in this project: Unión Fenosa Generación and Gas Natural, two of the majors agents in the Iberian Electricity Market (MIBEL).

The increase in the Spanish generation system of wind- and solar-power generation means more risk for the GenCos. Together with the volatility of fuel prices, calls for more emphasis in risk and hedging against it.

- **3.2.** Indicate the **background and previous results** of your group or the results of other groups that support the initial hypothesis

We trust in the success of the initial hypothesis of our proposal because of the satisfactory results obtained by the group, both in the modelization area and in the optimization field, in the previous research projects DPI 2002-0330 and DPI2005-09117-C02-01. We believe that the extension of the models developed in those projects with multimarket, risk and environmental issues will be of major relevance, based on (a) our solid knowledge of the international market rules, but specially of the most recent rules of the MIBEL national electricity market, (b) the numerical results obtained with the medium- and short-electricity market models with which we are working currently and, finally, (c) by the conversations with the EPO companies Unión Fenosa and Gas Natural.

The main results yet obtained, or probably obtained at the end of the current research project DPI2005-09117-C02-01, which support the validity of our hypothesis are, in the medium-term planning, area, are:

- The linear market-price function with respect to the load duration obtained from records of historical data and the endogenous variation of the prices with the generation by different technologies.
- The GP heuristic that avoids having to generate a large number of LMCs while satisfying all of them in the Bloom and Gallant formulation for matching LDCs.
- The extension of this procedures to consider uncertainty through scenario trees and its reduction and the calculation of the market equilibrium using the NIRA algorithm
- The modeling of wind-power in the medium term by decomposing it into a pseudo thermal unit with a given outage probability of about 10% plus a totally random generation represented by a uniform reduction of the LDC
- The inclusion of risk aversion by GenCos using the CvaR as risk measure while iterating in the

NIRA algorithm.

- The formulation of thr basic mixed market block of pool and bilateral contracts following a time-share hypothesis leading to a DC problem, and its efficient solution through its transformation to a problem with a convex objective function and a reserve convex constraint and solution with an interior point code.
- The GPb heuristic (similar to the GP heuristic for a pure-pool problem) for the mixed system (of market plus bilateral contracts) that having to generate a large number of LMCs while satisfying all of them in the Bloom and Gallant formulation for matching LDCs

And in the short-term planning filed, the main developments by this research team that support our research proposal have been:

- The development of a stochastic model for the day-ahead spot price, based on ARIMA forecasted techniques [Corchero06], which is the base for the scenario generations of the stochastic programming models.
- The formulation of stochastic optimization models that integrates the OMIP future contracts with physical delivery in the day-ahead optimal offer problem [Corchero06- Corchero07].
- The development of stochastic programming models to formulate the most recent regulation rules (July 2008) of the MIBEL affecting the organized bilateral contracts markets (distribution auctions and Virtual Power Plant bids) of the MIBEL.
- The development of a new modellization of the *optimal offer curve* for a price taker that, based on the marginal cost principle, can be adapted to the current complex day-ahead market situation where both the physical future and bilateral contracts must be integrated in the offer of a GENCO [Corchero07]]
- The development and preliminary study of the scenarios tree reduction techniques [Gröwe-Kuska03] and optimal scenario tree generation [Höyland01] applied to the MIBEL spot market, with very satisfactory results ([Roso07] and [Vila07]), and its future extension to a multimarket framework.
- The preliminary developments of optimization models for the joined optimization of the day-ahed and the AGC and reserve market, exploiting the models developed in the past by the group in the OPF optimization models with ramp constraints [Beltran02]
- Emission permit costs are nowadays a huge fraction of the total generation costs of the electrical utilities. In [Corchero06a] a first mathematical modellization of this cost was proposed, but it must be adapted to the most recent national and international rules and laws.
- Project DPI2005-09117-C02-01 doesn't incorporate in their objectives the modellization of combined cycle units, although both Gas Natural and Unión Fenosa own programming units of this kind. The mathematical model for a combined cycle unit that we propose to develop in this new project is similar, yet more sophisticated, than the model for a classical thermal unit. Our long experience in the solution of unit commitment problems should help us in the modellization of this new kind of generation units [Beltran02].
- The development and computational experience solving large scale mixed nonlinear optimization problems through augmented Lagrangian relaxations and Radar Multiplier methods.
- The three-stage model of finding optimal generations that satisfy an unit commitment, and determines the zero-priced bids and the generation levels to be bid by each thermal unit, and the hydro generation for all reservoirs considered in detail [Nabona07].

◆ **3.3.** Describe briefly the **objectives** of the project.

The main objective of this project can be expressed as:

To study and develop stochastic optimization models and algorithms that help electrical utilities to optimize the physical and financial electricity transactions decisions in a multimarket context, taken into account hedging and environmental constraints.

This generic objective addresses to **five** specific objectives or areas of development: **Multimarket Modelization**, **Modelization of Environmental Issues**, **Stochasticity**, **Optimization**, and **Solution Analysis:**

1. **Multimarket modellization**.
   - **1.1.** To develop short-term electricity multimarket stochastic programming models for the joined optimization of the day-ahead market and regulation and intra-diary market.
   - **1.2.** To integrate in the day-ahead market all the new and existing bilateral contracts (Nationals, Primary Energy Emissions (EPE), distribution auctions (SD) and the Physically Delivered future Contracts.
   - **1.3.** To perform simulations in the medium-term optimization, to determine the type of market behaviour in the Spanish electricity market: equilibrium, cartel, or mixed cartel-equilibrium
   - **1.4.** In the price-maker short-term environment: Joint optimization of the daily market with the spinning reserve market using an hourly forecast of the secondary regulation price and inelastic demand. Consideration of the bilateral contracts of a specific GenCo (SGC) and of the Rest of Participant GenCos (RoP).
   - **1.5.** Consideration of an hourly linear elastic demand bid-function, which results in a unit commitment problem with a (convex) quadratic mixed-integer objective function, and solution using a commercial solver (Cplex).
2. **Modellization of environmental issues.**
   - **2.1.** To precisely model both the costs of the pollutants emissions (cost of CO2 emission permits, NOx bubble) and the impact of the emission-free (wind-power and hydro-generation) and low-emission technologies (combined cycle).
   - **2.2.** The models proposed in the electrical market optimization area (as the ones developed at present at the GNOM projects) usually consider just the thermal and hydro units. It is our aim to extend these mathematical models to accommodate wind-power and combined-cycle generation units.
   - **2.3.** In medium-term planning, wind-power and solar-power will be specifically modelled decomposed into a pseudo unit with known outage probability plus a uniform deduction from the LDC, and representative scenarios of this will be taken into account.
   - **2.4.** In medium-term planning, hydro generation will be represented in full reservoir system for the SGC and as one or several pseudo-thermal unit plus constraints for the RoP. Scenarios of inflows will be developed for each part
3. **Stochasticity**. To improve the confidence of the stochastic optimization models previously developed through:
   - **3.1.** An appropriate modellization of the stochastic variables through time series analysis.
   - **3.2.** The design and implementation of specifically tailored scenario tree generation and reduction techniques.
   - **3.3.** Hedging with the derivatives in the electricity market against the risk of profit loss.
   - **3.4.** To study and validate the formulation of several relevant constraints of the electricity market (as the PDBF=0 rule) as probabilistic constraints.
   - **3.5.** In medium term planning, scenario generation must include many factors: wind- and solar-power, and hydro-inflow stochasticity, fuel- and emission-price stochasticity, and demand variation. Scenario reduction techniques should be employed to obtain problems that can be solved within an acceptable time. Both scenario generation and reduction require careful use of statistical properties of factors considered.
   - **3.6.** Introduction of hedging with futures and estimation of forward prices with exogenous and endogenous models. In the endogenous case, determination of forward prices considering that the market participants use a CVaR meausure of risk.

4. **Optimization.** To develop specialised optimization tools for large scale problems in the following areas.
   4.1. In IP methods we wish to develop efficient algorithms to solve problems whose objective function is DC, either directly, or using a convex objective plus a reverse-convex constraint. Then we would like to successively linearize the RCC, and use warm starts for the solutions to avoid having to restart the optimiztion from scratch.
   4.2. Global Optimization procedures should provide methods of decomposing the nonconvex objective functions encountered into a DC, so that the convex part is left as objective function and the nonconvex part is made into a RCC. It should also provide techniques that would speed up the solution process.
   4.3. Warmstartings and global optimization procedures, as the use of a reverse-convex constraint are to be employed
   4.4. Dual and decomposition methods in the presence of binary variables associated to the thermal and combined-cycle generation units management
   4.5. Nonlinear network optimization to treat the hydro-generation replicated network.
5. **Solution analysis.** Validation of the models and algorithm obtained by performing computational tests with the data of the real generation systems provided by the EPO. In mid-term planning, validation of the Spanish market behavioural assumption (equilibrium, cartel, or mixed) would be interesting. This is contemplated by comparing the generation by different technologies in the outcome of the model, and in reality. But this would require the active participation of the EPOs in refining the data employed.

It must be stressed that this project contributes, from the point of view of the mathematical modellization and numerical optimization, to several priorities of the "Plan Nacional de Investigación Científica, Desarrollo e Innovación Tecnológica 2008-2001", approved by the cabinet council of Spain (2007, 14th September), specifically in the **"Energetic planning"**, "**Climatic change**" and "**Environment**" areas.This document describes the objectives of the "Sector 3, Energia", in the following way:

> *"Es por tanto necesario garantizar, con la investigación y el desarrollo, el suministro energético, facilitando los medios científicos y tecnológicos que permitan* ***incrementar la contribución de las energías renovables y las tecnologías energéticas emergentes, de forma eficiente y competitiva, y su integración en el sistema energético nacional,*** *de tal manera que su aportación mejore la seguridad de suministro, la diversificación de las fuentes de abastecimiento, mejore la protección del medio ambiente* ***y todo ello sin que sus costes mermen la competitividad de nuestra economía****."*
>
> *(Plan Nacional de Investigación Científica, Desarrollo e Innovación Tecnológica 2008-2011, pág.: 48.)*

The objectives posed for this project falls completely into the aims of the fourth strategic action of the "Plan Nacional", "Energy and Climatic Change". Its general objective is:

> *"Energía y cambio climático están fuertemente relacionados.* ***La energía es responsable de un 80% de las emisiones de gases de efecto invernadero*** *de la Unión Europea y constituye la causa fundamental del cambio climático y de la contaminación de la atmósfera.* ***La energía es también un elemento esencial para la actividad económica*** *y el bienestar de los ciudadanos, enfrentándose el sector a un entorno de precios y a una dependencia de las importaciones crecientes. Ante esta situación, el reto de Europa pasa necesariamente por impulsar unas* ***políticas que reduzcan la dependencia energética, al tiempo que respeten los compromisos medioambientales, todo ello sin dañar la competitividad y el dinamismo de la economía****."*
>
> *(Plan Nacional de Investigación Científica, Desarrollo e Innovación Tecnológica 2008-2011, pág.: 89.)*

◆ **3.4. For Coordinated projects** only, the **coordinator** must indicate (maximum **2** pages):

- the global objectives of the coordinated project, the need for coordination, and the added value provided by this coordination
- the specific objectives of each subproject
- the interaction among the objectives, activities and subprojects
- the mechanisms of coordination for an effective execution of the project.

4. METHODOLOGY AND WORKING PLAN
(in the case of coordinated projects this title must include all the subprojects)

Detail and justify precisely the methodology and the working plan. Describe the working chronogram.

- The working plan should contain the tasks, milestones and deliverables. The projects carried out in the Hesperides or in the Antarctic Zone must include the operation plan.

- For each task, it must be indicated the Centre and the researchers involved in it.

- If personnel costs are requested, the tasks to be developed by the personnel to be hired must be detailed and justified. Remember that personnel costs are eligible only when personnel is contracted, **fellowships are not eligible** as personnel costs.

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p×m : person per moth (dedication).

Tasks:

Multimarket Modellization in the Short- and Medium-Term Planning (36 p×m):

- MMO_DAT (1 pxm) Collect data from the Spanish Electricity System (of futures by different type and duration, and their evolution)
- MMO_SEC (3 pxm) To extend the stochastic optimal day-ahead bid model integrating the futures contracts with physical delivery and bilateral contracts to a multistage stochastic multimarket model integrating the day-ahead, automatic generation control and reserve markets
- MMO_MUL (6 pxm) To extend the model SHO_SEC including a multistage stochastic multimarket model integrating the day-ahead, automatic generation control, reserve and intradiary markets (Stochastic Integrated Multimarket Optimal Bid model (SIMOB)).
- MMO_OOF (2 pxm) To extend the optimal day-ahead offer function for a price-taker to the SIMOB model.
- MMO_PRM (6 pxm) To study the extension of the SIMOB model for a price-maker company. The suitability of game theory models will be explored.
- MMO_NET (4 pxm) To study the convenience of embed an ORPF in the SIMOB model.
- MMO_RSK (2 pxm) To study the convenience of including risk constraints in the SIMOB model and to explore other short-term techniques for hedging
- MMO_DAT (1 pxm) Build a complete data base with the forecasted spinning reserves (demand), bids curves and spot prices of the Spinning Reserve Market.
- MMO_SRM (3 pxm) Extension of the price-maker model of the day-ahead market so as to include the optimization of the bids sent to Spinning Reserve Market
- MMO_BCT (2 pxm) Extension of the price-maker model of the day-ahead market so as to include forecasted bilateral contracts
- MMO_DEM (3 pxm) Extension of the price-maker model of the day-ahead market so as to include the consideration of elastic demand
- MMO_PMK (2 pxm) Solution of the full model of a price-maker assumption with AMPL plus a solver (such as CPLEX).

Modelization of the environmental issues (22 pxm)

- ENV_GGE (4 p×m) To include in the models a detailed formulation of the greenhouse gases permits costs constraints for each high-emission technologies (coal, fuel and fuel gas) for the specific generation company taking into account the European and Spanish regulation.
- ENV_HYD (2 p×m) To include in the short-term models a detailed formulation of hydrogeneration for the specific generation company, with deterministic natural inflows

- ENV_LEM (4 p×m) To include in the models a detailed formulation of low emission technologies (combined cycle) for the specific generation company (SGC) and emission-free technologies (wind-power, solar, …)
- ENV_REN (4 pxm) Analysis of the actual generation with wind- and solar-power, and propose an appropriate model according to the basic medium-term model. Generation of scenarios and its corresponding probabilities.
- ENV_INF (3 pxm) Analysis of the dynamics of water inflows from historical records and generation of scenarios for a medium-term framework.
- ENV_MOD (5 pxm) Development of appropriate models for hydro, wind and solar power generation

Modelization of the stochasticity (42 pxm)

- STO_PMP (3 p×m) To update the probabilistic short-term model of day-ahead market prices and to study the probabilistic short-term models for the futures market price and the AGC, reserve and intra-diary markets.
- STO_MTM (3 p×m) To study the probabilistic medium-term model of day-ahead market prices.
- STO_CMP (2 p×m) To study the short-term multivariate probabilistic model for all markets prices simultaneously.
- STO_CGP (3 p×m) To study the probabilistic model of combustible prices (coal, fuel and gas), of greenhouse gases permits prices and to obtain short-term forecasts.
- STO_FMP (3 p×m) To design a method for the generation and reduction of scenario trees for day-ahead, futures and automatic generation control market prices, independently and simultaneously, and to include this trees in the stochastic models.
- STO_PRC (3 pxm) To study the formulation of some of the constraints of the SIMOB model developed in SHO_MUL and SHO_PRM as probabilistic constraints.
- STO_TRI (9 pxm) According to the models developed, implementation of the most appropriate technique either for scenario tree generation and for its reduction, so the overall solution can be found in reasonable time and is useful in practice.
- STO_DAT (3 pxm) Analysis of the fluctuations of the price and determine correlate variables, such as generations (endogenous) or hydro inflows or fuel prices (exogenous).
- STO_RSK (4 pxm) Reformulate the models in order to include an evaluation of the risk (such as the CVaR) and the electricity futures prices.
- STO_HDG (9 p×m) Hedging with the derivatives in the electricity market against the risk of profit loss

Optimization algorithms development (47 pxm)

- ALG_BAF (9 pxm) To study the suitability of the *Branch and Fix* algorithms fro the solution of the SIMOB model.
- ALG_LAG (8 pxm) To study the suitability of the dual decomposition methods (Lagrangian Relaxation, Cutting Plane, ACCPM) to solve the SIMOB model
- ALG_NET (8 pxm) To explore the use of specialised nonlinear network flow problems to the solution of the hydro-subproblems of the SIMOB model.
- ALG_IDC (5 p×m) IP methods to solve problems whose objective function is DC
- ALG_RCC (5 p×m) IP methods to solve problems whose objective function is DC is transformed to convex plus a reverse convex constraint
- ALG_GLO (3 p×m) Global Optimization procedures for the decomposition of the DC function in the difference of two convex functions and successive approximations to the reverse convex constraint
- ALG_WRS (10 p×m) Warm starting procedures in own developed and in other available codes

Solution analysis (9 pxm)

- SOL_COM (3 p×m) Comparisons of generations by technologies between the medium-term results with different behavioural assumptions and the historical records of these generations.
- SOL_UFD (1 p×m) To create a real test case based on the Programming Unit's of Unión Fenosa
- SOL_GND (1 p×m) To create a real test case based on the Programming Unit's of Gas Natural.
- SOL_UFS (2 p×m) To validate the models developed with the Unión Fenosa's real test case.

- SOL_GNS (3 p×m) To validate the models developed with the Gas Natural's real test case.

Justification of Profs. J. Gondzio, S-E Fleten and M.J. Rider:

Prof. J. Gondzio is a leading expert in Interior Point methods for large structured problems. He has also developed novel methods of warm starting when there should be repeated solutions of a problem with modification or a part of its parameters. He is currently participating in part-time in our current MEC Project DPI2005-09117-C02-01. He has coadvised, during 5 months at University of Edinburgh, the work of our team member Adela Pagès, who is now Post-Doc in the Project cited above [Pagès07b]. The optimization problems encountered in the extension of the *basic mixed-market block* to the equilibrium using the NIRA algorithm, and in the consideration of CVaR, require either special development of an Interior Point code, or adaptation of the warm-starting process in the repeated solutions for existing codes as Ipopt. In both of these the expertise of Prof. Gondzio will be very valuable.

Associate professor Stein-Erik Fleten's competence is to combine engineering and operations research approaches with energy economics, real options and stochastic programming. He has several well-cited publications in operations research journals, energy engineering journals and economics/business journals. Fleten's past and current research activities include medium-term energy generation planning for hydropower companies, including a model for supporting risk hedging through forward and option contracts, and short term operational planning for hydropower companies, more exactly bidding and hydro unit commitment. Fleten's angle on this research focuses more on market and financial modelling than on computational challenges. Thus he complements the other team members well. Prof. Fleten has coadvised our team member in the current Project Mr. Matteo Tesser, during three months at NTNU Trondheim on risk analysis in electric markets.

Dr. Marcos Julio Rider will be working till December 2008 as a post doctoral researcher of the current project DPI2005-09117-C02-01. On January 2009 he will return to his dept. on the Universidade Estadual de Campinas, Brazil, from where he will continue a part-time collaboration with our team. Dr. Rider is a reputed expert in Optimal Reactive Power Flow problems and their solution with interior point methods. During his research in our group he has acquired experience in electricity markets, learning and modelling the new rules about the integration of the bilateral contracts in the energy production system of the MIBEL, specially the role of the "*Unidades de Programación Genéricas*". He is also the person committed to develop the Combined Cycle unit's model and the role of the transmission network in the stochastic integrated multimarket bid optimization problem.

Justification of the PostDocs.:

The expected workload of the Project and the specialization of some tasks require the contribution to the Project of very skilled participants, which would be two Post-Docs.

PD1: this postdoctoral researcher, to be hired for 30 month (from September 2009 to December 2011) is intended to give support to all the tasks related with the stochasticity of the problems: modelization of the stochastic variables and its simulation, generation of optimal multistage scenarios tree, formulation of probabilistic constraints, etc. (objective number 3, tasks STO_***). In our current project, these tasks are being done by Miss Cristina Corchero, FPI postgraduate student, who hopefully will finish her PhD thesis around September 2009. Her work has always been of high quality. Moreover, from March to June 2008 she will be visiting the Università degli Studi di Bergamo, Italy, working with prof. Marida Bertochi and Ma. Teressa Vespucci on some of these topics. We would like, if possible, to keep Miss Corchero in our team given their high level of proficiency and experience in the topics to be developed.

PD2: This is to pursue the tasks that, in the current Project DPI2005-09117-C02-01, are carrying out, on the one hand, our Post-Doc in the Project Adela Pagès, and on the other, our PhD student, also member of the current team, Mr. Matteo Tesser, on interior-point implementation and warm-starting, for special DC optimization problems encountered in the extension to equilibrium, the inclusion of detailed hydrogeneration models, and the consideration of CVaR constraints in the new basic module for the mixed market. The extent of these tasks is estimated in about 28 men-months (30 months in case the

Post-Doc would require further formation). The extra formation that the new Post-Doc may require would be provided at UPC (medium- and short term power planning in pure-pool and mixed-system markets, stochastic programming and scenario generation and reduction), University of Edinburgh (extensions of Interior Point methods and warm-startings) and NTN University, Trondheim (special hydro models, bidding in the Nord Pool, risk analysis, hedging with futures and forward-price estimation).

(It is expected that Mr. Tesser's thesis will be submitted in August-September 2008 and read before the end of our current Project DPI2005-09117-C02-01.)

Tasks' Table:

p×m 156	task	p×m	18	18	36	9	9	9	9	18	30
			NN	**FJH**	**CC PD1**	**MJR**	**AF**	**JG**	**S-EF**	**EM**	**AP PD2**
36	**MMO_DAT**	1	1								
	MMO_SEC	3		1	2						
	MMO_MUL	6		2	4						
	MMO_OOF	2		1	1						
	MMO_PRM	6		3	3						
	MMO_NET	4				4					
	MMO_RSK	2			2						
	MMO_DAT	1									1
	MMO_SRM	3	2								1
	MMO_BCT	3	1								2
	MMO_DEM	3	1								2
	MMO_PMK	2	1								1
22	**ENV_GGE**	4		1	3						
	ENV_HYD	3		1		2					
	ENV_LEM	3		1		2					
	ENV_REN	4	1						1		2
	ENV_INF	3	1								2
	ENV_MOD	5	2								3
42	**STO_PMP**	3			3						
	STO_MTM	3			3						
	STO_CMP	2			2						
	STO_CGP	3			3						
	STO_FMP	3			3						
	STO_PRC	3			3						
	STO_TRI	9	2				2		1		4
	STO_DAT	3							1		2
	STO_RSK	4						1	2		1
	STO_HDG	9	1					1	4		3
47	**ALG_BAF**	9		1						8	
	ALG_LAG	8		7						1	
	ALG_NET	8		1						7	
	ALG_IDC	5					2	2			1
	ALG_RCC	5	2				2	1			
	ALG_GLO	3					3				
	ALG_WRS	9	2					4			3
9	**SOL_UFD**	1			1						
	SOL_GND	1			1						
	SOL_UFS	2			1					1	
	SOL_GNS	2			1					1	
	SOL_COM	3	1								2

4.1 CHRONOGRAM MODEL (EXAMPLE)

This chronogram must indicate the persons involved in the project, including those contracted with project funds.
Underline the name of the person responsible of each task.

Tasks	Center	Persons (<u>responsible</u>)	First year (*)												Second year (*)												Third year (*)											
MMO_DAT	UPC	NN			X																																	
MMO_SEC	UPC	<u>FJH,</u> CC	X	X	X	X	X	X	X																													
MMO_MUL	UPC	<u>FJH,</u> PD1								X	X	X	X	X	X	X	X																					
MMO_OOF	UPC	<u>FJH,</u> CC	X	X	X	X	X	X	X																													
MMO_PRM	UPC	<u>FJH,</u> PD1									X	X	X	X	X																							
MMO_NET	UPC, UEC	<u>MJR</u>, FJH	X	X	X	X	X	X	X																													
MMO_RSK	UPC	<u>PD1</u>, FJH													X	X	X	X	X	X	X	X	X	X														
MMO_DAT	UPC	<u>PD2</u>										X																										
MMO_SRM	UPC	<u>NN,PD2</u>										X	X																									
MMO_BCT	UPC	PD2,NN											X	X	X																							
MMO_DEM	UPC	PD2,NN												X	X	X																						
MMO_PMK	UPC	NN,PD2													X	X																						
ENV_GGE	UPC	<u>PD1</u>, FJH									X	X	X	X	X	X	X	X																				
ENV_HYD	UPC, UEC	<u>FJH</u>, MJR																	X	X	X	X	X	X	X	X												
ENV_LEM	UPC, UEC	<u>MJR</u>, FJH																	X	X	X	X	X	X	X	X	X	X										
ENV_REN	NTNU,UPC	S-EF,NN,PD2															X	X	X	X																		
ENV_INF	UPC	NN,PD2																		X	X	X																
ENV_MOD	UPC	NN,PD2																				X	X	X	X	X												
STO_PMP	UPC	<u>CC,</u> FJH	X	X	X	X	X																															
STO_MTM	UPC	<u>CC,</u> FJH					X	X	X	X	X																											
STO_CMP	UPC	<u>PD1</u>, FJH									X	X	X	X	X																							
STO_CGP	UPC	<u>PD1</u>, FJH													X	X	X	X	X																			
STO_FMP	UPC	<u>PD1</u>, FJH																																				
STO_PRC	UPC	<u>PD1</u>, FJH													X	X	X	X	X																			
STO_TRI	UPC	AF,NN,S-EF,PD2																X	X	X	X	X	X	X	X	X												
STO_DAT	UPC	S-EF,PD2																						X	X	X												
STO_RSK	UPC	S-EF,JG,PD2																								X	X	X	X									
STO_HDG	UPC	S-EF,NN,JG,PD2																										X	X	X	X	X	X	X				
ALG_BAF	UPC, UPV	<u>EM</u>, FJH	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X																
ALG_LAG	UPC, UPV	<u>FJH</u>, EM													X	X	X	X	X	X	X	X	X	X	X	X	X	X	X									
ALG_NET	UPC, UPV	<u>EM</u>, FJH																	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					
ALG_IDC	UPC	JG,AF,PD2																X	X	X	X	X																
ALG_RCC	UPC	NN,AF,JG																				X	X	X	X	X												
ALG_GLO	UPC	AF																								X	X	X										
ALG_WRS	UofE,UPC	JG,NN,PD2																									X	X	X	X	X	X	X	X	X			
SOL_UFD	UPC	NN, PD2													X	X	X	X	X	X	X	X	X	X	X	X												

SOL_GND	UPC	FJH, NN, PD1, PD2													X	X	X	X	X	X	X	X	X	X	X	X												
SOL_UFS	UPC	FJH, NN, PD1, PD2																		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
SOL_GNS	UPC	FJH, NN, PD1, PD2																		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
SOL_COM	UPC	NN,PD2																																		X	X	X

(*) Mark an X inside the corresponding boxes (months)

5. BENEFITS DERIVED FROM THE PROJECT, DIFUSION AND EXPLOTATION OF RESULTS

(maximum **1** page)

The following items must be described:

- ♦ Scientific and technical contributions expected from the project, potential application or transfer of the expected results in the short, medium or large term, benefits derived from the increase of knowledge and technology.
- ♦ Diffusion plan and, if appropriate, exploitation plan of the results.

Scientific and technical contributions. The scientific contributions that are expected to be achieved during the present project are:

- In medium-term planning it is expected to contribute a model that can deal with the mixed-system market (with bilateral contracts) including stochasticity through scenarios, equilibrium and risk-management with futures.
- The medium-term model will have the possibility of using a detailed representation of hydro reservoir systems of the specific GenCo for which the study is made (that of which the generation units and other operational parameters are known in full).
- New ways of representing the wind- and solar-power generation in the medium-term, and procedures to hedge against the risk associated to its low reliability.
- The solution procedures and the computational experience for the optimization problems encountered in medium-term planning, either through a publicly available, or commercial solver, through a script that calls a solver, or own-developed solver.
- New mathematical models for the joined optimization of the "multimarket" nature of the MIBEL organization, with a portfolio of markets (futures, day-ahead, reserve, intradiary, VPP,…) and physical bilateral contracts, both in medium and short term planning.
- New mathematical models that precisely include the emissions permits in such a way that each generation technology (wind, solar, hydraulics, combined-cycle, thermal) will be used in the optimal way.
- Advances in the modellization of the relevant stochastic variables (MIBEL energy prices, fuel price, natural inflows, etc), in the generation of scenario trees and in the use of probabilistic constraints to solve the optimal multimarket risk and environmental constrained offer problem
- A short-term model for price-makers that jointly optimizes the daily and the secondary market while satisfying the market load and the bilateral contract load, giving the zero-priced bids, the generations and reserves to be bid, and the detailed exploitation of reservoir systems
- Advances in the development of specialized optimization algorithms for large scale continuous and mixed nonlinear programming problems needed to solve the deterministic equivalent of the stochastic programming models.
- Study of the real impact of the modellization hypothesis in the profit maximization of a GenCo operating in the MIBEL through computational experiments with the data provided by the EPO.

Potential application of the results. As it was stated in the objectives of the project, we will "*study and develop stochastic optimization models and algorithms that helps electrical utilities to optimize the physical and financial electricity transactions decisions in a multimarket context, taken into account hedging and environmental constraints"* This is a problem that all the generation companies must solve daily worldwide, with the help of, more or less sophisticated, analytical tools. This project will developed mathematical decision making procedures that, in the medium term, could be the base of new exploitation software to be used by the generation companies in a real operation context.

Benefits derived from the increase of knowledge. The project contributes to the knowledge of the current Spanish energy production system, one of the most relevant production planning problems, with social, economical and environmental nation-wide impact. By using the procedures developed in this project, generation companies will be able to do a more efficient management of its generation units, increasing its profits but, also, avoiding the energy prices to adopt unreal high prices. But the project isn't just focused on maximizing utilities profits., it also We think also that a better modellization of the low emission, emission free technologies and emission permits costs can help to improve the financial results of the utilities while being respectful with the environment.

Diffusion and exploitation plan of the results.

- The models and solution algorithms developed will be published in reports and papers in high standard journals, and presented in the most relevant conferences of the area.
- An specific web site for the new project, similar to the site of the current DPI2005-09117-C02-01 MEC project (http://www-eio.upc.es/research/gnom/meccyt06-08/) will be developed. This site will be the most important diffusion tool of the results of the project. As in the site of the current project, there will be a public part with the description of the project, the downloadable scientific production and news related with the evolution of the project. There will be also a private part of the site to support the coordination between the EPO's and the research team members.
- We will visit periodically the EPO's to show results and get their direct comments and advice.
- The research team led by prof. Ma. Pilar Muñoz, at the same dept. of our research team, is applying at this same call of the "Plan Nacional I+D" to engage a research project on forecasting techniques applied to electricity markets. We are planning to organise, at the end of the research project, a joint workshop on forecasting and optimization in electricity markets, to be held at the UPC.

6. BACKGROUND OF THE GROUP
(In the case of a coordinated project the topics 6. and 6.1. must be filled by each partner)
(maximum **2** pages)

- **Indicate the previous activities and achievements of the group in the field of the project:**

  If the project is related to other previously granted, you must indicate the objectives and the results achieved in the previous project.

  If the project approaches a new research field, the background and previous contributions of the group in this field must be indicated in order to justify the capacity of the group to carry out the project.

<u>Former activity and achievements in the proposed project subject:</u>

The project presented is the natural continuation of the current project DPI2005-09117-C02-01 "*Short and long-term electricity generation planning in a liberalized market including bilateral contracts*" carried out by a research team that is with a few exceptions the one for the project. The objectives of this project were:

1. To develop long and short-term scheduling models for electric generation companies that participates in the Spanish market with both the current and future regulation regarding the bilateral contracts. These models wick be fed with the available information of the generation companies.
2. To introduce new refinements in the scheduling long and short-term models developed in the previous projects, as the optimization of the spinning reserve in the short term, and the modelization of the stochasticity of the hydro generation in the long term
3. To develop efficient optimization algorithms that solves the models proposed, substituting the less efficient commercial optimization packages. Special attention will be devoted to algorithms for mixed optimization (continuous and binary variables): Lagrangean relaxation methods and interior point methods with global optimization
4. To validate the new models with the real data provided by an electric utility (EPO). The solution of those models will be obtained both through new specialized algorithms and through general purpose commercial optimization software, and the relative performance of both methodologies will be studied.

The main results already obtained or most probably obtained by the end of the current project DPI2005-09117-C02-01 are:

Medium-Term Electricity Market Modellization and Optimization:

- The linear market-price function with respect to the load duration obtained from records of historical data and the endogenous variation of the prices with the generation by different technologies.
- The GP heuristic that avoids having to generate a large number of LMCs while satisfying all of them in the Bloom and Gallant formulation for matching LDCs.
- The extension of this procedures to consider uncertainty through scenario trees and its reduction and the calculation of the market equilibrium using the NIRA algorithm
- The inclusion of risk aversion by GenCos using the CvaR as risk measure while iterating in the NIRA algorithm.
- The modelling of the mixed market of pool and bilateral contracts following a time-share hypothesis leading to a DC problem, and its efficient solution through its transformation to a problem with a convex objective function and a reserve convex constraint and solution with an interior point code.

Short-Term Electricity Market Modellization and Optimization:

- The formulation of stochastic optimization models that integrates the OMIP future contracts with physical delivery in the day-ahead optimal offer problem.
- The formulation of stochastic optimization models that integrates the new regulation rules for bilateral contracts (National, International, Distribution Auctions and Virtual Power Plants) in the day-ahead optimal offer problem.
- The development of a new modellization of the optimal offer curve for a price taker that, based on the marginal cost principle, could be adapted to the current complex day-ahead market situation where both
- The physical future and bilateral contracts must be integrated in the offer of a GENCO.
- The development of a stochastic model for the day-ahead spot price, based on ARIMA forecasted techniques, which is the base for the scenario tree generations of the stochastic programming models.
- The development and preliminary study of the scenarios tree reduction techniques and optimal scenario tree generation applied to the MIBEL spot market for two-stage stochastic optimization
- The development of optimization models for the joined optimization of the day-ahead and the "secondary market", exploiting the models developed in the past by the group in the OPF optimization models with ramp constraints.
- A first mathematical modellization of the emissions permits costs for thermal generation units (not for Combined Cycle), adapted to the most recent national and international emission laws.
- With the support of Union Fenosa (EPO), we are preparing real test cases with all their generation units (except combined cycle unit) to perform computational tests along 2008.

<u>The GNOM group:</u>

The group started the research activity in 1987 and has had since then a changing number of members. Their activities have been always focussed on:

- Study and implementation of numerical optimization techniques, especially those in network flows, Lagrangian relaxation with dual methods for mixed problems (with continuous and binary variables), linear and nonlinear interior-point procedures, and global optimization.
- New ways of modelling problems of short-term and medium-term hydrothermal coordination of electricity generation, and applications of the solution algorithms developed to solve these models.

The research group GNOM (Group on Numerical Optimization and Modelling) is led by Dr. Narcís Nabona, full professor and Dr. F. Javier Heredia, associate professor (coordinator of the project), both members of the Department of Statistics and Operations Research at UPC. Other members of the GNOM group are:

- Dr. Adela Pagés (who obtained her PhD working in our group) and Dr. Marcos Julio Flores, both hired researchers of the current project DPI2005-09117-C02-01 (Dept. SOR, UPC)
- Miss Cristina Corchero (FPI granted) and Mister Matteo Tesser (UPC granted) both working for a PhD thesis within the objectives of the current project DPI2005-09117-C02-01 (Dept. SOR, UPC)
- Dr. Alberto Ferrer, assistant professor from the Department of Applied Mathematics I at UPC (expert in global optimization).

For more information about the group please visit http://www-eio.upc.es/research/gnom/ The external members that collaborate with the GNOM team are:

- Dr. Eugenio Mijangos, assistant professor of the Department of Applied Mathematics, Statistics and Operations Research, Universidad del Pais Vasco (expert in nonlinear network flows and multiplier method)
- Prof. Jacek Gondzio, full professor of the School of Mathematics of the Univ. of Edinburgh (G.B.), (expert in interior-point optimization methods).
- Prof. Stein-Erik Fleten, associate professor of the Norwegian University of Science and Technology (Trondheim, Norway) (expert in risk analysis and electricity markets)

6.2 PUBLIC AND PRIVATE GRANTED PROJECTS AND CONTRACTS OF THE RESEARCH GROUP
Indicate the project and contract grants during the last 5 years (2003-2007) (national, regional or international)
Include the grants for projects under evaluation

Title of the project or contract	Relationship with this proposal (1)	Principal Investigator	Budget EUROS	Funding agency and project reference	Project period (2)
CASC: Computational Aspects of Statistical Confidentiality	2	J. Castro (J. Heredia and N. Nabona participants)	77.739€	European Comission IST-2000-25069	07/2000 - 06/2003 C
Coordination hidrotérmica a corto and largo plazo de the generation eléctrica en un mercado competitivo	1	N. Nabona	119.800€	CICYT M. Ciencia and Tecnología DPI -2002-03330	12/2002 – 11/2005 C
Planificación de la generación eléctrica a corto y largo plazo en un mercado liberalizado con contratos bilaterales	1	N. Nabona	289.408€	CICYT M. Ciencia and Tecnología DPI2005-09117-C02-01	31/12/2005-30/12/2008 C
Parallel solution of large scale structured nonlinear programs with interior point methods	2	Jacek Gondzio	203.420€	Engineering and Physical Sciences Research Council (EPSRC) GR/R99683/01	2002-2005 C
Conveying structure from modeling language to a solver	2	Jacek Gondzio	103.600€	Intel Corporation, Santa Clara, USA	2002-2007 C
Stochastic programming for risk analysis for a class of optimization problems in telecommunications	2	Jacek Gondzio	159.000€	France Télécom	2004-2006 C
FINERGY: Financial Engineering Analysis of Investment and Operations in Electricity Markets	2	Stein-Erik Fleten	806.038€	The Research Council of Norway, project 178374/S30	2007-2011 C
Financial Engineering Analysis of Electricity Spot and Derivatives Markets	1	Stein-Erik Fleten	488 000€	Økonomisk og adminis-trativt forskningsfond for Midt-Norge	08/2008-07/2012 S

(1) Write 0, 1, 2 or 3 according to: 0 = Similar project; 1 = Very related; 2 = Low related; 3 = Unrelated.
(2) Write C or S if the project has been funded or it is under evaluation, respectively.

7. TRAINING CAPACITY OF THE PROJECT AND THE GROUP
(In the case of Coordinated Projects this issue must be filled by each partner)

This title must be filled only in case of a positive answer to the corresponding question in the application form. Justify that the group is able to receive fellow students (from the Suprograma de Formación de Investigadores) associated to this project and describe the training capacity of the group. In the case of coordinated projects, each subproject requesting a FPI fellowship must fill this issue.

Note that all necessary personnel costs should be included in the total budget requested. The available number of FPI fellowships is limited, and they will be granted to selected projects as a function of their final qualification and the training capacity of the groups.

The research group has computing equipment acquired and renewed with the funding of successive Research Projects granted. We also have specialised bibliography and specialised software licenses (*Ampl, Cplex, Loqo, Matlab, Minos, Snopt*), related with the project to be developed. We also have access to the computing labs of our department (Statistics and Operations Research) for printers PC network etc., and to the UPC services (e-Mail, Inrternet, etc.) and to the supercomputing center at UPC CEPBA (Centro Europeo de Paralelismo de Barcelona) and the super-computer *Mare Nostrum*.

Six of the team members give tuition at honours level in Operations Research and post-graduate courses in Optimization, thus, this being a project within Operations Research, the group has a good tuition capacity in this area.

During the last twelve years (1995-2007) eight PhD thesis supervised and developed within the research team have been presented. All of them in Optimization related to subjects affine to the project area: J. Castro 1995, F.J. Heredia 1995, E. Mijangos 1996, J.A. González 1997, A. Ramos 2001, C. Beltran 2001, A. Ferrer 2004 and A. Pagès 2006. At present, professor Nabona and professor Heredia are the supervisors of the Ph.D. thesis of Mr. Matteo Tesser and Miss Cristina Corchero respectively. Numerous Final Year Projects and Technological Projects related to topics in the proposed project have been supervised by members of the research team.

It is thought that the novel topics and procedures within the project proposal may give rise to three new PhD thesis, and the members of the research team have availability to supervise them.