PLEXOS® Integrated Energy Modelling around the Globe

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European Energy Markets’ Integration Challenges

European Energy Markets are in a crossroad, being faced with a long list of significant challenges that are mostly lying ahead. An internally integrated Pan-European market that really works as a single, efficient, competitive market and that provides affordable energy to all EU member states and European consumers is still the main aim. It is widely recognised that not only a strong need of a common European Energy Policy implementation that also takes into account international developments, such as climate change, is more than ever necessary now, but also that the implementation of such a policy must ensure that objectives like competitiveness and security of supply are satisfied and that the equally important sustainability goals are achievable. Designing, analysing and testing the implementation of such multi-objective policies, especially in such an uncertain economic, financial, and technological global environment, calls for the application of more complex policy analysis methods with the respective employment and use of the most advanced analytical software tools.

More specifically, as Mr. Günther Oettinger1, EU Commissioner for Energy, said in one of his recent speeches, “...those big challenges in energy also need intelligent solutions” and these are needed fast. For example, the first and most important questions that need to be answered, as soon as possible, are a) what might be an optimum energy mix for Europe and b) how this mix more efficiently and more cost effectively can be allocated among the member states? EU Commissioner has also stressed the fact that, European politicians are tempted to seek “quick” solutions for possible problems that at first sight may seem purely national in nature. However, in practice, these solutions have not only a cross-border impact, but in the end of the day, they are almost always very expensive. What is actually needed from an internal integrated European market is that European citizens will be able, at some point in the near future, to benefit from economies of scale and synergies.

So, for the European Energy Markets, there are vital questions and it is really important to receive well defined and certain answers, like:

Why some countries are considering capacity investments on a national basis when, for example, there is plenty of unused capacity available in their European neighbours? or;

How can we make sure that any energy targets do not have adverse impacts on the competitiveness of European industry and the affordability of energy for European citizens? or

How can we better reflect the new risks which come with a different energy system that is based a) on more renewable, and thus less manageable and b) on more distributed electricity production and even more specifically,

What does that mean for uninterrupted/reliable electricity supply and system adequacy, for loop flows, for infrastructure investments and for the European market integration?

PLEXOS is such an advanced software tool, and it can provide specific answers needed to the above questions, employing the latest mathematical programming methods. It can provide significant insights on new Power & Gas Policies implementation, while at the same time, with its state of the art Stochastic Modelling & Optimisation abilities, it can effectively manage and cope with the associated uncertainties.

PLEXOS use in Europe for Policy Analysis

PLEXOS has a proven track record in the area of policy analysis and development. Common policy analysis with PLEXOS includes, among others:

- The design, analysis, and benchmarking of electricity market rules and effect on market participants;
- Assessing the effectiveness of renewable technology policies and resulting impact on carbon emissions, prices, transmission grid operations and investment incentives;
- Forecasting market entry and assessing future technology and fuel mixes as well as examining the development of system adequacy;
- Examining market competitiveness and market power.
- Analysing possible impacts of CO\textsubscript{2} emissions in power systems performance.

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Wind power generation in Europe has shown a very significant growth in recent years. The uptake of renewable energy such as wind can result in larger requirements for system reserves. Using the ancillary services features of PLEXOS the policy maker can:

- Optimise the uptake of renewables given their intermittent nature;
- Ensure system adequacy and the provision of reserves in future capacity expansion and dispatch planning;
- Calculate the cost to the system and effect on energy prices of the additional capacity and reserve requirements; and
- Calculate expected ancillary service prices.

All these are possible due to PLEXOS ability to set dynamic reserve requirements based on generator, load and/or line contingencies. Having a robust analytical framework it is used by European Energy Producers, Traders and Retailers, Transmission System & Market Operators, Energy Regulators/Commissions, Consultants, Analysts and Research Institutions, Power Plant Manufacturers and Construction companies.

Recently it was released and was integrated within PLEXOS the **NEW Gas (modelling) Module**. The new PLEXOS Gas module provides the capability to model the costs and constraints of gas delivery from its source fields via a network of pipelines, through storages and on to meet demands, including those associated with the Power production model. More importantly though, it is now possible in PLEXOS®, the Integrated Modelling of both Natural Gas and Power Systems & associated Markets. That practically means that, it can be now also used in:

- Least cost co-optimization OPEX and CAPEX of gas and electric system expansion
- Combined economic benefit analysis for gas and electric rate payers
- Strategic energy development for public policy regarding renewables’ integration along with Gas Policy
- Valuation of gas and electric storage opportunities and dual fuel optimizations

**Fig. 1 - Gas Pipeline Volumes (flow)**
- Evaluation of gas and or electric contingencies that can impact reliability
- De-rating of gas powered generators due to gas network constraints
- Assessing emerging gas constraints with generation retirements
- Inter-regional market and asset development planning for gas and electricity

**Fig. 2 - Integrated Gas/Electricity LMP (Nodal) Pricing**

The first European Gas/Power Integrated applications and studies from European PLEXOS users are expected to see the light later this and the next year.

**Australian Energy Markets’ Integration Challenges**

In Australia the contribution of renewable generation has increased in the last years with special focus in wind and solar technologies. Deployment of those types of energies has encouraged policies linked to carbon taxes or renewable targets. For example, the state of South Australia has had an important development of green energies resulting in a target of 33% for renewable energy generation by 2020.

Currently Australia is in the verge of an energetic dilemma which adds uncertainty to any electricity generation investment. For example, carbon tax has been on the table of discussion among politicians, academics and stakeholders from the energy and industry sectors. This fee was implemented in order to move to a low-carbon economy where electricity generation from fossil fuel will be penalized with a fee proportional to its carbon content and would contribute to uncertainty in investment evaluation.

Another aspect that adds uncertainty to the future mix of electricity generation is the price of fossil fuel, especially the gas price. The shale gas revolution has appeared in the United States and certainly would affect the international gas market changing the roles of the participants. Australia is endowed with important quantities of natural gas and certainly breakthroughs in fracturing technology would encourage gas market developments. These facts would foster uncertainty to the price of this fossil fuel and any generation technology associated with it such as open or combined gas cycle power plants.

For the reasons mentioned above, Australia will face critical and important changes in the energy sector, such as: new generation technologies, climate change policies and a movement to a low carbon economy especially driven by gas and coal prices. Therefore the generating electricity price would vary in the following years and definitely the future scenario is uncertain.
The result of the uncertainties in electricity planning expansion studies could be treated by scenarios. For example, the Australian Electricity Market Operator (AEMO) and the Department of Resources, Energy and Tourism (DRET) have developed for the National Transmission Network Development Plan (NTNDP) report possible future scenarios for the energy sector until 2030. The main variables in those scenarios are determined by price-demand relationships, economic and policy settings, assumptions of generation technologies and generation technology cost. It should be noted that each scenario was based on assumptions related to supply, demand and impact of government initiatives (i.e. carbon emission reduction policy). The resulting scenarios were five which come from the main changes described previously.

In the Australian context, electricity market investment research should take at least into account the following uncertainties:

- Demand forecast which is determined by changes in economy and demographics
- Carbon price would result into changes in the generation mix
- Fossil fuel prices, especially the gas price

From these three main drivers could be obtained several scenarios which could be analysed using least-cost generation expansion with stochastic optimisation techniques.

The aim of a least-cost generation expansion model is to determine a set of generation options from a range of technologies, which minimize the capital and operational costs over time. For that reason in order to perform an accurate model and analysis, PLEXOS provides the tools for:

- Long-term planning module, which is used for modelling long-term planning problems.
- Medium-term schedule, which is used for modelling medium-term to long terms decisions.
- Short-term schedule, which is used to model short-term constraints and get for example five minutes resolution outcomes.

The NTNDP developed by AEMO in 2012 was based in the least-cost modelling approach. AEMO publishes annually these reports with the aim of providing an independent and strategic tool for the deployment of transmission network in NEM. In addition to this aspect, those reports yield an investment perspective for projects in the long-run. The aim of the least-cost expansion planning model is to deliver an optimized 20 year plan of optimal generation capacity and location of new generation investment in the NEM considering different technologies, timing and location; optimal generation retirement and optimal interconnection expansion.

The least-cost modelling used in this study expanded the generation and transmission capacity such that the total system cost (operating and capital) is minimized, subject to the following constraints:

- There was enough generation capacity to fulfil demand over the planning horizon of 20 years.
The reliability standard of the region was maintained.
The energy policy objectives (mainly the renewable energy target scheme) were met.

The 2012 NTNDP report used PLEXOS for the least-cost expansion modelling. The 2012 NTNDP expansion solution then is analysed using power system simulation studies in order to measure the security and reliability of the transmission network. The following figure from the NTNDP 2012 depicts how the elements and data are used for this study.


A similar strategy was performed by ElectraNET-AEMO for the South Australian interconnector feasibility study. This report considered various transmission expansion options between South Australia and other NEM load centres, and identified expansion options that had the highest market benefit. Similar to AEMO, the report by ElectraNET-AEMO conducted least-cost expansion modelling using PLEXOS.

Hydro System Modelling in PLEXOS with Chilean Case Study

Power systems having both hydro-electric and thermal generation require a systematic and coordinated approach in order to determine an optimal policy for large-dam operations. The goal of this is to minimize expected operational cost, along the period which is mainly composed of fuel costs plus penalties for failure in load supply. The problem in large hydro dominated power systems is complex to solve because:

- Natural inflows to dams are stochastic processes in nature.
- Availability of water stored in dams is limited.
- Complex cascading hydro facilities.
Specific water usage policies and constraints (e.g. irrigation settlements).

Water as a fuel supply is cost-free, but its opportunity cost is fundamental to finding the optimal strategy for operations. This issue creates a link between a decision in a given time period. We don’t want to drain the storages too low to incur generation shortfalls (or excessive thermal output). On the other hand, we also want to avoid spillage of water and lost opportunities. PLEXOS® Integrated Energy Model offers a methodology which provides a useful operational policy. The PLEXOS algorithm determines an optimal planning solution in medium-term and then uses these results in a detailed short-term problem and solution to enable optimal hydro-electric unit commitment.

**Study Case: Chilean System**

The regulator of the Chilean electric system, called the National Energy Commission (CNE), sets a nodal price calculation every 6 months for the main nodes over a 4 year period. Public information was downloaded from CNE’s website and a PLEXOS database was constructed. The study focuses on the main Chilean interconnected system called the Central Interconnected System (SIC). The inputs for this calculation are described in the following points:

- Load forecasting for a 10 years period.
- Actual and planned transmission system for 10 years (up to 58 nodes and 65 lines).
- Actual and planned generation plans for 10 years (up to 259 generators at the end of horizon).
- Price indexation of fossil combustibles.
- Maintenance of all generators along the horizon of simulation.
- Forced outage rates of thermal units.
- 4 cascading hydro networks.
- Irrigation settlements of two main cascading hydro networks.
- 52 historical inflow samples.
- Future inflows were built concatenating historical consecutive years to create each inflow possibility up to the end of the horizon, meaning that one scenario is composed by a sequence of annual consecutive inflows equally probable.
A representation of the Chilean cascading hydro network is showed in the following figure:

Similarities and accuracies in the results validated and provided a proof-of-concept when compared to procedures used by the regulatory agency in Chile. The results are summarized in the following graph taking an average of 52 samples in “Quillota 220 kV” node, which is located north of Santiago (Main center load of SIC).
US Integrated Datasets for Power and Natural Gas Sector Challenges

The US is seeing resource change driven by environmental policy and public policy where many areas of the US have minimal load growth projections. Although many organizations, regulators, ISO’s, federal departments, labs, consultants and others are engaged in a multitude of studies for the future grid designs in America. In the past few years there has been increased recognition that environmental policy and public policy in combination to the vast shale gas developments will lead to increased reliance of the power sector on natural gas generation. Gas Electric coordination has emerged as a complex topic for regulators and the gas and electric sectors to confront along with the electrical system operators with concerns of present and future potential gas constraints that impact electric system operation and reliability. Many studies have been initiated for gas electric coordination in the major interconnects of the US. As well integration of renewables have driven IRP managers and ISO’s to consider sub-hourly ancillary co-optimization analysis in production cost models for major areas of the US. In addition many regulators are interested in co-optimization of generation and transmission expansion to optimize resource change. New strategies of co-optimization of electric and gas infrastructure are becoming of interest as much of the natural gas sector growth may likely be driven by resource change and dependency of electrical sector on pipeline network and gas network operational issue. This is all in the back drop of active demand response, energy efficiency, and renewable portfolio standard adoptions by state governments as well as federal regulator orders such as FERC Order 1000 of considering public policy in transmission planning. Thus the study process and the complexity of issues is driving the demand for integrated datasets and integrated models i.e. one software package that can handle all the complexities of planning and operations and market analysis in the short, medium and long term. The following diagram displays the integrated dataset for the PLEXOS® Integrated Energy Model.
The integrated database allows for co-optimization of ancillary services and energy market to study renewable integration and curtailments for sizing of transmission systems where traditional reliability tools are unable to size transmission optimally for public policy considerations. With the integrated datasets the system planner can switch on the fly from LOLE and LOLP studies to gas electric expansion to co-optimization of generation and transmission expansion and other planning analysis too. As the gas and electric sector coupling increases, transmission projects or pipeline projects can have impacts on electric or gas rate payers or both where the integrated energy model assists in the assessment of winners and losers in asset evaluations and for public policy cost allocations and inter regional planning assessments. The planning process has changed significantly since the 70’s when much of the planning software was initially being used for solving complex problems of the day where today’s world with the current challenges of the power and natural gas sectors the advantages of modern computer science can be exploited and the rapid growth of computing power and cheap memory and storage make integrated datasets a new trend that will help bring efficiency to the planning process. With the integrated datasets and integrated model frameworks the following table highlights some of the relevant modern applications of such tools.

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<tr>
<th>Planning Objectives</th>
<th>PLEXOS Capability</th>
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| Renewables Integration and System Flexibility Requirement Assessments | • Sub-Hourly Co-Optimization of Ancillary Services with Energy Market and Transmission Power Flows  
• Stochastic Optimization and Stochastic Renewables Models  
• PHEV, EE, DR, SG, Energy Storage Models |
| Least Cost Resource Change within and Across Regions | • Co-Optimization of Generation and Transmission Expansion  
• Generation Retirements and Environmental Retrofit Models  
• Reliability Evaluation |
| Minimizing production costs and consumer costs to electricity and natural gas rate payers | • Co-Optimization of Production cost of Electrical and Natural Gas Sectors  
• Electrical Network Contingencies and Natural Gas Network Contingencies |
| Sizing Natural Gas Network Components and Natural Gas Storage | • Co-Optimization of Natural Gas Network Expansion along with Electricity Sector Expansion  
• Electrical Network Contingencies and Natural Gas Network Contingencies |
| Environmental Policies | • Co-Optimization of Annual and Mid-Term constraints with short term optimizations  
• Energy Storage and |
| Integrated Reliability Evaluation | • Integrated Reliability Evaluation to Ensure LOLE and other Metrics Maintained with Co-Optimization of Electric and Gas Sector Expansion or True Monte Carlo |