ECONOMIC DISPATCH MODEL OF THE COLOMBIAN ELECTRICITY SYSTEM

ILOG'S PREMIER USER CONFERENCE
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Wholesale Market
XM S.A E.S.P.

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Summary and Objectives

A software application called Programmed Dispatch and Re-Dispatch (DRP for its initials in Spanish) based on Mixed Integer Programming techniques (MIP) has been developed by XM to solve the economic dispatch problem on the Colombian Electricity Market using CPLEX as the optimizer engine.

This application is being used to improve the energy dispatch process, carried out by the System Operator of the Colombian Power System (called XM), attending to energy demand according to the rules of the Colombian Electricity Market.

The aim of this presentation is to give a brief description of the Colombian System and its dispatch process and how the optimization problems have been faced by XM which is the System Operator and Market Administrator in Colombia.
Contents

1. Characteristics of the Colombian Power System

2. Description of the Colombian Market

3. Economic dispatch model of the Colombian electricity system and other solutions developed by the Colombian ISO using ILOG – CPLEX – OPL

4. Conclusions and Results
1. Characteristics of the Colombian Power System
Overview
Characteristics of the Colombian Power System

The total installed capacity is 13,457 MW composed of 64% Hydroelectric power and 36% Thermal.

In 2008, the peak load was 9,079 MW. The energy demand accounted for 53,870 GWh, with an increase of 1.64% compared with 2007.

End User Tariffs (USDc/kWh)
- Residential: 9.1
- Industrial: 8.4

In 2008, the peak load was 9,079 MW. The energy demand accounted for 53,870 GWh, with an increase of 1.64% compared with 2007.
Characteristics of the Colombian Power System and International Interconnections

Colombia – Panama
Future

Colombia – Ecuador
Implicit Auctions (2003)

Colombia – Venezuela
Bilateral contracts

Colombia – Panamá
300 MW

Colombia – Venezuela
500 MW

Colombia – Ecuador
336 MW

Implicit Auctions Decoupled Systems

Bilateral contracts

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<th>2007</th>
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<td>ECUADOR &gt; COLOMBIA</td>
<td>GWh</td>
<td>million USD</td>
<td>av. price USD c/kWh</td>
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<td>157.65</td>
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<td>3.22</td>
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| COLOMBIA > ECUADOR | GWh | million USD | av. price USD c/kWh |
| 1.129,26 | 1.681,08 | 1.757,88 | 1.608,62 | 876,60 |
| 80,30 | 135,10 | 151,73 | 127,10 | 66,26 |
| 7,11 | 8,04 | 8,63 | 7,90 | 7,56 |

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2. Description of the Colombian Market
Colombia's restructuring began in 1991 with the Constitutional reform.
Market Structure

**COMMERCIALIZATION**
- Buy and sell energy
- Competition
- Commercialization margin approved by CREG for the regulated market

**DISTRIBUTION (wires)**
- Regional Monopolies
- Free access to the grid
- Regulated charges

**TRANSMISSION**
- Natural Monopoly
- Competition since 1999 in expansion (for the market)
- Free access to the grid and regulated charges

**GENERATION**
- Competition
- OTC contracts, negotiated prices
- Bid Competition in the spot market
- Imports from other countries (No TIE)

**CLIENTS**
- Regulated
- Unregulated
- Public Lighting
- Exports to other countries (No TIE)

**SYSTEM OPERATION**

**MARKET ADMINISTRATION**

**SYSTEM**
- National Dispatch Center
- Financial Operations

**MARKET**
- Ecuador Market
  - Short Term International Energy Transactions (TIE)

XM is in charge of operating the National Interconnected Power System through the National Dispatch Center (CND) and of administering the Wholesale Electricity Market (MEM).
Market Transaction – Wholesale Energy Market

WHOLESALE ENERGY MARKET

Energy is traded on two competitive markets

- Long Term Energy Market
  where energy is traded on an hourly basis by bilateral contracts

- Short Term Energy Market
  where energy is traded on an hourly basis just for the next day

- Bilateral contracts market carried out by public auctions for supplying electricity to the Regulated Market and free negotiations for supplying electricity to the Non-Regulated Market or Hedge Operations.

- The spot market through bids to the Pool, where available capacity must be declared for centralized dispatch.

Electricity Pool

- On the Colombian Wholesale Electricity Market, the Pool is where all generation plants compete on the basis of bidding prices to supply the electricity demand of the National Interconnected System.
- Traders do not participate in an active way in the Pool since they cannot submit bids.
- When prices are not the result of competition, generation plants are paid based on their variable costs which have regulated maximum values.
3. Economic Dispatch Model
Economic Dispatch (Day – Ahead Hourly Based Dispatch)

- Prices bid
- Declared availability
- Transmission constraints (represented by the area import/export limits and network constraints)
- Up and down reserve for AGC
- Unit characteristics
- Demand forecast
- Reliability Information

Coordinated Dispatch

- Interconnections price curves (exportation)
- Import price curve

A 24-hour optimization process aimed at the minimization of operating costs subjected to generation and network constraints.

The System Operator computes the optimal schedule for each thermal unit and hydro plants for each hour of the next day and for the international interconnection with Ecuador (Implicit auction).
Dispatch Model

General Characteristics
The DRP is a Unit Commitment problem with Network Linear Constraints (NLC - Optimal Power DC Flow). The application finds the optimal generation program of thermal units and hydro plants according to the Colombian Regulations and the international interchange programs.

Basic characteristics of the DRP program:
- Mathematical formulation using Mixed Integer Programming.
- The DRP has been developed by components.
- Extremely fast execution times.
- Module of mathematical modeling.
- Matrix generation in standard formats (LP).
- Advanced User Interface Graphic.
- High performance.
- DRP allows the modeling of different scenarios (dispatch, test, training, etc)
- DRP models the technical characteristics of the units and the transmission network with voltage levels equal to or greater than 110 kV. The dispatch problem is modeled with a network of 212 generation units, 600 transmission lines and 438 buses.
Dispatch Model

Problem Description
The dispatch problem is solved by optimization techniques using Mixed Integer Programming. Minimizing the operational cost of the system subject to the technical characteristics of the units, the frequency reserve and the network constraints.

DRP models a system of 212 generation units, 600 transmission lines and 438 buses and gets the solution in an average of 83 seconds.
Dispatch Model

Mathematical formulation

Minimize \( \sum_{T} \sum_{i} p_{i,t} * G_{i,t} \)

Subject to

Thermal unit minimum starting up/down times
\( u_{i,t} = \begin{cases} 
1 & 1 \leq x_{i,t} \leq t_{i}^{on} \\
0 & -1 \geq x_{i,t} \geq -t_{i}^{off} \\
1,0 & \text{in other case}
\end{cases} \)

Operation reserve requirements
\( \sum_{i=1}^{l} G_{i,t} - g_{i,t}^{min} \geq r_{i}^{down} \quad \forall \ U_{i,t} = 1 \)
\( \sum_{i=1}^{l} -G_{i,t} + g_{i,t}^{max} \geq r_{i}^{up} \quad \forall \ U_{i,t} = 1 \)

Electric area flows limit
\( \sum_{i=1}^{l} G_{i,a,t} + I_{a,t} \leq d_{a,t} \)
\( -I_{a,t}^{exp} \leq I_{a,t} \leq I_{a,t}^{imp} \)

Network constraint
\( P_{k} = \frac{\left(\theta_{k} - \theta_{i}\right)}{x_{k}} \)
\( p_{k}^{min} \leq P_{k} \leq p_{k}^{max} \)

Nodal balance demand
\( U_{i,t} g_{i,t}^{min} \leq G_{i,t} \leq G_{i,t}^{max} \ U_{i,t} \)

Security constraints

Demand balance:
\( \sum_{i=1}^{l} G_{i,t} = d_{i,t}^{sistema} \)

Ramping constraints
\( G_{i,t} - G_{i,t-1} \leq \left[1-U_{i,t} (1-U_{i,t-1})\right] U_{i,t} + U_{i,t} (1-U_{i,t-1}) \delta_{i,t}^{min} \)
\( G_{i,t-1} - G_{i,t} \leq \left[1-U_{i,t-1} (1-U_{i,t})\right] U_{i,t} + U_{i,t-1} (1-U_{i,t}) \delta_{i,t}^{min} \)

Blocks ramps and special linear ramps
Dispatch Model

Ramping Constraints

The dispatch problem faces two different kinds of ramp constraints: ramp constraints under normal operating state, startup and shutdown ramp constraints; which are defined as follows:

i) **Operating ramp**: DRP model lets to have five different $\Delta$ of up/down generation levels of unit $i$ on any two successive on-line periods (either startup or shutdown periods).

ii) **Startup ramp**: When an off-line unit is turned on, it takes $T$ periods with fixed increasing blocks of generation to reach the minimum rated capacity of the unit.

iii) **Shutdown ramp**: When an on-line unit is turned off, its generation level has to be reduced with fixed decreasing blocks of generation to reduce to zero.

\[
\alpha * P_i(t) - \beta * P_i(t-1) \leq UR_i; \\
\gamma * P_i(t-1) - \delta * P_i(t) \leq DR_i;
\]
Fecha de reporte: Enero 18 de 2008  (Fecha de aplicación: Operación de 05 de Febrero)
Planta: TERMOVALLE 1
Minimo Técnico (MW): 100

<table>
<thead>
<tr>
<th>Rango de disponibilidad</th>
<th>Configuración</th>
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<tr>
<td><strong>Mínimo</strong></td>
<td><strong>Máximo</strong></td>
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<td>200</td>
<td>205</td>
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**Descripción:** 1TC X 1HRSG X 1TV
**Combustible:** Gas

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**Bloques UR (MWh)**

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<tr>
<th>Modulo 1</th>
<th>Bloque de despachos &gt; MT a Cero</th>
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<td>UR1</td>
<td>44</td>
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<tr>
<td>UR2</td>
<td>36</td>
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<tr>
<td>UR3</td>
<td>87</td>
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<tr>
<td>UR4</td>
<td>DR4</td>
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<td>UR5</td>
<td>DR5</td>
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**Arranque Intermedio**

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<tr>
<th>Modulo 2</th>
<th>Segundo DR (MWh)</th>
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<tbody>
<tr>
<td>UR1</td>
<td>62</td>
</tr>
<tr>
<td>UR2</td>
<td>85</td>
</tr>
<tr>
<td>UR3</td>
<td>93</td>
</tr>
<tr>
<td>UR4</td>
<td>118</td>
</tr>
<tr>
<td>UR5</td>
<td>DR5</td>
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**Bloques DR (MWh)**

<table>
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<tr>
<th>Modulo 3</th>
<th>Bloque de despachos &gt; MT a Cero</th>
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</thead>
<tbody>
<tr>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>c</td>
<td>d</td>
</tr>
</tbody>
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**T/VALLE UNIT**

Cold Start Up Operation

| Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|--------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Generation | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 44 | 80 | 173 | 200 | 110 | 178 | 200 | 110 | 100 | 100 | 100 | 100 | 12 | 0 | 0 |

**Fixed Blocks Up**

**Up Time.**

**Fixed Block Down**
Other Optimization Applications
Other Applications (1)

Firm Energy for the Reliability Charge (ENFICC)

ENFICC refers to the maximum electric energy that a generation plant is able to deliver on a continual basis during a year, in extreme conditions of hydro inflows.

Basic characteristics:
The ENFICC of hydraulic plants is calculated using a computational model (available in the Web Page www.creg.gov.co), which maximizes the minimum energy that a hydraulic generation plant can produce monthly during dry periods, using CPLEX as the optimization engine. This model incorporates the following technical parameters:

- Historical statistics of average monthly water inflows;
- Interaction of the generation plant with the water sources, discharges and restrictions in the water conduction systems;
- Characteristics of the generation plants: average efficiency of the plants, minimum and maximum generation;
- Water reservoir: i) minimum technical water level, ii) maximum technical water level and iii) other uses of water like aqueduct or irrigation and environmental restrictions;
- Index of Historical Unavailability due to Forced Outages of the Plants (Índice de indisponibilidad histórica por salidas forzadas de la planta or IHF, its acronym in Spanish);
- Flow constraints.
Other Applications (2)

Ideal Dispatch (ILOG – OPL)

- Actual dispatch is more expensive than the ideal dispatch because it takes into account transmission system limitations.
- Constrain costs are paid by suppliers and passed through to end users.
- Out of merit generation has a regulated cap.

An hour optimization process aimed at the minimization of operating costs subjected to generation and demand constraints. And also computes the Spot Price Market for each hour of the previous day.

This year is going to be released a new application developed using ILOG – OPL.

Calculated by the DRP Program:
- Prices bid
- Declared availability
- Transmission constraints (represented by the area import/export limits and network constraints)
- Up and down reserve for AGC
- Unit characteristics
- Demand forecast
- Reliability Information
Bilateral Contracts Market in which generators and electricity suppliers sell and purchase energy at freely-negotiated prices and quantities. This market is fundamentally financial: the purpose of the contracts is to reduce the exposure of both the supplier and the end-user to price volatility in the spot market, while the physical delivery of the energy committed in these contracts occurs via the spot market.
Other Applications (4)

DRP with non linear network constraints (DRP – OPF AC/ in phase of construction with OPL)

- Unit commitment
- DRP

Operation Program

Network constraints
OPF AC

Benders Cuts

Hydrothermal dispatch system with linear network constraints for short, medium and long term operation studies (in phase of construction with OPL)

Stochastic optimization methodology
- Thermal plant modeling
- A Complete hydro plants modeling
- Transmission network
- Market constraints
- Risk
4. Conclusions and Results
Results

• Since March 1st 2003, DRP is being used as the official software to calculate the economic dispatch in the Colombian Power System. Although the economic dispatch is a big and a complex problem which must be solved in a very short period of time, DRP has allowed us to reach high levels of reliability and opportunity, nearly to 100%, in the delivering of the final dispatch program.

• Sum up, DRP is a Unit Commitment problem with Network Linear Constraints (NLC - Optimal Power DC Flow), which resolves the economic dispatch problem according to all the rules of the Colombian Market.

• Among others, DRP obtains the following results: The dispatch program for each thermal unit and hydroelectric plant, marginal nodal prices, the marginal system price, power flows between electric areas and transmission lines, the frequency reserve program and international transaction programs (TIE), etc.

• XM is working to develop in house some of the most critical applications for the business (power systems and energy markets); as the DRP, Ideal Dispatch, Firm Energy, Contracts, Hydrothermal dispatch.
Conclusions

• According to the dynamics of the Colombian Power Markets, it has become necessary to control our own application software. DRP and the other applications allow us to implement new and very complex constraints, making it possible to incorporate new rules into any power and energy market solutions.

• The Applications have been developed according to the specifications and requirements of proper users in order to reduce the processing time and the human mistakes in the manipulation of data.
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