Energy System Optimization Modelling through PLEXOS for SAARC member states
Energy Exemplar
Why Energy Exemplar?

1. Market Leader since 1999. **350+ clients in 62+ countries**
2. No consulting. We’re **focused on our platform**.
3. **24x6 support worldwide**
4. Strong **investment in development**
5. **Social gateway** to a global community
   1. Network at User Group Meetings
   2. Adopt Best Practices
   3. Enjoy the knowledge transfer
Energy Exemplar footprint

1,700 users at over 350 companies in 62 countries

Clients by Region:

<table>
<thead>
<tr>
<th>Region</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilities</td>
<td>97</td>
</tr>
<tr>
<td>Consultants</td>
<td>44</td>
</tr>
<tr>
<td>Power Producers</td>
<td>39</td>
</tr>
<tr>
<td>Researchers</td>
<td>28</td>
</tr>
<tr>
<td>Regulators</td>
<td>21</td>
</tr>
<tr>
<td>TSOs</td>
<td>14</td>
</tr>
<tr>
<td>ISOs</td>
<td>13</td>
</tr>
<tr>
<td>Traders</td>
<td>5</td>
</tr>
<tr>
<td>Energy Analysts</td>
<td>4</td>
</tr>
<tr>
<td>International Institutes</td>
<td>3</td>
</tr>
</tbody>
</table>
Asia Pacific Customers

- AEMO
- synergy
- origin
- CLP
- TENAGA NASIONAL
- TENAGA NASIONAL
- ABOITIZ POWER GROUP
- SESB
- POSOCO
- sarawak energy
- Electricity Planning & Engineering Institute
- Energy Market Authority
- EVN
- ElectraNet
- Aboitiz Power
- EREA
- Meralco
Why optimization?

Is your existing approach optimal enough?

- Manage Uncertainty
- Evaluate multiple scenarios
- Foresight
- Optimized forecasting accuracy
- Minimize costs
- Fuel savings
PLEXOS Integrated Platform
Why PLEXOS?

Best In Class
- Power
- Gas
- Water

Cutting-edge
- Mathematical Optimization
- Deterministic & Stochastic Techniques
- Robust

Multi-task
- Long Medium Short-term
- Integrated Tools

Transparent
- Not a black box
- Customizable
How PLEXOS works?

**INPUT DATA SERIES**
- Fuel Prices
- Renewable Forecasts
- Energy Demand
- Generation Availability
- Water Demand
- Fuel Contracts

**DATA SETS**
- Zonal Data
- Nodal Data

**HIGHLY DETAILED PORTFOLIO DATA**
- Heat rates
- Ramp rates, start profiles
- Fuel blends and limits
- Emissions constraints
- Trading positions

**ENGINE**
- Data read
- Power system logic
- Formulation & solution
- MIP and LP
- Solution interpretation

**RELIABILITY EVALUATION**
- PSS®E AC OPF

**USER INTERFACE**
- Engine Solver
  - CPLEX, Xpress, Gurobi, etc.

**OUTPUT**
- Solution review
- Output reports
- Graphical interface
- Data export

**USER INTERFACE**
PLEXOS Main Applications

- Dispatch Optimization
- Hydro-thermal Coordination
- Reliability Analysis
- Energy and Reserves Co-optimization
- Policy and Strategy Evaluation
- Renewables Integration
- Generation and Transmission Planning
- Electricity and Gas Co-optimization
PLEXOS® Integrated Energy Model

Why single engine?

• Collaboration among institutions
• Co-optimize across use cases
• Performant for the most complex problems
• Role based UI
PLEXOS® Long-Term Planning

MIP Objective: Minimize NPV of capital & production

C(x): Capital Cost
P(x): Production Cost

Cost $ vs. x = Assets

Minimum cost plan

Which
Tech to build/retire

How Much
Capacity to build/retire

When
To build/retire

Where
To build/retire
Indicative Generation Capacity Expansion Plan (IGCEP 2047)

Objectives:
Identify new generation requirements by capacity, fuel technology and commissioning dates on year-by-year basis;
Satisfy the Loss of Load Probability (LOLP) not more than 1% year to year;
Cater for the long-term load growth forecast and reserve requirements; and
Provide a least cost optimal generation expansion plan for development of hydroelectric, thermal, nuclear and renewable energy resources to meet the expected load demand up to the year 2047.
Load Forecasting

Base Load Profile

Historical Load 2017

Peak and Energy Forecast

Energy (TWh) - Peak Load (MW)

Forecasted Load Profile
Renewable Energy Integration

PLEXOS® Stochastic Optimization considers multiple renewable profiles to deliver a single optimal build decision.

Uncertainty doesn’t disappear… it’s just accounted for properly.
GREENING THE GRID: Pathways to Integrate 175 Gigawatts of Renewable Energy into India’s Electric Grid

A 175-GW RE target by 2022 that places greater emphasis on wind over solar (60 GW wind, 100 GW solar), achieves higher RE capacity factors.

<table>
<thead>
<tr>
<th>SCENARIO NAME</th>
<th>SOLAR (GW)</th>
<th>WIND (GW)</th>
<th>DESCRIPTION</th>
<th>PURPOSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>No New RE</td>
<td>5</td>
<td>23</td>
<td>Wind and solar capacities installed as of 2010</td>
<td>Establish a baseline to measure impact of adding new RE to the system</td>
</tr>
<tr>
<td>20S-50W</td>
<td>20</td>
<td>50</td>
<td>Total installed capacity as targeted in Green Energy Corridors &amp; National Solar Mission</td>
<td>Evaluate changes to power system planning and operations to meet near-term targets</td>
</tr>
<tr>
<td>100S-60W</td>
<td>100</td>
<td>60</td>
<td>Current Government of India target for 2022</td>
<td>Evaluate changes to planning and operations to meet the official target of 175 GW RE</td>
</tr>
<tr>
<td>80S-100W</td>
<td>60</td>
<td>100</td>
<td>Solar and wind targets reversed in comparison to official target</td>
<td>Understand differential impacts of wind versus solar on need for system flexibility</td>
</tr>
<tr>
<td>150S-100W</td>
<td>150</td>
<td>100</td>
<td>Ambitious RE growth</td>
<td>Evaluate how needs for system flexibility would change under a higher wind and solar build-out</td>
</tr>
</tbody>
</table>

Higher RE penetration levels brings benefits of reduced fuel consumption and lower CO² emissions.
PLEXOS® Medium Term Planning

Decompose inter-temporal constraints that would otherwise be too long for ST Schedule

- Hydro storage levels
- Fuel constraints
- Inter-temporal Constraints
- Generator technical limits
- Emission limits

LT Plan → MT Schedule → ST Schedule

Graph showing end volume (1000 m³) from 1/1/2020 to 1/12/2020.
Projected Assessment of System Adequacy (PASA) is a simulation phase that focuses on the balance of supply and demand in the medium term. The functions of the PASA simulation phase are:

- To schedule maintenance events of any asset (transmission lines, generators, gas pipelines).
- Allocate outages events
- Compute reliability statistics such as:
  - EDNS
  - LOLP
  - LOLE
  - EENS

System Security and Maintenance Planning
Hydro Optimization

<table>
<thead>
<tr>
<th><strong>Multiple phase simulation</strong></th>
<th>Ensures optimal use of storage down to chronological level</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Long – Medium – Short)</td>
<td></td>
</tr>
<tr>
<td><strong>Cascading networks</strong></td>
<td>Major and minor storages and junctions</td>
</tr>
<tr>
<td></td>
<td>Natural inflows and spillways and canals</td>
</tr>
<tr>
<td><strong>Constraints</strong></td>
<td>Minimum releases for environment</td>
</tr>
<tr>
<td></td>
<td>Operational constraints and hydro generation efficiency</td>
</tr>
<tr>
<td><strong>Monte Carlo or Stochastic Optimisation</strong></td>
<td>Multistage stochastic optimisation for better modelling of storage release policies under uncertainty</td>
</tr>
</tbody>
</table>
Hydro Operation and Planning

**Challenges:**

1) **Transmission:** High congestions in the transmission lines due to large supply of solar energy in the north to serve high demand in the central zone.

2) **Cycling:** Increase in startups between 16 and 21 hours (Solar gen decrease) and shutdowns between 6 and 12 hours (Solar gen increase).

3) **Ramping:** High ramping requirements with solar generation increase/decrease.

4) **Hydro constraints:** Highly complex irrigation constraints.
PLEXOS® Short Term Formulation

**Minimize:** Operational Costs + Start-up/Shutdown Costs
*(Maximization of societal benefits)*

**Subject to:**
- Energy balance
- Technical limits
- System security requirements

- **How** serve Load at minimum cost
- **When** should each unit be started/stopped
- **How Much** should each unit generate
- **How** meet system security requirements
Dispatch Optimization

Mixed Integer Programming
Over 300+ Unit Commitment properties
Constraints modelling
Resolution down to 1-second

Combined Cycle Gas Turbine (CCGT) Generation Profile of 1 week

Minimum Up Time
Minimum Down Time
Start Costs
Minimum Stable level
1. PLEXOS unit commitment algorithms work to minimize costs subject to constraints
2. CLP has many fuel constraints
   1. Coal port and different mix ratios for coal plant in Hong Kong
   2. Nuclear imports from China
   3. Gas supply contracts with max daily quantity, take or pay etc.
3. CLP has different technologies like steam turbines, CCGTs and GTs
   1. Over 300 UC properties in PLEXOS emulate life like dispatch
4. CLP has an emissions constraint for Hong Kong
   1. The PLEXOS constraint class allows almost any constraint to be applied
   2. The PLEXOS conditional class is like setting up “if” statements in excel
   3. The PLEXOS variable class allows relationships to be assigned
5. These features together with Mixed Integer Programming emulate the real world.
6. Very significant savings are achieved
Cascading System Optimization

Time: \( t \)
Total Generation = 1255 MW

- Generators flow water from their Head Storage to their Tail Storage or ‘to the sea’.
- A Waterway flows water from one Storage to another
- As the water runs downstream in a cascade system, there is also a loss of potential energy during the trajectory which can be handle with PLEXOS

Inflow1: 117.2 m³/s
Inflow2: 34.84 m³/s
Inflow3: 126 m³/s
Inflow4: 306.9 m³/s
Inflow5: 113.8 m³/s
Inflow6: 300 m³/s

Lake 1: 89.6 Hm³
Lake 2: 726.7 Hm³
Lake 3: 120.1 Hm³
Lake 4: 967.4 Hm³

Gen1: 0 MW
Gen2: 105 MW
Gen3: 42.9 MW
Gen4: 53.5 MW
Gen5: 23.8 MW
Gen6: 0 MW
Gen7: 34 MW
Gen8: 25.1 MW
Gen9: 6 MW
Gen10: 2 MW
Gen11: 550 MW
Gen12: 298 MW
Gen13: 64.2 MW
Gen14: 37 MW
Gen15: 13.4 MW
Gen16: 0 MW

Irrigation Constraints
Leaks
& Irrigation constraints

Inflow7: 58.1 m³/s
Inflow8: 292.8 m³/s
Inflow9: 272.9 m³/s
Inflow10: 306.9 m³/s
Inflow11: 192.7 m³/s
Inflow12: 13.8 m³/s
Inflow13: 13.8 m³/s
Inflow14: 306.9 m³/s
Inflow15: 272.1 m³/s
Inflow16: 13.8 m³/s
Transmission Modelling

- Transmission operation
- Transmission Expansion Planning
- Security Constrained Economic Dispatch (SCED)
- ‘N-x’ Contingency Analysis
- Congestion Costs
- Transmission aggregation and Network reduction
- PSSE Power Flow Raw Data file Importer

Single Line Diagram (SLD) allow users to review nodal connection
Battery Energy Storage System

Solar Generation and Battery Net Generation

- Solar farm
- BESS 1
- BESS 2

Battery charging
Battery discharging

Built in best in class battery models
BESS technical and economic representation
Represent all types of energy storage technologies

Max Input Power (MW)
Charge Efficiency (%)
Discharge Efficiency (%)
Max Input Power (MW)
Max SoC (%)
Initial SoC (%)
Min SoC (%)
Max Ramp Up/Down (MW/min)
Build Cost
Economic Life
Technical Life
WACC
FO&M Charge

Capacity (MWh)
Ancillary Services Modelling

- What price and hence cost was imposed by reserve?
- Which generators and / or interruptible load provide reserves?
- How reserve costs were allocated to generators?
Electricity and Gas Co-optimization

- Right-sizing for supply, storage, and transportation contracts given gas and power demand
- Reliability requirements for delivering gas
- Renewable generation impact studies to serve both power and gas demand
- Storage injection and withdrawal target optimization given both power and gas demand
Integrated Strategic Optimization

- High & low renewable penetration scenarios impact on gas demand
- Impacts of nuclear & coal retirements to the gas demand
- Increasing carbon price impact on merit order between gas and coal
- Modelling the injection of Biomethane or Hydrogen into the gas system
- Power (excess wind power) to Gas Production (Hydrogen) Scenarios
- Scenario Analysis- Electricity & Gas
Concluding Remarks

- Better knowledge
- Accurate foresight
- A confident direction
- Optimal operation
Thank you for your kind attention

Do not hesitate to contact us if you have any question or want to know more about our solutions.

Belen Leveroni  
Business Development Executive  
belen.leveroni@energyexemplar.com

Dr. Dante Recalde  
Lead Market Analyst  
dante.recalde@energyexemplar.com