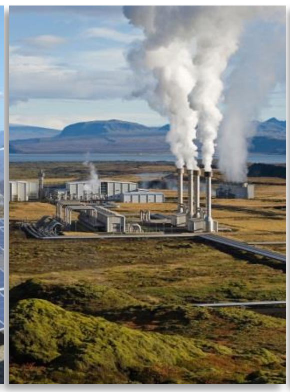
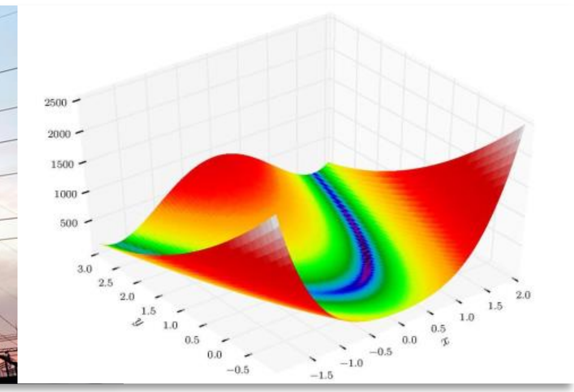
Planning of the National Electric System





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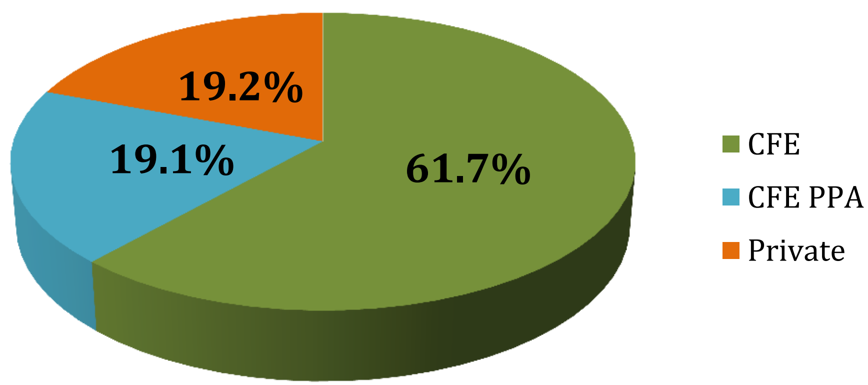
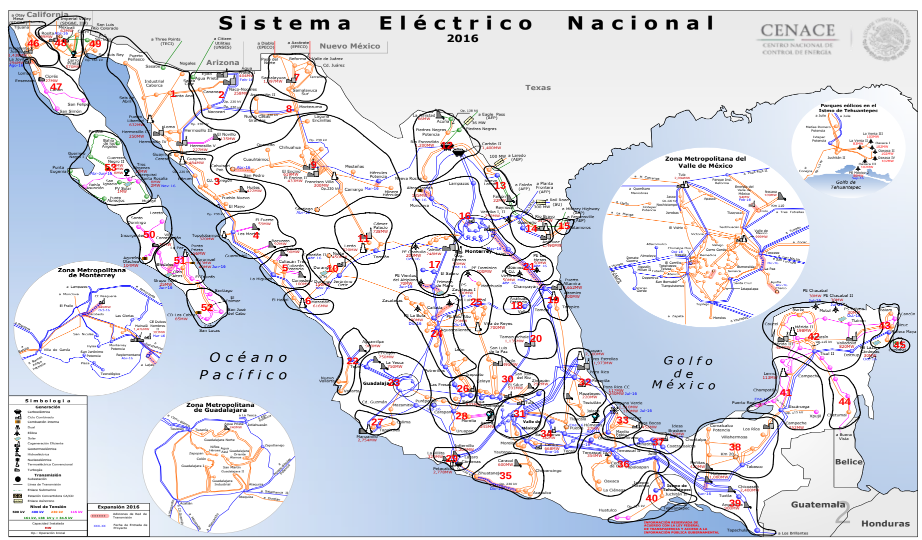
Background: Electricity Sector in Mexico

	Generation Capacity (MW)	
Conventional 48 GW	Combined Cycle	24,043
	Steam (Fuel Oil and Gas)	13,291
	Coal	5,378
	Simple Cycle	4,904
	Internal Combustion	1,163
Clean 19 GW	Hydro	12,489
	Wind	2,805
	Geothermal	926
	Solar	56
	Nuclear	1,510
	Biomass	760
	Efficient Cogeneration	583
	Other	7
	Total	**67,913**

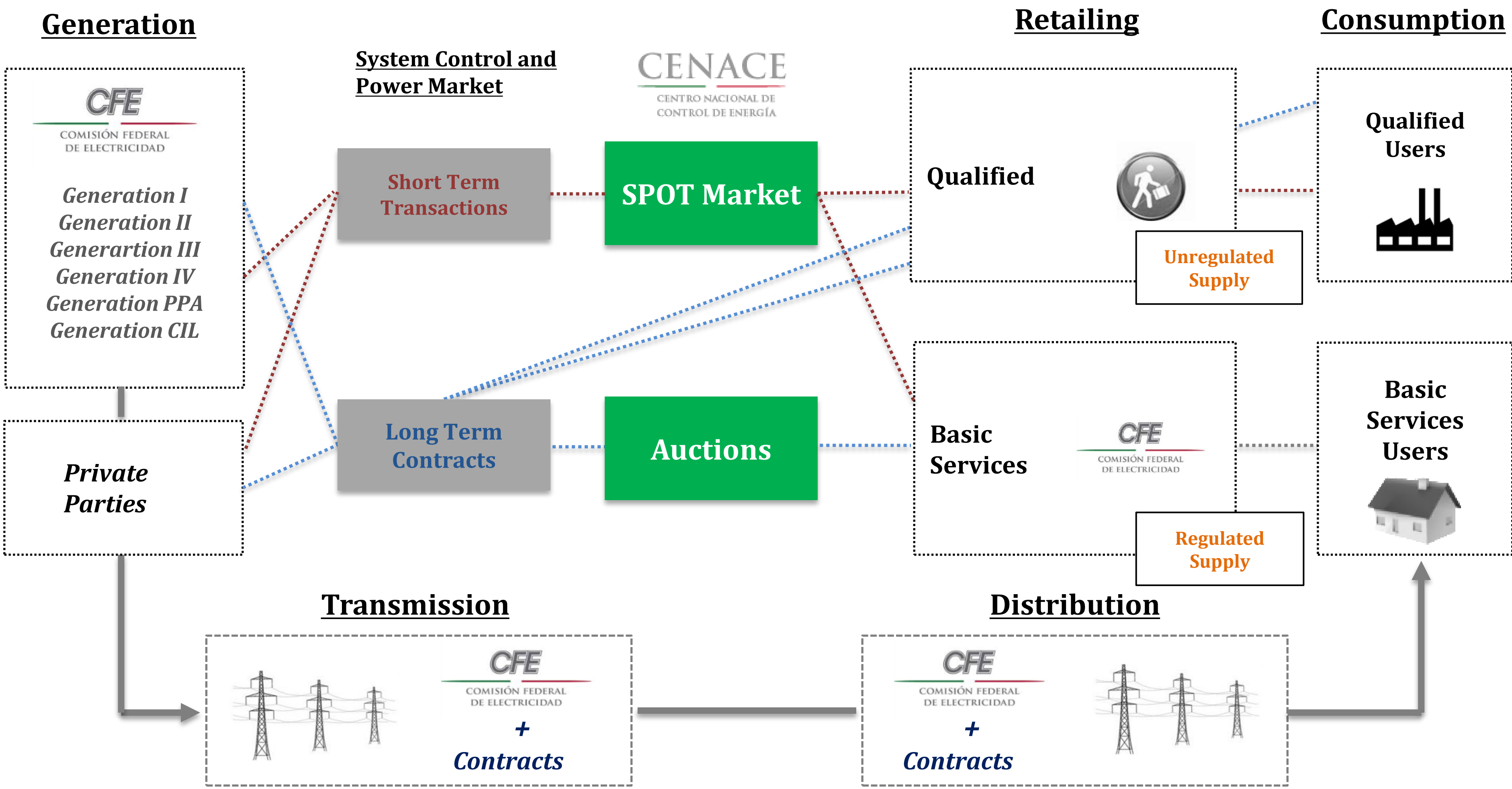
Grid (km-c)	
400 kV	23,641
230 kV	27,543
Subtransmission (≥ 69 kV)	56,851
Distribution	683,226

Generation by ownership





New scheme for the electricity sector



PPA: Power Purchase Agreement
CIL: Legacy Interconexion Contracts

Why Planning?

The features of electricity may cause productive inefficiencies.

Electricity Characteristics

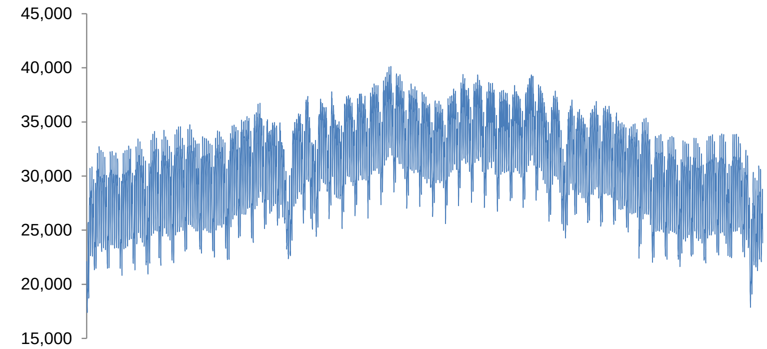
Characteristics	Description
Funible good	• Electricity is not stored on a large scale, which involves maintaining a continuous and instantaneous balance between production and consumption to avoid a failure in the electric system.
Volatility	• Electricity demand presents hourly swings, this involves having an efficient management of the electric system, depending on the relationship between demand and installed capacity.
Homogeneous good with heterogeneous sources of supply	• Electricity is a uniform good which doesn´t allow to identify their origin and destination. • There is a complex diversity of electricity production technologies that are not technically and economically homogeneous (scale, maturity and costs).
Continuous flow	• Capability constraints network. • Coordination in planning network to promote scale economies and allow continuos flow between adjacent regions.

The main task of having electric-planning tools is:

1. Send signal to project developers with the best system information, for decision making.
2. Define the infrastructure needed to allow efficiently the energy flow.

Why Planning?

Countries design **planning instruments** for electric systems base on technical tools and prospective analysis of variables that impact in the generation and transmission expansion, and electricity supply, like:



- Energy demand
- Generation units economic assessment
- Options and new trends of power generation technologies
- Electric System reliability
- Available resources and environmental considerations
- Generation and transmission technical constraints
- Other constraints for electric system planning

Electric system planning

Electric system planning *encompasses a broad collection of activities spanning several time horizons and can be divided into categories of analysis such as* ***demand****,* ***generation****,* ***transmission*** *and* ***distribution.***

Each category of analysis may be carried out for a short time, a medium time or a ***long time*** *frame.*

Long-term planning *addresses the economic selection of* ***generation*** *and transmission* ***addition*** *necessary to meet projected load requirements.*

Examples (generation):

Short-time frame: *optimum for the system is often to add low capital cost vs high operating cost options.*

Long-time frame: *units with higher capital costs but lower operating costs become more likely to enter the optimum solution*

Electric system planning

Long-term generation expansion planning problem

Minimize the total present discounted value of investment and operation costs among the expansion plans which satisfy a given reliability level.

Questions to be answered:

- ***What*** *capacities to install to ensure an appropriate level of reliability?*
- ***How*** *to pick the best combination among the different technologies at hand now and later on?*
- ***Where*** *to locate this new equipment?*
- ***When*** *is the proper time to incorporate them into the system?*

Before the Energy Reform

Electricity Public Service Law (LSPEE)*

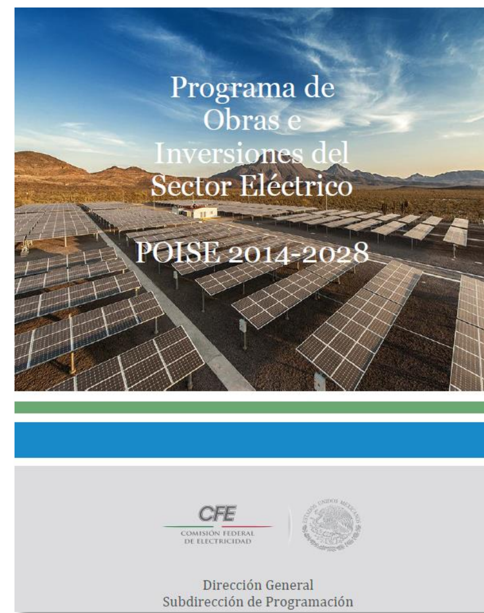
LSPEE → **Supply of Electricity as a Public Service** → COMISIÓN FEDERAL DE ELECTRICIDAD

The public service included…

The Planning of the National Electric System (SEN)

Generation, transmission, transformation, distribution and sale of electricity.

The performance of the works and installations required for the planning, execution, operation and maintenance of the national electric system.



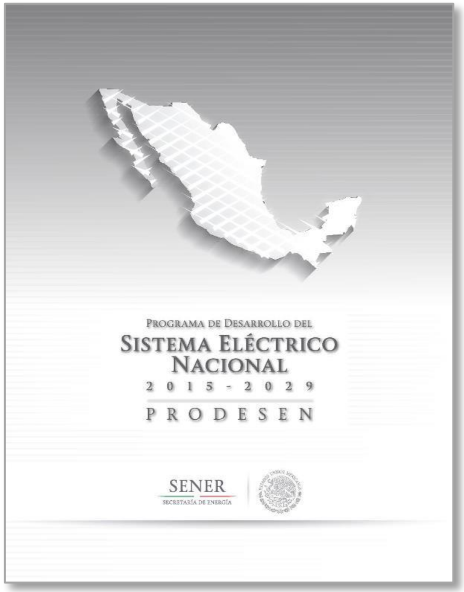
** Abrogated 11 august 2014*

Development Program of the National Electric System (PRODESEN)

Electricity Industry Law (LIE)*

LIE → ***Lead the planning of the National Electric System and elaborate PRODESEN*** → SENER
SECRETARÍA DE ENERGÍA

Programa de Desarrollo del Sistema Eléctrico Nacional: *encompasses the plan for the National Electricity System and gathers the relevant elements of the indicative Programs for the commission and decommission of power plants as well as the enlargement and upgrade Programs for the national transmission grid and the general distribution networks.*



**** DOF 11 de agosto de 2014***
***** Art. 27 … "Corresponde exclusivamente a la Nación la planeación y el control del sistema eléctrico nacional;…" DOF 20 diciembre 2013***

PRODESEN…What is it?

Development Program of the National Electric System
PRODESEN 2016-2030 (updated yearly)

Electricity master plan

Indicative programs for the commission and decommission of power plants, as well as expansion and modernization programs for the national transmission grid and the general distribution networks.

Certainty for industry participants

Timely information

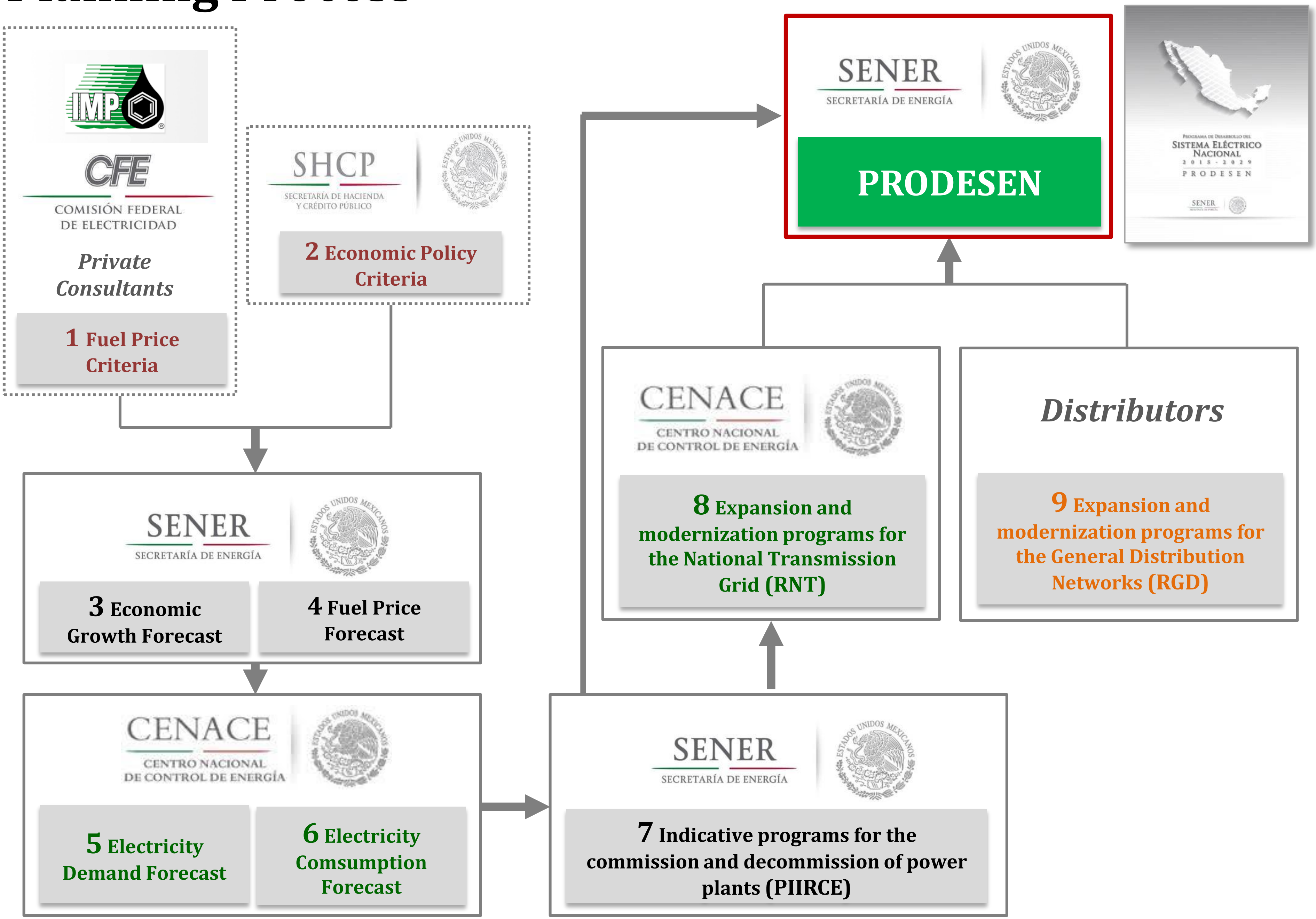
Next 15 years

EFFICIENCY, QUALITY, RELIABILITY, CONTINUITY, SECURITY AND SUSTAINABILITY

Competition in generation and commercialization

Private investment through public-private partnership to upgrade national transmission grid.

Planning Process



Sectorial Econometric Model of Electricity Consumption

$$ECM = f(Rc, Cc, Sl, Ss, Ce, Ap)$$

Where the variables used by region $_{i=1,\dots,10}$ and NES to the next 15 years:

- Rc **Residential consumption**
- Cc **Commercial consumption**
- Sl **Street lighting**
- Ss **Sewage and safe drinking waterpumping**
- Ce **Consumption of medium and large industry**
- Ap **Agricultural pumping**

Peak Load Mathematical Forecasting Model

$$PL = f\left(\widehat{EC}, Lf, Hl\right)$$

Where the variables used to forecast the next 15 years:

- $\widehat{EC}$ **Electricity Consumption by region** $_{i\,=\,1,\,\ldots\,,\,10}$ **and NES**
- Lf **Load Factor by sector** $_{i\,=\,1,\,\ldots\,,\,6}$
- Hl **Hourly Load Factor Profile by region** $_{i\,=\,1,\,\ldots\,,\,10}$ **and NES**

Asumption:

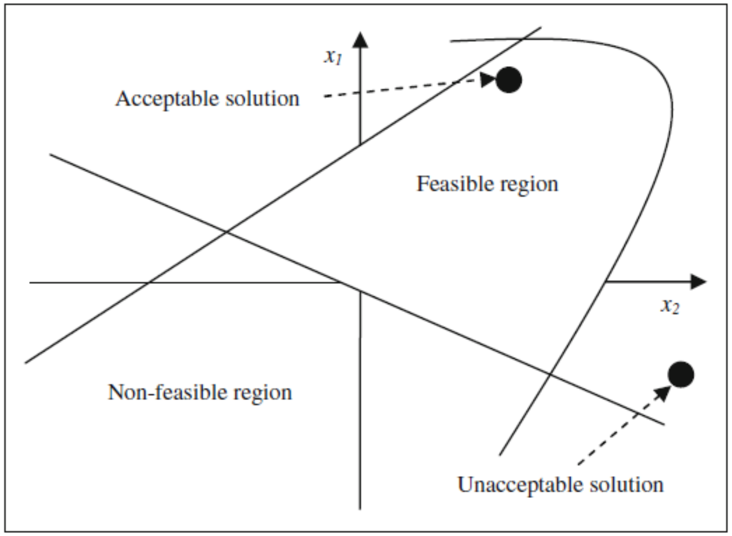
$$Lf \begin{cases} \Delta \\ = \\ \nabla \end{cases} \text{Load Factor by sector } i = 1, \ldots, 6 \text{ to the next 15 year}$$

Indicative programs for the commission and decommission of power plants (PIIRCE)

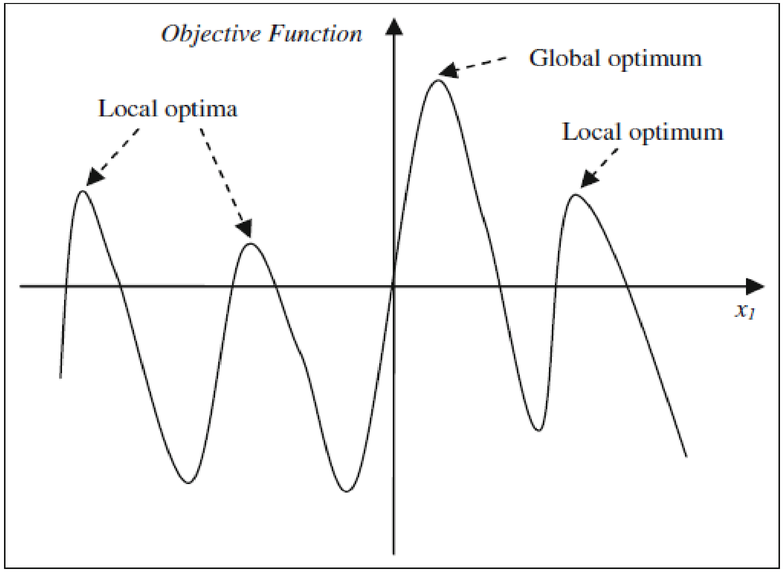
Problem description

Generation expansion planning (GEP) is modeled as a Mixed-Integer Linear Programming (MILP), where the optimization problem aims to determine the new generation plants in terms of when to be available, what type and capacity they should be and where to allocate so that an objective function is optimized and various constraints are met. It may be of static type in which the solution is found only for a specified stage (typically, year) or a dynamic type, in which, the solution is found for several stages in a specified period

Constraints functions



Objective functions



Indicative programs for the commission and decommission of power plants (PIIRCE)

Model

$$\textbf{Minimize}\ \{\boldsymbol{C}_{\text{Investment}} + \boldsymbol{C}_{\text{O\&M}} + \boldsymbol{C}_{\text{ENS}}\}$$

donde:

$\boldsymbol{C}_{\text{Investment}}$: present discounted value of investment cost.
$\boldsymbol{C}_{\text{O\&M}}$: present discounted value of operation and maintenance cost.
$\boldsymbol{C}_{\text{ENS}}$:present discounted value of the cost of energy not served.

Decision variables:

- Number of units of the generator ($\boldsymbol{g}$) built in year ($\boldsymbol{y}$);
- Number of units of the generator ($\boldsymbol{g}$) decomission in year ($\boldsymbol{y}$);

Input data

Variable cost ($\boldsymbol{g}$), fixed cost ($\boldsymbol{g}$), capital investment cost (*overnight cost*) ($\boldsymbol{g}$), cost of energy not serve , minimum generating capacity ($\boldsymbol{g}$), maximum generating capacity ($\boldsymbol{g}$), renewable energy availability ($\boldsymbol{g}$) ($\boldsymbol{t}$), ($\boldsymbol{g}$), fuel cost for ($\boldsymbol{g}$), discount rate.

Indicative programs for the commission and decommission of power plants (PIIRCE)

Model

$$\textbf{Minimize}\ \{\boldsymbol{C}_{\text{Investment}} + \boldsymbol{C}_{\text{O\&M}} + \boldsymbol{C}_{\text{ENS}}\}$$

Constraints:

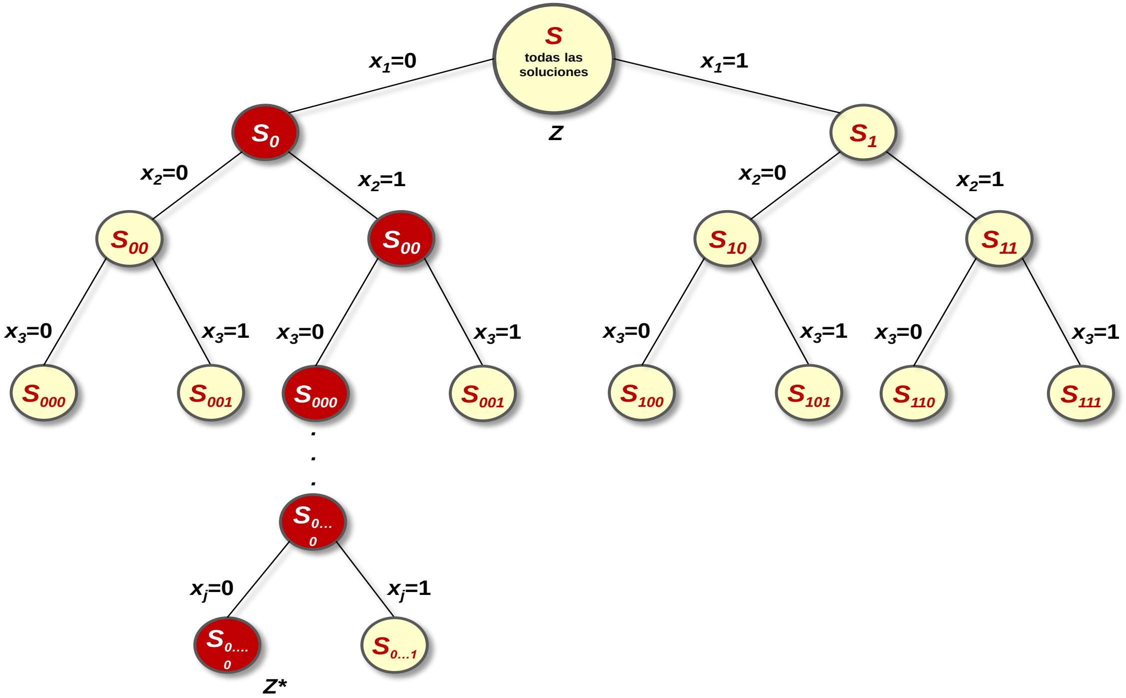
- **Energy Balance;**
- **Reserve capacity;**
- **Hydrological conditions;**
- **Renewable energy potential;**
- **Transmission capacity;**
- **Technical constraints;**
- **Clean energy generation goals.**

Indicative programs for the commission and decommission of power plants (PIIRCE)

Solution

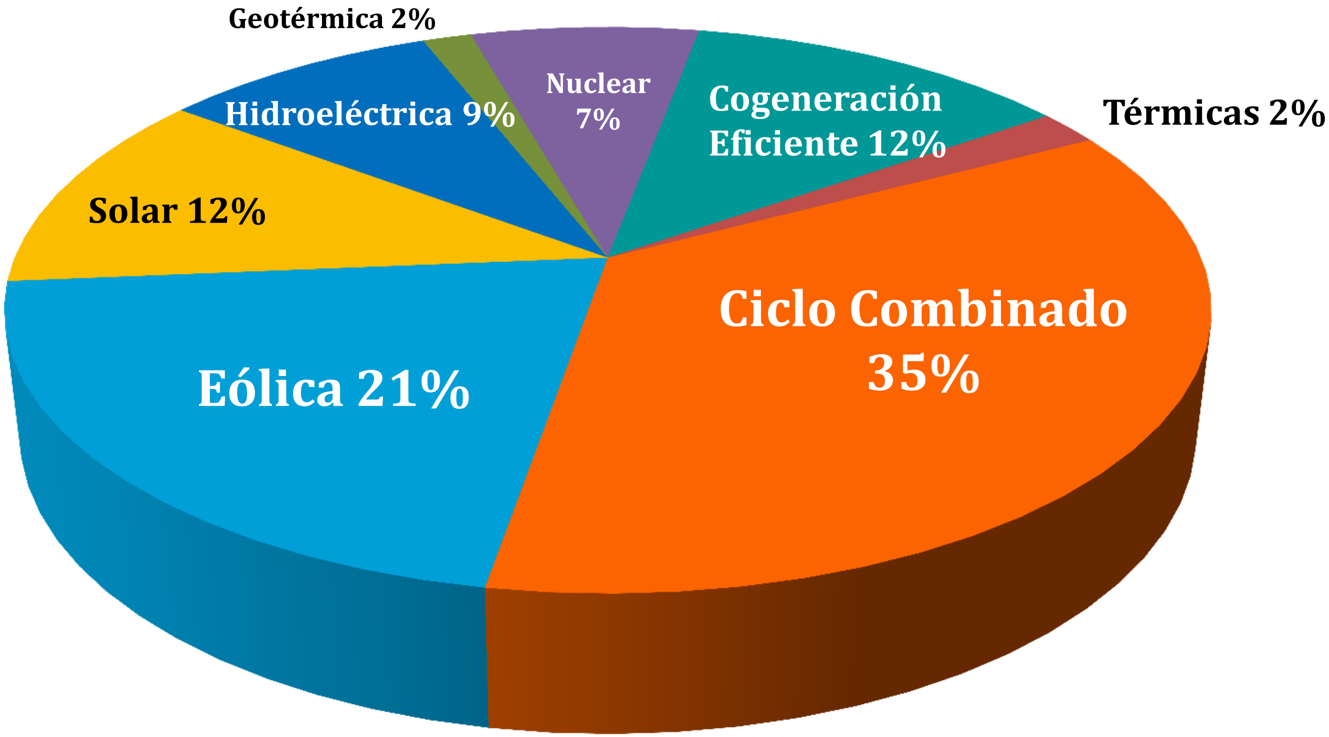
PLEXOS uses the "*Branch and Bound*" algorithm to solve the MILP problem.

- **linear programming relaxation:** drop integer constraints
- **Branching:** enumerate solution of subproblems;
- **Bounding:** select the best solution.
- **GAP:** solution is reached when the difference between between the best known integer solution and the best known bounding linear solution meets certain value.



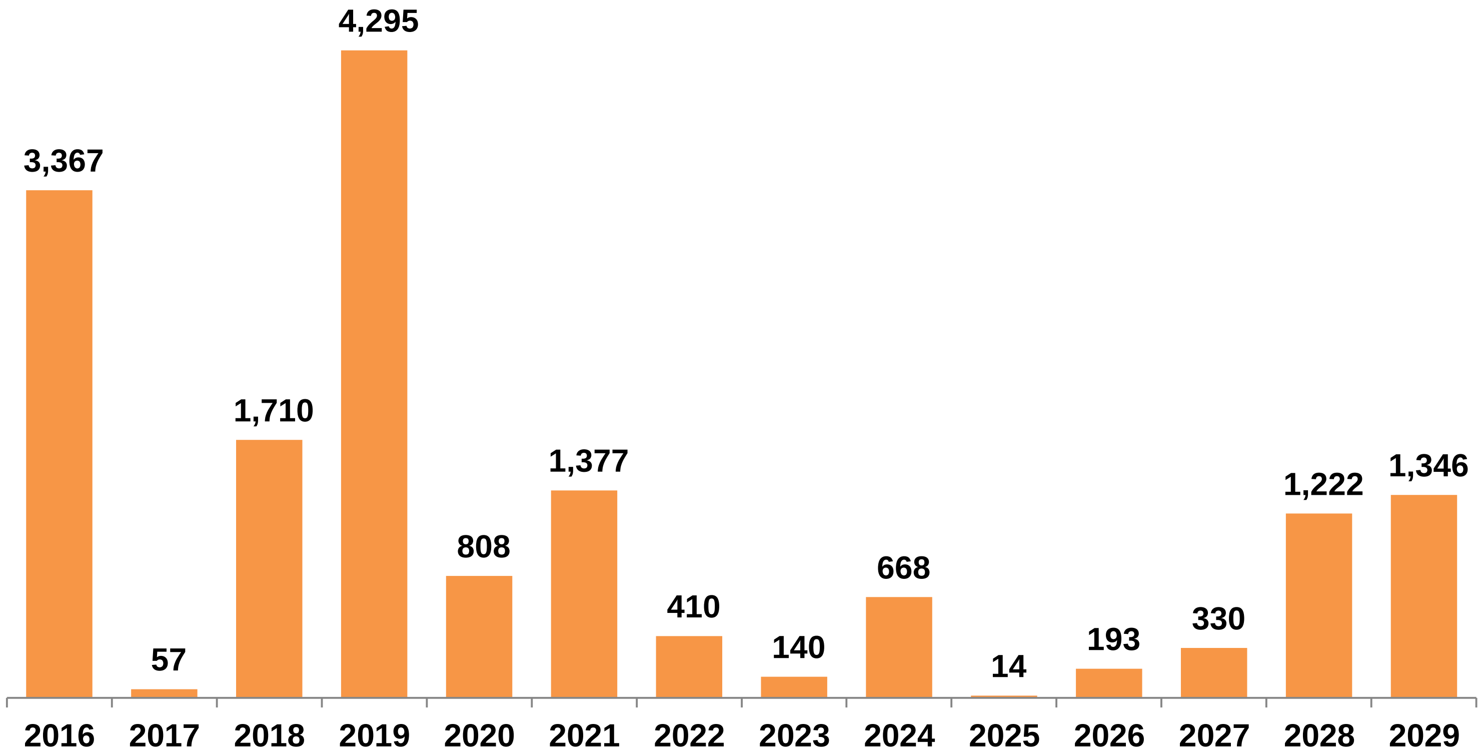
Indicative programs for the commission and decommission of power plants (PIIRCE)

		PRODESEN 2016-2030
COMMISSION	Total	57 mil MW
	Clean	35.8 mil MW
DECOMMISSION		15,937 MW



Indicative programs for the commission and decommission of power plants (PIIRCE)

- Of all the power plants to be decommissioned, **64% will be removed form service over the next 5 years.**
- PIIRCE includes the decommissioning of the least efficient power plants.
- Conventional thermoelectric plants represent **69%** of the removed capacity, in terms of capacity.



*Preliminary data PIIRCE 2016-2030

Method to Solve the Power Flow Model

$$PFM = f(Is, It, Rp, Lo, Ap, Gv, Lp)$$

Where modeling elements, which are constant values:

- ***Is*** Impedance and shunt admittance
- ***It*** Impedance and transformation ratio on transformers
- ***As*** Admittance shunt elements, capacitors and reactors
- ***Lo*** Load connected to each node
- ***Ap*** Active power output of each generator
- ***Gv*** Generation voltage or reactive power of each generator
- ***Lp*** The limits of reactive power output of each generator

THANK YOU

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