GE MARS Training

Tuesday April 16th, 2019

Start	End	Description
9:00	9:15	Welcome and Introduction
9:00	10:45	Probabilistic Reliability Methods
10:45	11:00	Break
11:00	12:00	Introduction to GE MARS
12:00	1:00	Lunch

Tuesday April 16th, 2019

Start	End	Description
1:00	1:30	Introduction to the Sample System
1:30	2:00	GE MARS Master Input File
2:00	2:15	Starting our database
2:15	2:30	Demand Modelling – Lecture
2:30	3:00	Demand Modelling – Hands-on Exercise
3:00	3:15	Break
3:15	3:45	Thermal Unit Modelling – Lecture
3:45	4:30	Thermal Unit Modelling – Hands-on Exercise
4:30	5:00	GE MARS Python API (snappy) – Reading and Writing the MIF

Wednesday April 17th, 2019

Start	End	Description
9:00	9:15	Running our first case
9:15	9:45	GE MARS Output Files, and Results Reporting
9:45	10:30	GE MARS Python API (snappy) – Output Reporting
10:30	10:45	Break
10:45	11:00	Hourly Modifier Unit Modelling - Lecture
11:00	11:30	Wind and Solar Unit Modelling – Hands-on Exercise
11:30	12:00	System Imports and Exports – Hands-on Exercise
12:00	1:00	Lunch

Wednesday April 17th, 2019

Start	End	Description
1:00	1:30	Energy Limited Unit Modelling – Lecture
1:30	2:15	Energy Limited Unit Modelling – Hands-on Exercise
2:15	2:30	Transmission Interconnections – Lecture
2:30	2:45	Break
2:45	3:30	Transmission Interconnections – Hands-on Exercise
3:30	3:45	Emergency Operating Procedures – Lecture
3:45	4:30	Emergency Operating Procedures – Hands-on Exercise
4:30	5:00	Contract Modelling

Thursday April 18th, 2019

Start	End	Description
9:00	9:30	GE MARS Python API (snappy) – Running a Case
9:45	10:00	Load Forecast Uncertainty - Lecture
10:00	10:30	Load Forecast Uncertainty – Hands-on Exercise
10:30	10:45	Break
10:45	11:15	Capacity Value and Effective Load Carrying Capability - Lecture
11:15	12:00	Capacity Value and Effective Load Carrying Capability – Hands On Exercise
12:00	1:00	Lunch
1:00	4:00	Scenario Analysis
4:00	4:45	Q&A / User Feedback

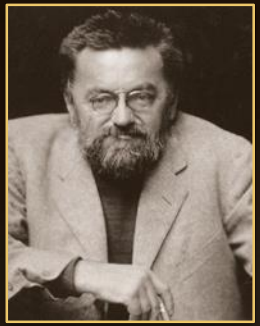
GE Energy Consulting

Turning Knowledge Into Power

16 - 18 April 2019

Our **heritage** ...

Industry Pioneers who literally “wrote the book” on how to engineer and operate the interconnected electrical system we know today...



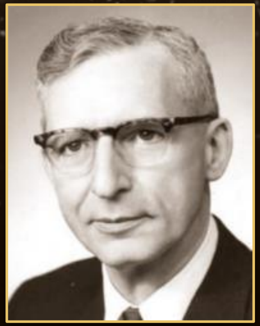
Charles **Steinmetz**

- Was One of the first employees of General Electric; started Energy Consulting in 1915 (named “Central Station Engineering”).
- Developed the theories and mathematical equations behind alternating current (AC).

Edith **Clarke**

- Was First woman professionally employed as an electrical engineer in the U.S.
- She was the first person to publish a mathematical examination of power lines longer than 300 miles.
- Invented the math that was the first step leading to the smart grid.

www.gereports.com/edith-clarke-mother-of-invention



Charles **Concordia**

- Joined GE in 1926 and in the 1940’s became Energy Consulting & GE's consultant to public utilities.
- Focused on large scale computing devices to model the economic and technical operations of the large-scale grid systems.
- Authored 1944 paper "Steady State Stability of Synchronous Machines as Affected by Voltage-Regulator Characteristics”, one of the most cited papers in the utility industry. The concepts in this paper are now represented and used worldwide as part of EC’s PSLF software

www.geenergyconsulting.com/practice-area/software-products

Energy Consulting ... the **first 100 years**

Birth of an Industry

Thomson Houston Co.
Power & Mining Dept.

April 15, 1892:
GE formed by merger of Edison General Electric and Thomson Houston

Central Station Engineering

Infrastructure Growth

Central Station Engineering with Analytical Engineering

Combined Electric Utility & Industrial Application Engineering

Large Centralized Gen. Stations & EHV Regional Grids

Electric Utility Engineering Operation

Oil Embargo

Electric Utility Systems Engineering Department

Stagnation

Systems Development & Engineering Department

Deregulation

Power Systems Energy Consulting

Competition

Energy Consulting

1880s 1920s 1930s 1950s 1960s 1970s 1980s 1990s 21st Century

Market **challenges** drive the **need for energy consulting**

- There are nearly **1 billion people globally without access to reliable, affordable and efficient electric power**
- The **economics and operations of the electric power systems globally are changing drastically** with the increased penetration of low cost, intermittent and variable renewable generation
- **New policies and business models are shaping the utility** of the future, with more focus on distributed energy resources
- **Grid systems that weren't originally designed for this changing landscape** need detailed planning and protection to ensure reliable, affordable and efficient energy is available when and where it's needed

Systems engineers **solving challenges** that deliver customer value

SERVICES

POWER ECONOMICS

- Power systems strategy
- Energy financial analytics
- Energy Systems Transformation

POWER SYSTEMS OPERATIONS & PLANNING

- Systems Engineering & Equipment Applications
- Renewables

GENERATION PRODUCTS & SERVICES

- Grid Code Compliance Testing
- Specialty Hardware, Protection & Controls

VALUE OUTCOME

Profitable and **sustainable** investment strategy

Compliant and **reliable** from concept to engineered design

Project life-cycle testing and compliance

PRODUCTS

All powered by **cutting-edge software technology**

PSLF* **MAPS*** **MARS***

CONCORDA* Software Suite

TAILORED Power Systems and Energy Course: Longest running energy executive development program

Solving our customers **toughest** electrical systems **challenges**

Protect customer operations (Newmont Mining, Nevada, U.S.A)

CUSTOMER SITUATION

- Mining customer uses on-site generation to provide efficient, reliable and economical power to the site
- Generation is connected to the local grid, and excess power is sold back to the utility

CHALLENGE

- Utility adds series capacitors to the grid
- These Could expose customer's generators to severe system disruptions
- These disruptions could cause torsional stresses that could result on-site generation to break risking an outage and lost revenue

GE SOLUTION

- GE Energy Consulting engineers, designs and installs blocking filter technology to minimize system disruptions from the grid
- The customer's Generation equipment is protected, the outage is avoided, saving time and money

Saved millions of dollars in potential repairs and down-time

Renewables integration (Pan-Canadian Wind Integration Study)

CUSTOMER SITUATION

- Canada has high quality wind resources nation-wide
- Canadian policy makers and planners are interested in understanding impact of higher penetration of wind energy in their power systems, going from 5% now up to 35% by 2025

CHALLENGE

- Canadian grid is run provincially
- Need to understand how to most effectively integrate large amounts of wind within the provinces
- Identifying the impact of higher wind penetration on power system operations, dispatch of thermal generation, fossil fuel consumption, and carbon emissions

GE SOLUTION

- GE Energy Consulting conducts the first-ever nationwide analysis of wind energy integration
- Analysis shows Canada can get more than one-third of its electricity from wind without compromising grid reliability, while reducing greenhouse gas emissions and generating new export opportunities

GE system planning & **modeling expertise** provides a roadmap to help achieve renewables integration objectives across Canada

Microgrids & grid resiliency (National Grid Potsdam Microgrid Project, Potsdam NY, U.S.A)

CUSTOMER SITUATION

- Mission critical facilities in Potsdam, NY, as well as Clarkson University and SUNY Potsdam get affordable, reliable and efficient power from the traditional interconnected grid
- These facilities traditionally have some back-up generation capabilities

CHALLENGE

- A sever winter storm damaged several parts of the electric grid in the town, putting facilities with critical power needs at risk
- Power was interrupted in some cases for a few hours and the grid was unavailable for several days in some places
- In many cases back-up power wasn't sufficient

GE SOLUTION

- Conducted technical and economic studies to assess the feasibility of a microgrid solution
- Developing technology design and cost estimates, as well as an advanced microgrid controller for the project in collaboration with National Grid to provide reliable and efficient power

GE and its partners are developing resilient microgrid with a first of its kind microgrid-specific controller

Power Island **protection, controls & compliance** (Major LNG Import/Export Terminal, Texas, U.S.A)

CUSTOMER SITUATION

- LNG plant customer could potentially draw electricity from the grid
- The customer pays predetermined wholesale rates to utility
- The plant could be out of commission if electric grid is damaged, costing time and money

CHALLENGE

- Customer chose to develop its own islanded power on-site to ensure reliable, efficient and affordable power
- On-site power requires complex electrical systems to serve loads
- The on-site Connected is to the grid and needs to be grid code compliant

GE SOLUTION

- Conducting electrical systems studies and designing the complex electrical systems for the customer
- Developing and designing protections
- Ensuring power system is grid code compliant

GE's systems engineers help enhance plant efficiency while helping ensure compliance

A **Blueprint** for **Hybrid Grid-Scale Renewable Energy** (IL&FS Development)

CUSTOMER SITUATION	CHALLENGE	GE SOLUTION
		
• India has set an ambitious goal of increasing renewable capacity to 175GW by 2022. • Technical and commercial feasibility of an integrated wind, solar and energy storage (IWSES) plant with combined generation capacity of more than 1,200MW evaluation is needed.	• Efficient use of existing land and grid infrastructure, while also having a better generation profile • Renewables intermittency and variability • A number of regulatory and grid code adjustments necessary to make a hybrid wind, solar and battery plant like this operate at it's best	• Provided a Blueprint for Developing the Financial & Technical Elements of an Integrated Wind, Solar & Storage Plant • Addressed challenges by connecting and siting wind, solar and battery storage together all in the same place, and laying out the business case to make it economically viable

GE provides insights on global emissions reductions around the world while helping ensure economic viability

Defining the **Value of Distributed Solar** to a Utility (Colorado Springs Utilities)

CUSTOMER SITUATION

- Colorado statute requires that six percent of Springs Utilities retail electricity sales for the years 2015-2019 and 10 percent for the year 2020 and beyond are generated by renewable energy resources.
- Colorado Springs Utilities wanted to identify ways to mitigate potential cost-shifting between solar and non-solar customers within the same rate class, as distributed solar has grown in its service territory.

CHALLENGE

- Utilities often recover more of their costs through variable rather than fixed rates, even though their fixed costs may be much higher than their variable costs.
- Net metering essentially requires utilities to purchase electricity from customers at this variable rate even if it is higher than the value that the solar brings.
- Often utilities are required to purchase this generation whether it is needed or not, which can make it challenging to balance supply and demand.

GE SOLUTION

- Compared the impact of retaining net energy metering (NEM) versus other options for solar customers
- Determined alternative rate designs could more adequately recover the costs of serving solar customers, enabling Springs Utilities to more sustainably scale distributed solar and other DERs.
- One of the rate designs, Time Of Use (TOU), could incentivize customer behavior which can reduce overall cost

GE Energy Consulting supports local utilities with the benefits Distributed solar can bring to the grid

Global Grid Planning Insights in Emerging Markets (Myanmar)

CUSTOMER SITUATION

- Myanmar emerged from decades of international sanctions under a new political system and needed to build out infrastructure to achieve economic growth.
- The government needed to create and implement an electric power system master plan for the country.

CHALLENGE

- Model and plan the country's future grid, while helping ensure more people can get access to reliable, affordable and efficient energy.
- Educating the country's power systems engineers on how to conduct detailed generation, transmission and distribution planning and analysis.

GE SOLUTION

- Reviewed generation, transmission and distribution planning practices including production simulation, load flow, short circuit and contingency analysis.
- Provide training on best practices for developing electric power markets as well as the regulations that could govern them with the country's key stakeholders

GE Global Grid Planning: Connecting People to Power Around the World

Serving global customers with local expertise

WORLD - RENOWNED

More than 100 recognized electric power systems **industry experts**

INNOVATING & PIONEERING

More than 100 patents awarded in the **last 30 years**

INDUSTRY LEADERSHIP

3 IEEE Life Fellows, and one member of the U.S. National Academy of Engineering

VISIT, JOIN, FOLLOW …

VISIT our **Website**

GEEnergyConsulting.com

JOIN us on **LinkedIn**

Linkedin.com/GEEnergyConsulting

FOLLOW us on **Twitter**

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Probabilistic Reliability Methods

Adequacy vs Security

Resource Adequacy

Deals with the ability of a power system to adequately supply power and energy to satisfy customer demand.

- Steady state
- May or may not consider transmission adequacy

Security

Deals with the ability of a power system to respond to sudden disturbances.

- Dynamic
- Internal failures (network overload, voltage, instability)
- External Interference (physical or cyber attack)

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Most historical loss of load events have been caused by transmission security.

Hierarchal Levels in Power System Reliability Planning

Level 1

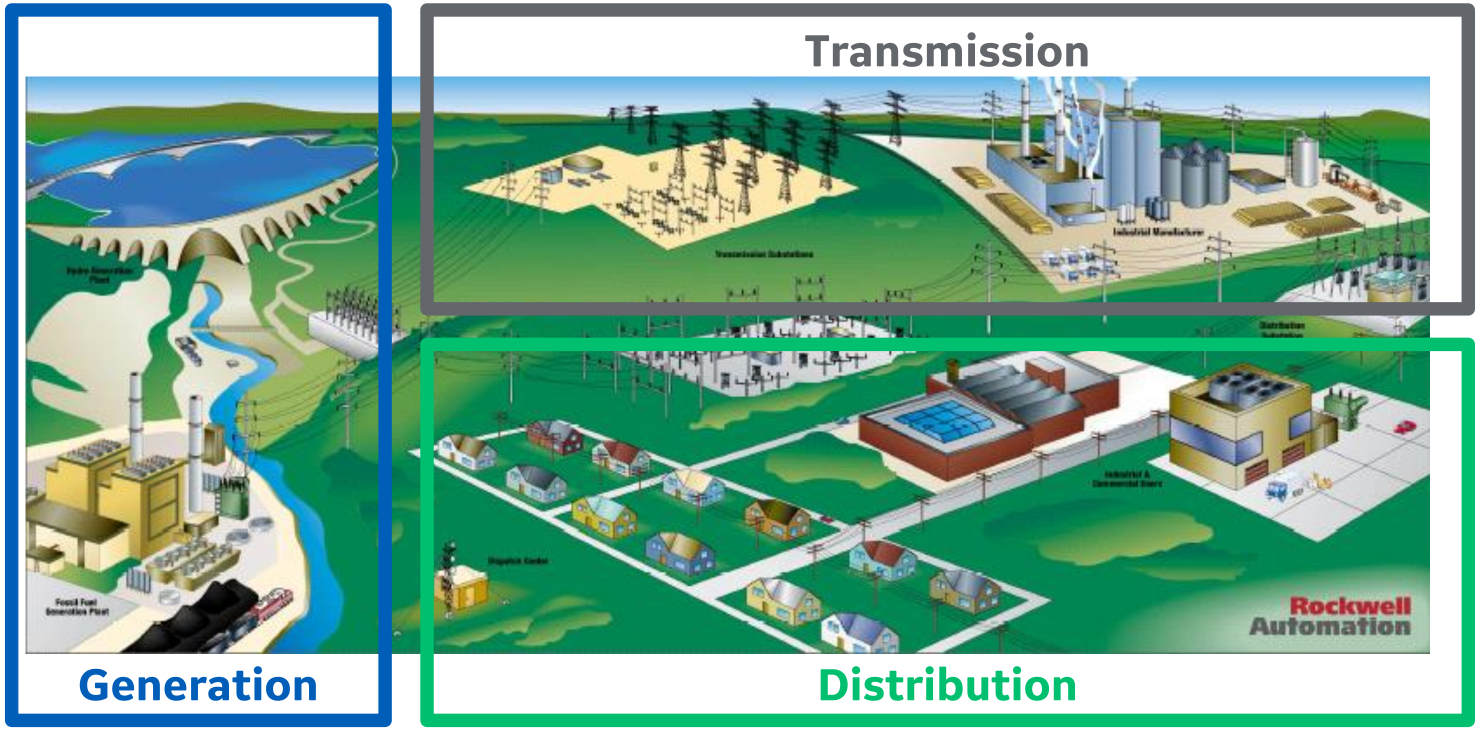
Generation Only

Level 2

Generation and Transmission

Level 3

Generation, Transmission and Distribution



Hierarchal Levels in Power System Reliability Evaluation

Level 1

The ability of the generation facilities, to satisfy the system load requirement

Level 2

The ability of the generation and transmission facilities to satisfy the load requirements at major load points

Hierarchal Levels in Power System Reliability Evaluation

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Less common and may have widespread and potentially catastrophic consequences

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The ability of the generation and transmission facilities to satisfy the load requirements at major load points

Level 3

The ability of the generation, transmission, and distribution facilities to satisfy individual customer load requirements

Less common and may have widespread and potentially catastrophic consequences

Hierarchal Levels in Power System Reliability Evaluation

Level 1

The ability of the generation facilities, to satisfy the system load requirement

Level 2

The ability of the generation and transmission facilities to satisfy the load requirements at major load points

Level 3

The ability of the generation, transmission, and distribution facilities to satisfy individual customer load requirements

Less common and may have widespread and potentially catastrophic consequences

More common but localized

Approaches to Power System Reliability Evaluation

Deterministic

Qualitative measures

Short-term operating indices

- Reserve % of load
- Largest Unit's Capacity of reserve

Probabilistic

Quantitative

Long-term planning indices

- Loss of Load Probability (LOLP)
- Daily and Hourly Loss of Load Expectation (LOLE)
- Loss of Energy Expectation (LOEE – also referred to as Expected Unserved Energy or EUE)

Approaches to Power System Reliability Evaluation

Deterministic

Qualitative measures

Short-term operating indices

- Reserve % of load
- Largest Unit's Capacity of reserve

Should not be used to compare the RELATIVE adequacy of different systems

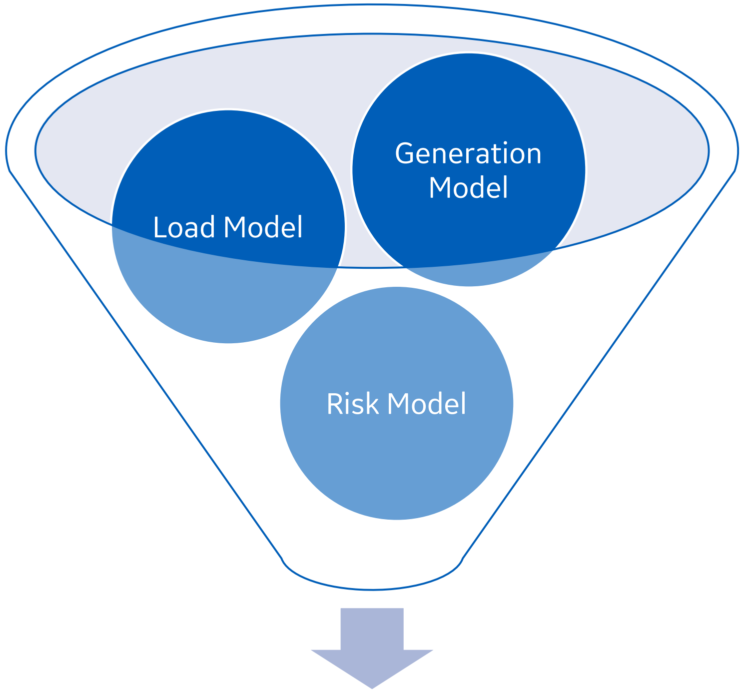
Probabilistic

Quantitative

Long-term planning indices

- Loss of Load Probability (LOLP)
- Daily and Hourly Loss of Load Expectation (LOLE)
- Loss of Energy Expectation (LOEE – also referred to as Expected Unserved Energy or EUE)

Basic Approach



Calculated Adequacy Indices

Generation Adequacy evaluations are fundamentally the same for any approach used.

Generation and Load Models are combined, or convolved, with an appropriate risk model to calculate system adequacy indices.

Transmission limitations and reliability may or may not be included. Thus, the calculated indices are not meant to reflect generation deficiencies at any specific load point, rather they measure the overall adequacy of the system.

Analytical Method

- Capacity Outage Probability Table (COPT) is built for each area in the model using a recursive convolution of generator capacities and forced outage rates
- This COPT is compared to the load in each hour of the year (or peak hour of each day for Daily LOLE) to determine the probability that there is less capacity available in that hour than the load
- Daily Loss of Load Expectation can not be inferred from hourly calculations. Similarly, Duration and size of events cannot be determined.
- Transmission limitations between areas can be evaluated, but significantly increases the computational intensity

Simulation Method

Monte-Carlo Simulation

Stochastic simulation, commonly referred to as Monte-Carlo simulation, is an alternative to the analytical method which ***estimates*** reliability indices.

Unlike the analytic approach, there is no set mathematical representation for Monte-Carlo Simulation - it is instead based on a series of random numbers generated by a computer.

By taking random samples of various system operating conditions, an estimate of the system reliability can be obtained without knowing an exact numerical formulation.

If the number of samples is sufficiently large, the simulation method should converge to a value very near the analytic.

Probabilistic Methods

Analytical

Represent reliability using a direct numerical model of the system

Simulation

Represent reliability by simulating trials of the actual random behavior of the system

Probabilistic Methods

Analytical

Represent reliability using a direct numerical model of the system

Provide expectation indices in a short period of time

Simulation

Represent reliability by simulating trials of the actual random behavior of the system

Can theoretically take into account all aspects of system operation and planning

Can provide frequency and duration metrics which are not readily available using analytical methods

Can represent systems where past history impacts the present condition

Probabilistic Methods

Analytical	Simulation
Represent reliability using a direct numerical model of the system	Represent reliability by simulating trials of the actual random behavior of the system
Provide expectation indices in a short period of time	Can theoretically take into account all aspects of system operation and planning
Simplifying assumptions are often needed to develop analytical models	Can provide frequency and duration metrics which are not readily available using analytical methods
Evaluation of complex systems and complex operating procedures cannot easily be represented	Can represent systems where past history impacts the present condition
Incorporating transmission interconnection can be computationally expensive	For simple systems will likely require more computation

Analytical Method

Generation Model

Capacity Outage Probability Table (COPT)

A generation model consisting of a simple array of capacity levels and the and the probability of the system existing at that level

For a system where all units are identical the COPT can be calculated using a binomial distribution.

$$P(x = r) = {}_{n}C_{r}\, p^{r} q^{n-r}$$

$$n = total\ number\ of\ states$$
$$r = the\ current\ state$$
$$p = probability\ of\ failure$$
$$q = probability\ of\ success = (1 - p)$$

$${}_{n}C_{r} = \frac{n!}{(n-r)!\,r!}$$

Generation Model

Capacity Outage Probability Table (COPT)

Assume a simple system consisting of two 50 MW units, each with identical forced outage rates of 5%

Units Out	Capacity Out	P(x=r)	Probability
0	0	${}_2C_0 \cdot (0.05)^0 \cdot (1\text{-}0.05)^{2-0}$	0.9025
1	50	${}_2C_1 \cdot (0.05)^1 \cdot (1\text{-}0.05)^{2-1}$	0.0950
2	100	${}_2C_0 \cdot (0.05)^2 \cdot (1\text{-}0.05)^{2-2}$	0.0025

Generation Model

Capacity Outage Probability Table (COPT)

In practical systems, it is highly unlikely that that all units in the system will be identical. The binomial distribution approach has limited functional application.

The same result can be achieved by enumerating the capacity states for each unit and combining the probability of each state.

Generation Model

Capacity Outage Probability Table (COPT)

Unit 1 Capacity Out	Unit 2 Capacity Out	Total Capacity Out		Probability
0	0	0	(1-0.05) · (1-0.05)	0.9025
50	0	50	(0.05) · (1-0.05)	0.0475
0	50	50	(1-0.05) · (0.05)	0.0475
50	50	100	(0.05) · (0.05)	0.0025

Generation Model

Capacity Outage Probability Table (COPT)

Capacity Out	Binomial Distribution	State Enumeration
0	0.9025	0.9025
50	0.0950	0.0950
100	0.0025	0.0025

Combining the enumerated capacity states with the same capacity yields identical probabilities to the binomial distribution approach.

Generation Model

Capacity Outage Probability Table (COPT)

Capacity Out	Binomial Distribution	State Enumeration
0	0.9025	0.9025
50	0.0950	0.0950
100	0.0025	0.0025

Each row in the capacity outage probability table can be interpreted as the probability that ***EXACTLY*** the indicated amount of capacity is unavailable.

Generation Model

Capacity Outage Probability Table (COPT)

Capacity Out	Binomial Distribution	State Enumeration	Cumulative Probability
0	0.9025	0.9025	1.0000
50	0.0950	0.0950	0.0975
100	0.0025	0.0025	0.0025

By adding a cumulative probability to the table we can ascertain the probability that the capacity on outage is greater than or equal to the indicated amount.

Generation Model

Recursive Convolution

The cumulative probability of a capacity outage state after a unit of capacity C is added can be represented using a simple recursive algorithm

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$

Where $P'(X)$ is the is the cumulative probability of capacity X being on outage before the unit is added

Generation Model

Recursive Convolution

Add the first 50 MW Unit; C = 50, FOR = 0.05

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(0) = (1 - 0.05) \cdot P'(0) + 0.05 \cdot P'(0 - 50)$$

The probability that the capacity on outage is greater than or equal to X (0 MW) before the first unit is added is 1.0 – i.e. P'(X) = P'(0) = 1.0

Generation Model

Recursive Convolution

Add the first 50 MW Unit; C = 50, FOR = 0.05

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(0) = (1 - 0.05) \cdot P'(0) + 0.05 \cdot P'(0 - 50)$$

The probability that the capacity on outage is greater than or equal to X (0 MW) before the first unit is added is 1.0 – i.e. P'(X) = P'(0) = 1.0

Similarly the probability that the capacity on outage is greater than X-C (0-50 = -50 MW) before the first unit is added is also 1.0 – i.e. P'(X-C) = P'(-50) = 1.0

Generation Model

Recursive Convolution

Add the first 50 MW Unit; C = 50, FOR = 0.05

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$

$$P(0) = (1 - 0.05) \cdot P'(0) + 0.05 \cdot P'(0 - 50)$$

$$P(0) = (1 - 0.05) \cdot 1.0 + 0.05 \cdot 1.0 = 1.0$$

Generation Model

Recursive Convolution

Add the first 50 MW Unit; C = 50, FOR = 0.05

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(0) = (1 - 0.05) \cdot P'(0) + 0.05 \cdot P'(0 - 50)$$
$$P(0) = (1 - 0.05) \cdot 1.0 + 0.05 \cdot 1.0 = 1.0$$

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(50) = (1 - 0.05) \cdot P'(50) + 0.05 \cdot P'(50 - 50)$$

Before the first unit is added, the probability that the capacity on outage is greater than or equal to X (50 MW) is 0.0 – i.e. P'(X) = P'(50) = 0.0

Generation Model

Recursive Convolution

Add the first 50 MW Unit; C = 50, FOR = 0.05

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(0) = (1 - 0.05) \cdot P'(0) + 0.05 \cdot P'(0 - 50)$$
$$P(0) = (1 - 0.05) \cdot 1.0 + 0.05 \cdot 1.0 = 1.0$$

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(50) = (1 - 0.05) \cdot P'(50) + 0.05 \cdot P'(50 - 50)$$

Before the first unit is added, the probability that the capacity on outage is greater than or equal to X (50 MW) is 0.0 – i.e. P'(X) =P'(50) = 0.0

As above, the probability that the capacity on outage is greater than X-C (50-50 = 0 MW) before the first unit is added is 1.0 – i.e. P'(X-C) = P'(0) = 1.0

Generation Model

Recursive Convolution

Add the first 50 MW Unit; C = 50, FOR = 0.05

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$

$$P(0) = (1 - 0.05) \cdot P'(0) + 0.05 \cdot P'(0 - 50)$$

$$P(0) = (1 - 0.05) \cdot 1.0 + 0.05 \cdot 1.0 = 1.0$$

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$

$$P(50) = (1 - 0.05) \cdot P'(50) + 0.05 \cdot P'(50 - 50)$$

$$P(50) = (1 - 0.05) \cdot 0.0 + 0.05 \cdot 1.0 = 0.05$$

Generation Model

Recursive Convolution

Add the first 50 MW Unit; C = 50, FOR = 0.05

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(0) = (1 - 0.05) \cdot P'(0) + 0.05 \cdot P'(0 - 50)$$
$$P(0) = (1 - 0.05) \cdot 1.0 + 0.05 \cdot 1.0 = 1.0$$

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(50) = (1 - 0.05) \cdot P'(50) + 0.05 \cdot P'(50 - 50)$$
$$P(50) = (1 - 0.05) \cdot 0.0 + 0.05 \cdot 1.0 = 0.05$$

Add the second 50 MW Unit; C = 50, FOR = 0.05

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(0) = (1 - 0.05) \cdot P'(0) + 0.05 \cdot P'(0 - 50)$$
$$P(0) = (1 - 0.05) \cdot 1.0 + 0.05 \cdot 1.0 = 1.0$$

Generation Model

Recursive Convolution

Add the first 50 MW Unit; C = 50, FOR = 0.05

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(0) = (1 - 0.05) \cdot P'(0) + 0.05 \cdot P'(0 - 50)$$
$$P(0) = (1 - 0.05) \cdot 1.0 + 0.05 \cdot 1.0 = 1.0$$

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(50) = (1 - 0.05) \cdot P'(50) + 0.05 \cdot P'(50 - 50)$$
$$P(50) = (1 - 0.05) \cdot 0.0 + 0.05 \cdot 1.0 = 0.05$$

Add the second 50 MW Unit; C = 50, FOR = 0.05

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(0) = (1 - 0.05) \cdot P'(0) + 0.05 \cdot P'(0 - 50)$$
$$P(0) = (1 - 0.05) \cdot 1.0 + 0.05 \cdot 1.0 = 1.0$$

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(50) = (1 - 0.05) \cdot P'(50) + 0.05 \cdot P'(50 - 50)$$

Before the second unit is added, the probability that the capacity on outage is greater than or equal to X (50 MW) is 0.05 – i.e. P'(X) = P'(50) = 0.05

Generation Model

Recursive Convolution

Add the first 50 MW Unit; C = 50, FOR = 0.05

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(0) = (1 - 0.05) \cdot P'(0) + 0.05 \cdot P'(0 - 50)$$
$$P(0) = (1 - 0.05) \cdot 1.0 + 0.05 \cdot 1.0 = 1.0$$

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(50) = (1 - 0.05) \cdot P'(50) + 0.05 \cdot P'(50 - 50)$$
$$P(50) = (1 - 0.05) \cdot 0.0 + 0.05 \cdot 1.0 = 0.05$$

Add the second 50 MW Unit; C = 50, FOR = 0.05

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(0) = (1 - 0.05) \cdot P'(0) + 0.05 \cdot P'(0 - 50)$$
$$P(0) = (1 - 0.05) \cdot 1.0 + 0.05 \cdot 1.0 = 1.0$$

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(50) = (1 - 0.05) \cdot P'(50) + 0.05 \cdot P'(50 - 50)$$
$$P(50) = (1 - 0.05) \cdot 0.05 + 0.05 \cdot 1.0 = 0.0975$$

Generation Model

Recursive Convolution

Add the first 50 MW Unit; C = 50, FOR = 0.05

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(0) = (1 - 0.05) \cdot P'(0) + 0.05 \cdot P'(0 - 50)$$
$$P(0) = (1 - 0.05) \cdot 1.0 + 0.05 \cdot 1.0 = 1.0$$

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(50) = (1 - 0.05) \cdot P'(50) + 0.05 \cdot P'(50 - 50)$$
$$P(50) = (1 - 0.05) \cdot 0.0 + 0.05 \cdot 1.0 = 0.05$$

Add the second 50 MW Unit; C = 50, FOR = 0.05

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(0) = (1 - 0.05) \cdot P'(0) + 0.05 \cdot P'(0 - 50)$$
$$P(0) = (1 - 0.05) \cdot 1.0 + 0.05 \cdot 1.0 = 1.0$$

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(50) = (1 - 0.05) \cdot P'(50) + 0.05 \cdot P'(50 - 50)$$
$$P(50) = (1 - 0.05) \cdot 0.05 + 0.05 \cdot 1.0 = 0.0975$$

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(100) = (1 - 0.05) \cdot P'(100) + 0.05 \cdot P'(100 - 50)$$
$$P(100) = (1 - 0.05) \cdot 0.00 + 0.05 \cdot 0.05 = 0.0025$$

Generation Model

Recursive Convolution

Capacity Out	Binomial Distribution	State Enumeration	Cumulative Probability	Recursive Convolution
0	0.9025	0.9025	1.0000	1.0000
50	0.0950	0.0950	0.0975	0.0975
100	0.0025	0.0025	0.0025	0.0025

The recursive convolution approach yields the same cumulative probability table as the state enumeration and binomial distribution approaches.

Generation Model
Example

Calculate the cumulative probability distribution of the same system examined thus far after the addition of a 100 MW unit with a forced outage rate of 10%.

1) Use the state enumeration method
2) Use the recursive convolution

Generation Model

Example – Full State Enumeration

Unit 1 Capacity Out	Unit 2 Capacity Out	Unit 3 Capacity Out	Total Capacity Out		Probability
0	0	0	0	(1-0.05) · (1-0.05) · (1-0.10)	0.81225
50	0	0	50	(0.05) · (1-0.05) · (1-0.10)	0.04275
0	50	0	50	(1-0.05) · (0.05) · (1-0.10)	0.04275
50	50	0	100	(0.05) · (0.05) · (1-0.10)	0.00225
0	0	100	100	(1-0.05) · (1-0.05) · (0.10)	0.09025
50	0	100	150	(0.05) · (1-0.05) · (0.10)	0.00475
0	50	100	150	(1-0.05) · (0.05) · (0.10)	0.00475
50	50	100	200	(0.05) · (0.05) · (0.10)	0.00025

Generation Model

Example – Full State Enumeration

Total Capacity Out	Probability	Cumulative Probability
0	0.81225	1.00000
50	0.08550	0.18775
100	0.09250	0.10225
150	0.00950	0.00975
200	0.00025	0.00025

Generation Model

Example – Simplified State Enumeration

Unit 1 & 2 Capacity Out	Unit 1 & 2 Combined Probability	Unit 3 Capacity Out	Total Capacity Out		Probability
0	0.9025	0	0	$0.9025 \cdot (1\text{-}0.10)$	0.81225
50	0.0950	0	50	$0.0950 \cdot (1\text{-}0.10)$	0.08550
100	0.0025	0	100	$0.0025 \cdot (1\text{-}0.10)$	0.00225
0	0.9025	100	100	$0.9025 \cdot (0.10)$	0.09025
50	0.0950	100	150	$0.0950 \cdot (0.10)$	0.00950
100	0.0025	100	200	$0.0025 \cdot (0.10)$	0.00025

Generation Model

Example – Simplified State Enumeration

Total Capacity Out	Probability	Cumulative Probability
0	0.81225	1.00000
50	0.08550	0.18775
100	0.09250	0.10225
150	0.00950	0.00975
200	0.00025	0.00025

Generation Model

Example – Recursive Convolution

P(0), P(50), P(100)

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(0) = (1 - 0.10) \cdot P'(0) + 0.10 \cdot P'(0 - 50)$$
$$P(0) = (1 - 0.10) \cdot 1.0 + 0.10 \cdot 1.0 = 1.00000$$

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(50) = (1 - 0.10) \cdot P'(50) + 0.10 \cdot P'(50 - 50)$$
$$P(50) = (1 - 0.10) \cdot 0.0975 + 0.10 \cdot 1.0 = 0.18775$$

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(100) = (1 - 0.10) \cdot P'(100) + 0.05 \cdot P'(100 - 100)$$
$$P(100) = (1 - 0.10) \cdot 0.0025 + 0.10 \cdot 1.0 = 0.10255$$

P(150), P(200)

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(150) = (1 - 0.10) \cdot P'(150) + 0.10 \cdot P'(150 - 100)$$
$$P(150) = (1 - 0.10) \cdot 0.0 + 0.10 \cdot 0.0975 = 0.00975$$

$$P(X) = (1 - FOR) \cdot P'(X) + FOR \cdot P'(X - C)$$
$$P(200) = (1 - 0.10) \cdot P'(200) + 0.10 \cdot P'(200 - 100)$$
$$P(200) = (1 - 0.10) \cdot 0.0 + 0.10 \cdot 0.0025 = 0.00025$$

Load Model

The generation system discussed thus far can be convolved with a load model to determine loss of load indices in several ways

1) Constant Load
2) Daily Peak Load Variation Curve
3) Hourly Peak Load Duration Curve

Load Model
Constant Load

Assume a constant load of 160 MW

Total Capacity Out	Total Capacity Available	Probability	Cumulative Probability
0	200	0.81225	1.00000
50	150	0.08550	0.18775
100	100	0.09250	0.10225
150	50	0.00950	0.00975
200	0	0.00025	0.00025

Load Model
Constant Load

Assume a constant load of 160 MW

Total Capacity Out	Total Capacity Available	Probability	Cumulative Probability
0	200	0.81225	1.00000
50	150	0.08550	0.18775
100	100		
150	50		
200	0		

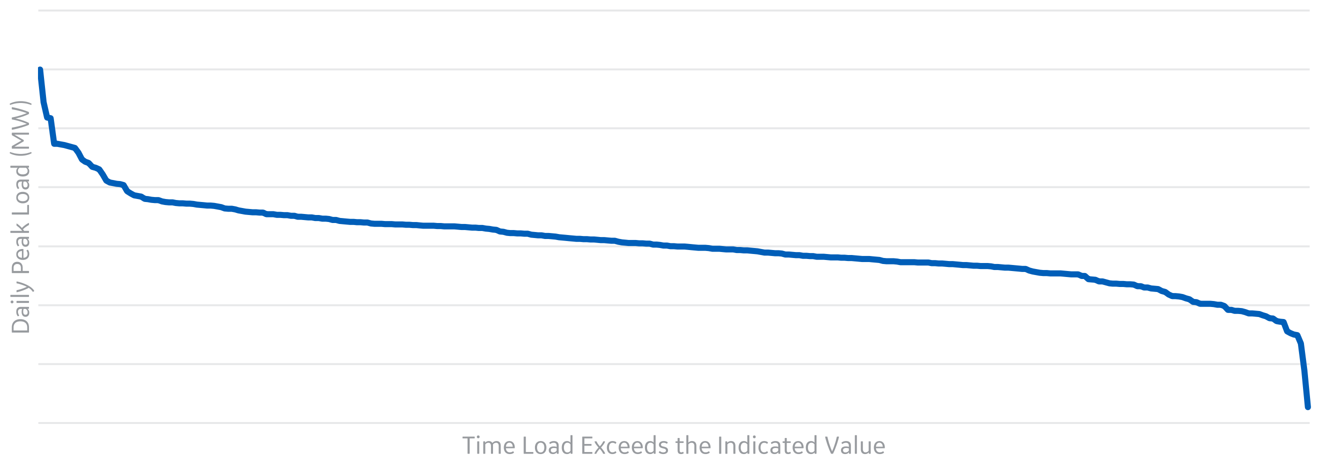
The probability that the total capacity available is less than 160 MW is 0.18775. The Loss of Load Probability (LOLP) is then said to be 0.18775.

Load Model

Daily Peak Load Variation Curve

A Daily Peak Load Variation Curve consists of each day of the year, represented by its peak load, and sorted from largest to smallest.

A Daily Peak Load Variation Curve can be interpreted as the amount of time daily peak load exceeds a given value.

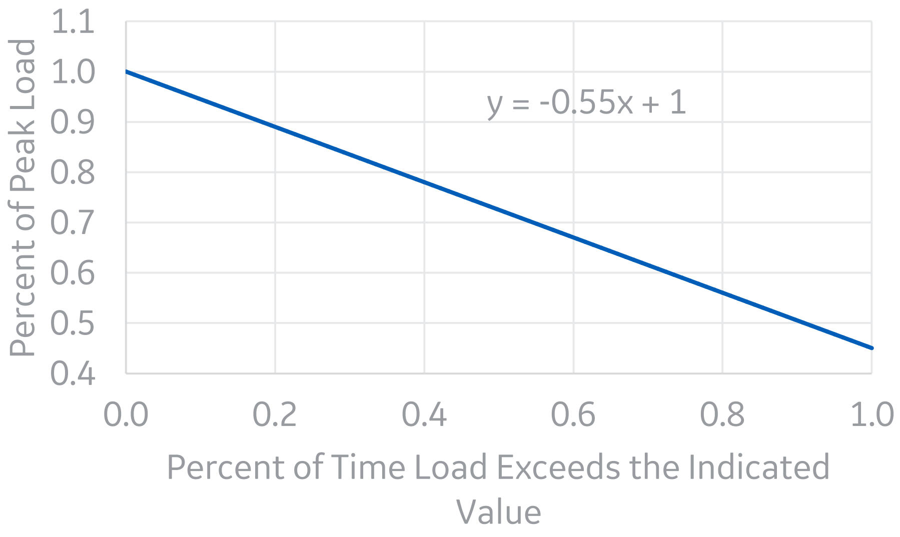


Load Model

Daily Peak Load Variation Curve

Assumed Daily Peak Load Variation

For simplicity of calculation, we will assume a linear daily peak load variation curve. As in the previous example a peak load of 160 MW will be assumed.

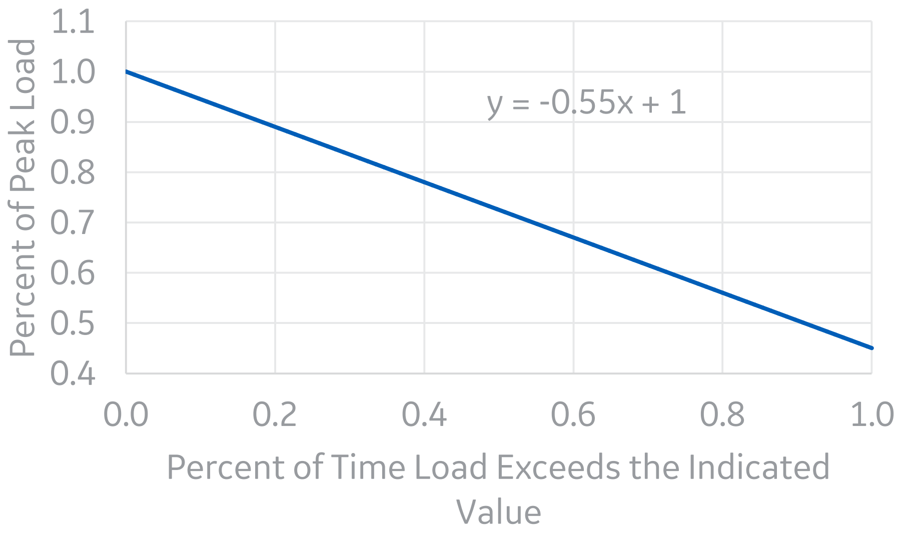


Load Model

Daily Peak Load Variation Curve

Assumed Daily Peak Load Variation

For simplicity of calculation, we will assume a linear daily peak load variation curve. As in the previous example a peak load of 160 MW will be assumed.



Loss of Load Calculation

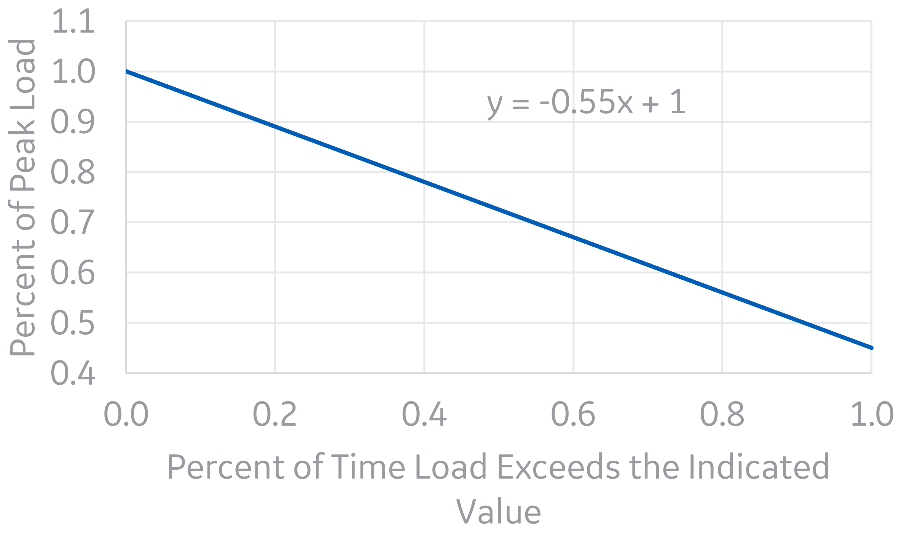
Using the assumed Daily Peak Load Variation Curve, the amount of time load exceeds available capacity can be calculated

$$t_k = \frac{\left(\frac{Capacity\ Available}{Peak\ Load}\right) - 1}{-0.55}$$

Load Model
Daily Peak Load Variation Curve

Assumed Daily Peak Load Variation

For simplicity of calculation, we will assume a linear daily peak load variation curve. As in the previous example a peak load of 160 MW will be assumed.



Loss of Load Calculation

Using the assumed Daily Peak Load Variation Curve, the amount of time load exceeds available capacity can be calculated

$$t_k = \frac{\left({Capacity\ Available}/{Peak\ Load}\right) - 1}{-0.55}$$

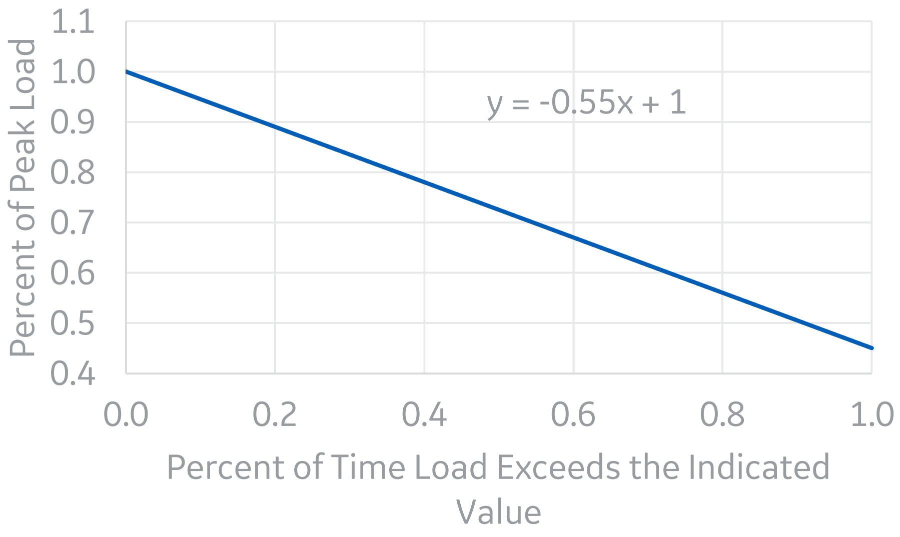
Total Capacity Available	% of Time
200	0.000
150	0.1136
100	0.6818
50	1.000
0	1.000

Load Model

Daily Peak Load Variation Curve

Assumed Daily Peak Load Variation

For simplicity of calculation, we will assume a linear daily peak load variation curve. As in the previous example a peak load of 160 MW will be assumed.



Loss of Load Calculation

Using the assumed Daily Peak Load Variation Curve, the amount of time load exceeds available capacity can be calculated

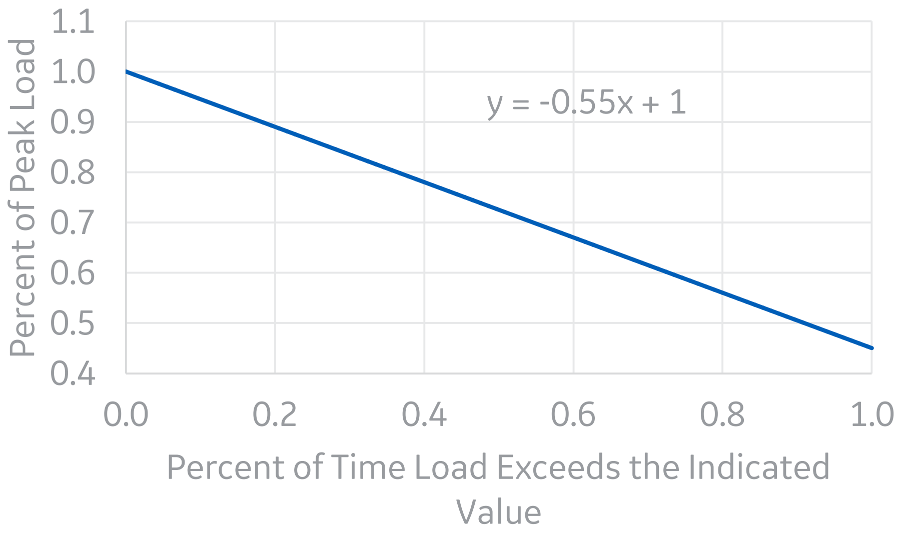
$$t_k = \frac{\left(\frac{Capacity\ Available}{Peak\ Load}\right) - 1}{-0.55}$$

Total Capacity Available	% of Time	Probability
200	0.000	0.81225
150	0.1136	0.08550
100	0.6818	0.09250
50	1.000	0.00950
0	1.000	0.00025

Load Model
Daily Peak Load Variation Curve

Assumed Daily Peak Load Variation

For simplicity of calculation, we will assume a linear daily peak load variation curve. As in the previous example a peak load of 160 MW will be assumed.



Loss of Load Calculation

Using the assumed Daily Peak Load Variation Curve, the amount of time load exceeds available capacity can be calculated

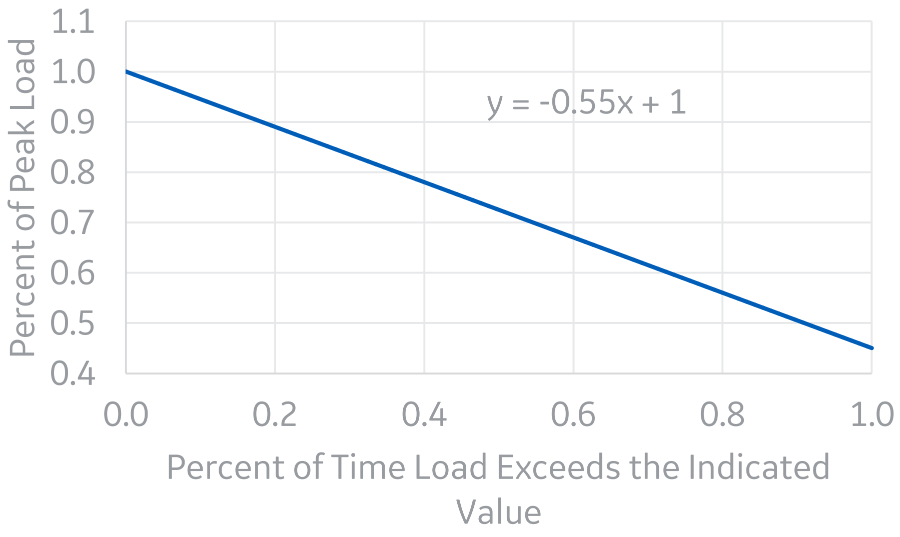
$$t_k = \frac{\left(\frac{Capacity\ Available}{Peak\ Load}\right) - 1}{-0.55}$$

Total Capacity Available	% of Time	Probability	LOLP
200	0.000	0.81225	
150	0.1136	0.08550	0.00971
100	0.6818	0.09250	0.06307
50	1.000	0.00950	0.00950
0	1.000	0.00025	0.00025

Load Model
Daily Peak Load Variation Curve

Assumed Daily Peak Load Variation

For simplicity of calculation, we will assume a linear daily peak load variation curve. As in the previous example a peak load of 160 MW will be assumed.



Loss of Load Calculation

Using the assumed Daily Peak Load Variation Curve, the amount of time load exceeds available capacity can be calculated

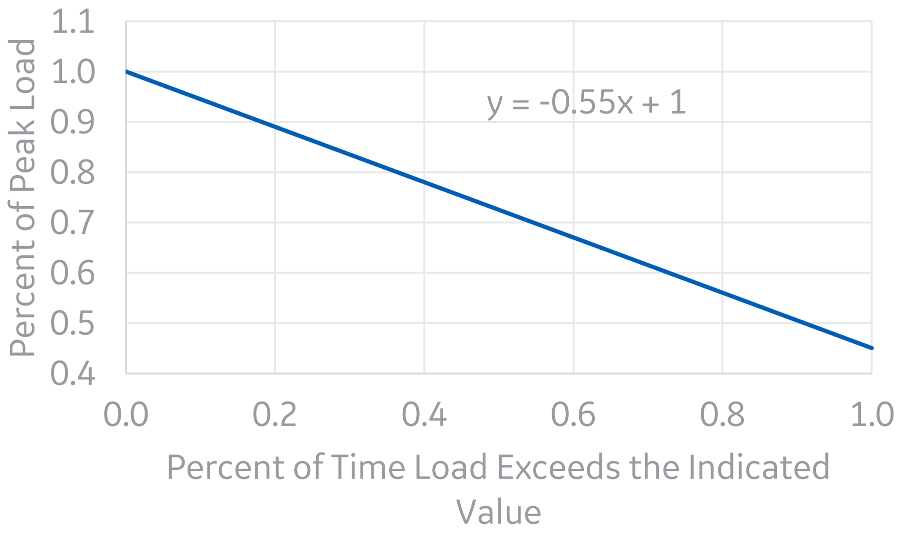
$$t_k = \frac{\left({Capacity\ Available}/{Peak\ Load}\right) - 1}{-0.55}$$

Total Capacity Available	% of Time	Probability	LOLP
200	0.000	0.81225	
150	0.1136	0.08550	0.00971
100	0.6818	0.09250	0.06307
50	1.000	0.00950	0.00950
0	1.000	0.00025	0.00025
		Total =	**0.08253**

Load Model
Daily Peak Load Variation Curve

Assumed Daily Peak Load Variation

For simplicity of calculation, we will assume a linear daily peak load variation curve. As in the previous example a peak load of 160 MW will be assumed.



Loss of Load Calculation

Using the assumed Daily Peak Load Variation Curve, the amount of time load exceeds available capacity can be calculated

$$t_k = \frac{\left({Capacity\ Available}/{Peak\ Load}\right) - 1}{-0.55}$$

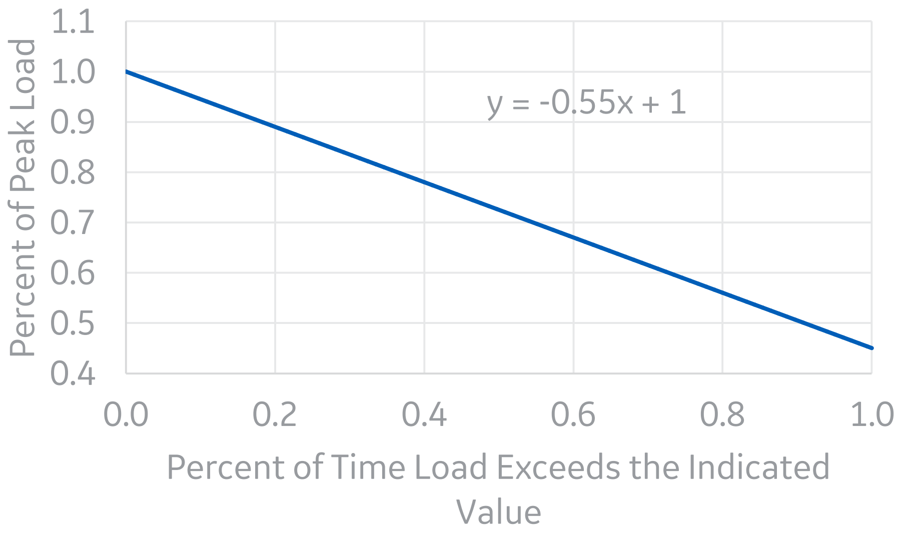
Total Capacity Available	% of Time	Probability	LOLP	LOLE (Days / Year)
200	0.000	0.81225		
150	0.1136	0.08550	0.00971	3.5
100	0.6818	0.09250	0.06307	23.0
50	1.000	0.00950	0.00950	3.5
0	1.000	0.00025	0.00025	0.1
		Total =	**0.08253**	

Load Model

Daily Peak Load Variation Curve

Assumed Daily Peak Load Variation

For simplicity of calculation, we will assume a linear daily peak load variation curve. As in the previous example a peak load of 160 MW will be assumed.



Loss of Load Calculation

Using the assumed Daily Peak Load Variation Curve, the amount of time load exceeds available capacity can be calculated

$$t_k = \frac{\left({Capacity\ Available}/{Peak\ Load}\right) - 1}{-0.55}$$

Total Capacity Available	% of Time	Probability	LOLP	LOLE (Days / Year)
200	0.000	0.81225		
150	0.1136	0.08550	0.00971	3.5
100	0.6818	0.09250	0.06307	23.0
50	1.000	0.00950	0.00950	3.5
0	1.000	0.00025	0.00025	0.1
		Total =	**0.08253**	**30.1**

Load Model
Load Duration Curve

Hourly Loss of Load metrics can be calculated using a similar approach to the Daily Peak Variation Curve model

A Load Duration Curve can be generated by sorting the hourly chronological load from largest to smallest

This can be similarly interpreted as the percentage of time the hourly load exceeds the indicated load value

Load Model
Load Duration Curve

Hourly Loss of Load metrics can be calculated using a similar approach to the Daily Peak Variation Curve model

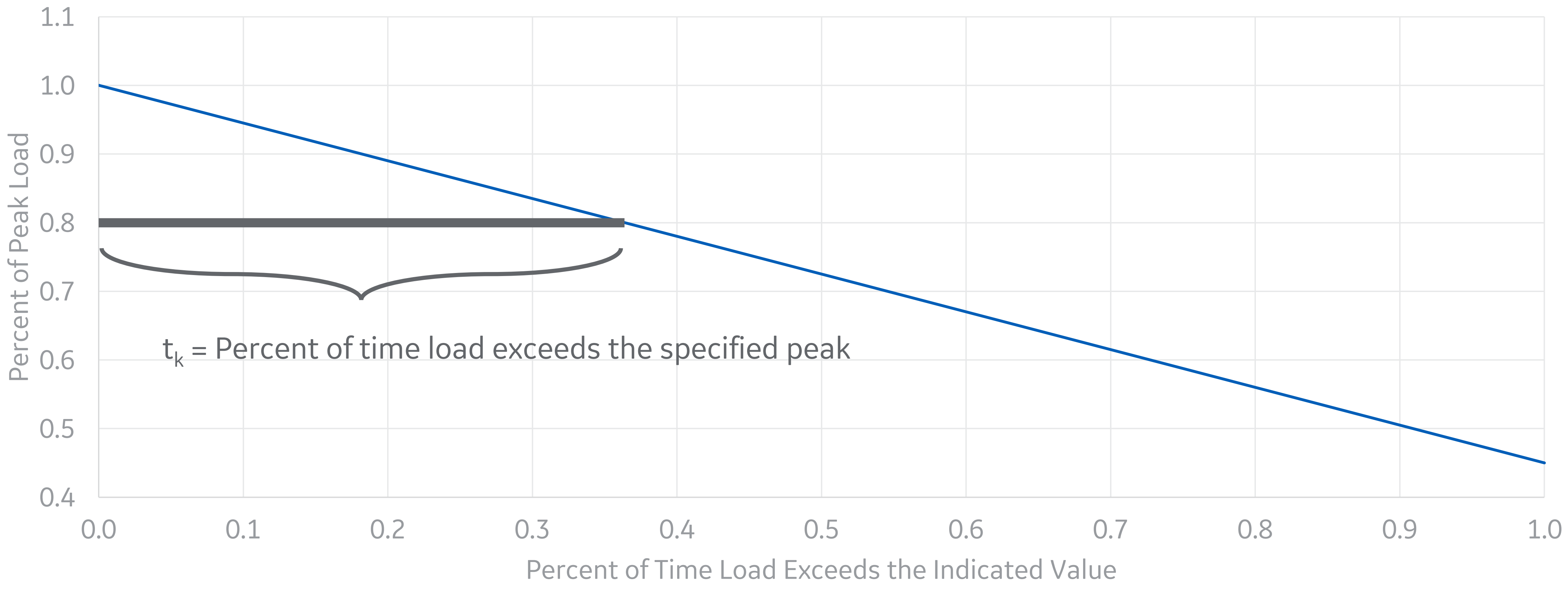
A Load Duration Curve can be generated by sorting the hourly chronological load from largest to smallest

This can be similarly interpreted as the percentage of time the hourly load exceeds the indicated load value

Daily Loss of Load metrics cannot be inferred from these calculations

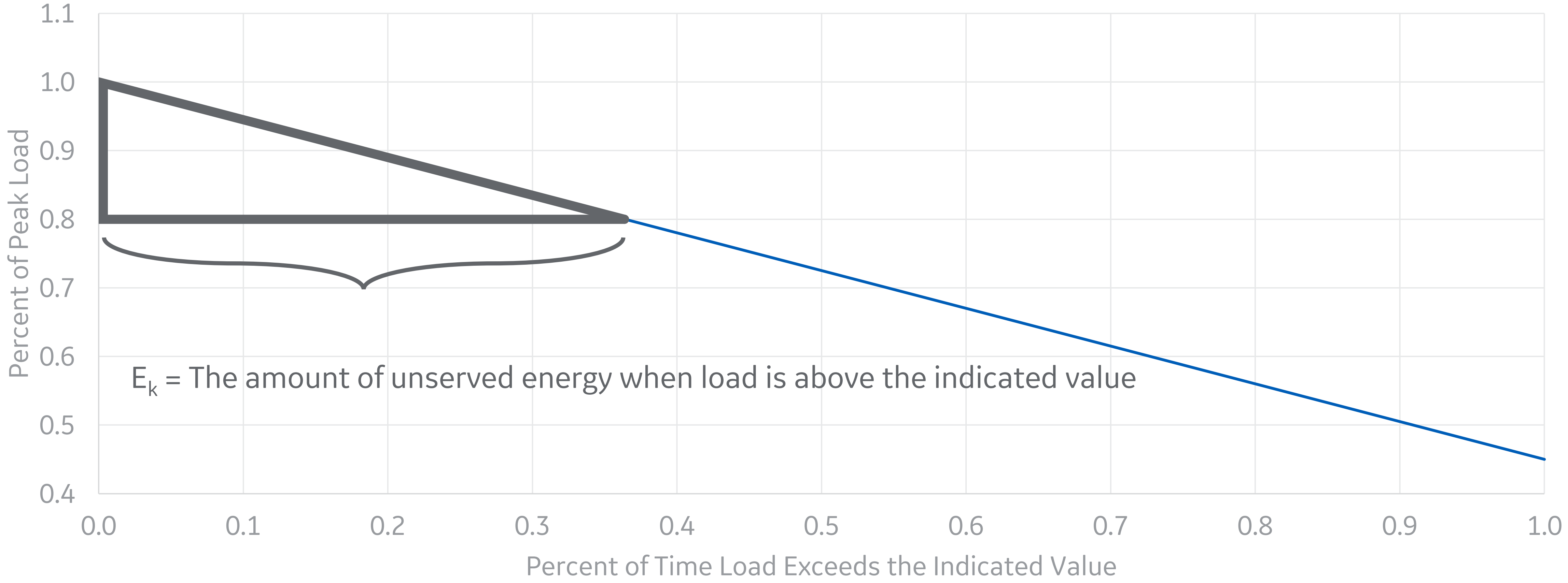
Load Model

Load Duration Curve



Load Model

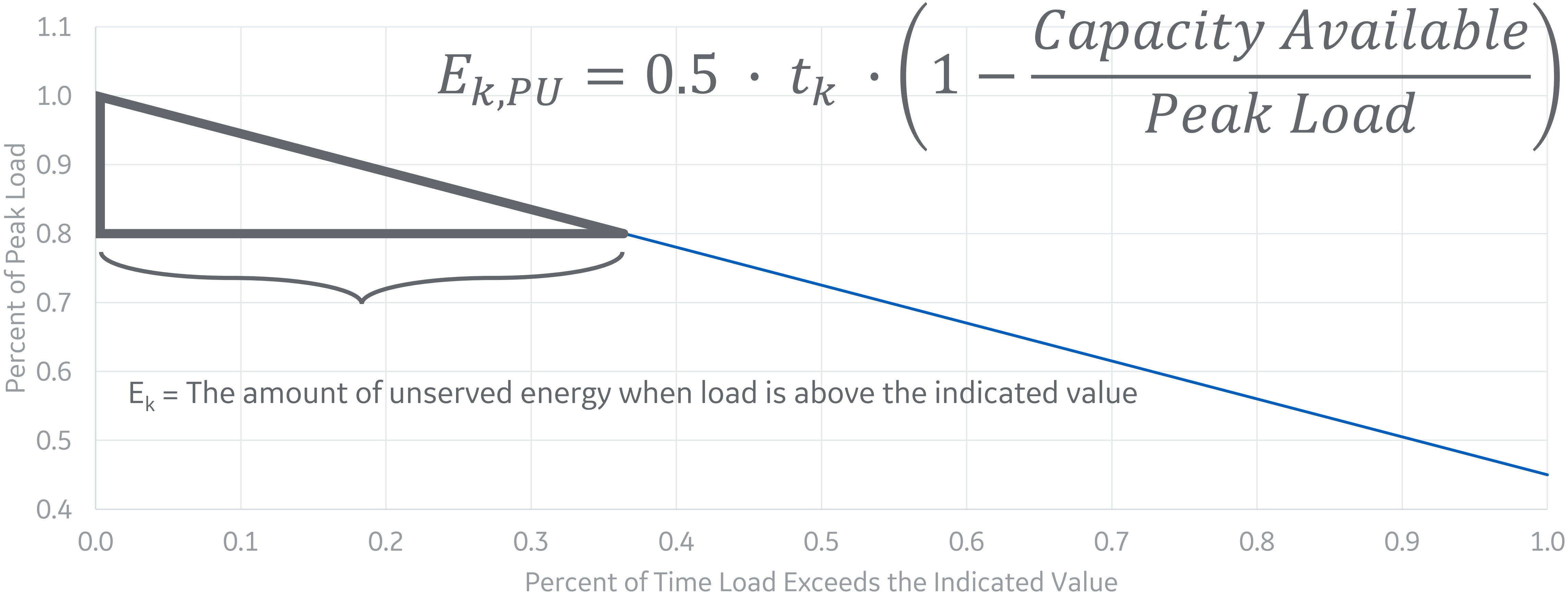
Loss of Energy Expectation



Load Model

Loss of Energy Expectation

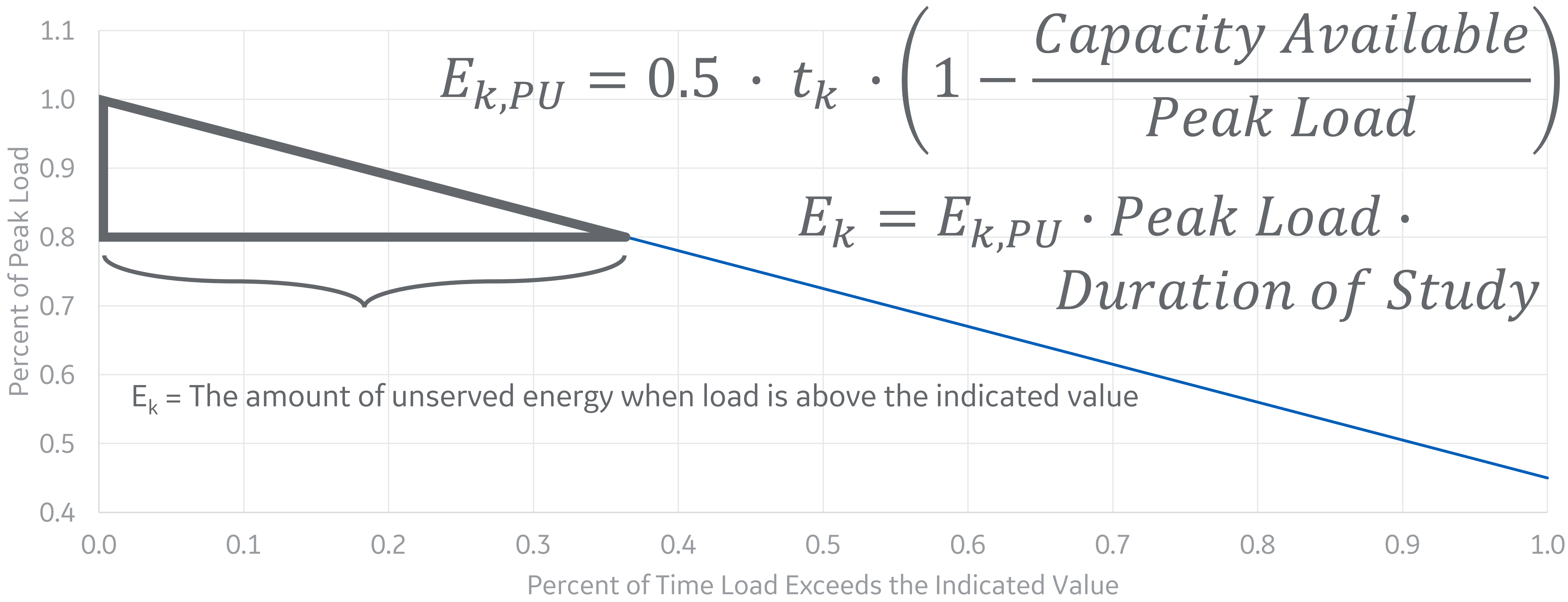
$$E_{k,PU} = 0.5 \cdot t_k \cdot \left(1 - \frac{Capacity\ Available}{Peak\ Load}\right)$$



E_k = The amount of unserved energy when load is above the indicated value

Load Model

Loss of Energy Expectation



$$E_{k,PU} = 0.5 \cdot t_k \cdot \left(1 - \frac{Capacity\ Available}{Peak\ Load}\right)$$

$$E_k = E_{k,PU} \cdot Peak\ Load \cdot Duration\ of\ Study$$

E_k = The amount of unserved energy when load is above the indicated value

Load Model

Loss of Energy Expectation

Total Capacity Available	% of Time	$E_{k,PU}$	E_k
200	0.0000	0.0000	0
150	0.1136	0.0036	4,976
100	0.6818	0.1278	179,177
50	1.0000	0.3438	481,800
0	1.0000	0.5000	700,800

Load Model

Loss of Energy Expectation

Total Capacity Available	% of Time	$E_{k,PU}$	E_k	Probability	LOEE (MWh / Year)
200	0.0000	0.0000	0	0.81225	0
150	0.1136	0.0036	4,976	0.08550	425
100	0.6818	0.1278	179,177	0.09250	16,574
50	1.0000	0.3438	481,800	0.00950	4,577
0	1.0000	0.5000	700,800	0.00025	175
				Total =	**21,752**

Analytic Method Example

For each sample system:

1) Create a Capacity Outage Probability Table
   - *All units will be identical so you may use the binomial distribution approach*
   - *You may ignore any combination of outages for which probability < 10^{-6}*
2) Assuming a linear Load Duration Curve for 8760 hours ranging from 30% of peak to 100% of peak, calculate the following for each of the two load conditions specified
   a) Loss of Load Probability (LOLP)
   b) Hourly Loss of Load Expectation (Hourly LOLE)
   c) Loss of Energy Expectation (LOEE)

Analytic Method Example

System 1

20 identical generators

- 10% FOR
- 10 MW Capacity

Condition 1:

150 MW Peak Load

Condition 2:

10% Reserve Margin (Peak Load = 90% of Capacity)

System 2

10 identical generators

- 5% FOR
- 20 MW Capacity

Condition 1:

150 MW Peak Load

Condition 2:

10% Reserve Margin (Peak Load = 90% of Capacity)

System 3

16 identical generators

- 15% FOR
- 25 MW Capacity

Condition 1:

250 MW Peak Load

Condition 2:

20% Reserve Margin (Peak Load = 80% of Capacity)

System 4

8 identical generators

- 9% FOR
- 50 MW Capacity

Condition 1:

250 MW Peak Load

Condition 2:

20% Reserve Margin (Peak Load = 80% of Capacity)

Analytic Method Example

System 1, Condition 1

Units Out	Capacity Out MW	Capacity In MW	Probability	% of Hours	LOLP	LOLE Hours / Year	LOEE MWh/Year
				Total:	0.001345	11.8	87.5
0	0	200	0.121577	0.000000			
1	10	190	0.270170	0.000000			
2	20	180	0.285180	0.000000			
3	30	170	0.190120	0.000000			
4	40	160	0.089779	0.000000			
5	50	150	0.031921	0.000000			
6	60	140	0.008867	0.095238	0.000844	7.4	37.0
7	70	130	0.001970	0.190476	0.000375	3.3	32.9
8	80	120	0.000356	0.285714	0.000102	0.9	13.4
9	90	110	0.000053	0.380952	0.000020	0.2	3.5
10	100	100	0.000006	0.476190	0.000003	0.0	0.7
11	110	90	0.000001	0.571429	0.000000	0.0	0.1

Analytic Method Example

System 2, Condition 1

Units Out	Capacity Out MW	Capacity In MW	Probability	% of Hours	LOLP	LOLE Hours / Year	LOEE MWh/Year
				Total:	**0.001304**	**11.4**	**86.8**
0	0	200	0.598737	0.000000			
1	20	180	0.315125	0.000000			
2	40	160	0.074635	0.000000			
3	60	140	0.010475	0.095238	0.000998	8.7	43.7
4	80	120	0.000965	0.285714	0.000276	2.4	36.2
5	100	100	0.000061	0.476190	0.000029	0.3	6.4
6	120	80	0.000003	0.666667	0.000002	0.0	0.5

Analytic Method Example

System 3, Condition 1

				Total:	0.000975	8.5	151.9
Units Out	Capacity Out MW	Capacity In MW	Probability	% of Hours	LOLP	LOLE Hours / Year	LOEE MWh/Year
0	0	400	0.074251	0.000000			
1	25	375	0.209650	0.000000			
2	50	350	0.277478	0.000000			
3	75	325	0.228511	0.000000			
4	100	300	0.131058	0.000000			
5	125	275	0.055507	0.000000			
6	150	250	0.017958	0.000000			
7	175	225	0.004527	0.142857	0.000647	5.7	70.8
8	200	200	0.000899	0.285714	0.000257	2.2	56.2
9	225	175	0.000141	0.428571	0.000060	0.5	19.8
10	250	150	0.000017	0.571429	0.000010	0.1	4.4
11	275	125	0.000002	0.714286	0.000001	0.0	0.7

Analytic Method Example

System 4, Condition 1

Units Out	Capacity Out MW	Capacity In MW	Probability	% of Hours	LOLP	LOLE Hours / Year	LOEE MWh/Year
				Total:	**0.001053**	**9.2**	**266.4**
0	0	400	0.470253	0.000000			
1	50	350	0.372068	0.000000			
2	100	300	0.128793	0.000000			
3	150	250	0.025475	0.000000			
4	200	200	0.003149	0.285714	0.000900	7.9	197.1
5	250	150	0.000249	0.571429	0.000142	1.2	62.4
6	300	100	0.000012	0.857143	0.000011	0.1	6.9

Analytic Method Example

System 1, Condition 2

Units Out	Capacity Out MW	Capacity In MW	Probability	% of Hours	LOLP	LOLE Hours / Year	LOEE MWh/Year
				Total:	**0.040740**	**356.9**	**3,627.5**
0	0	200	0.121577	0.000000			
1	10	190	0.270170	0.000000			
2	20	180	0.285180	0.000000			
3	30	170	0.190120	0.079365	0.015089	132.2	660.9
4	40	160	0.089779	0.158730	0.014251	124.8	1,248.4
5	50	150	0.031921	0.238095	0.007600	66.6	998.7
6	60	140	0.008867	0.317460	0.002815	24.7	493.2
7	70	130	0.001970	0.396825	0.000782	6.8	171.2
8	80	120	0.000356	0.476190	0.000169	1.5	44.5
9	90	110	0.000053	0.555556	0.000029	0.3	9.0
10	100	100	0.000006	0.634921	0.000004	0.0	1.4
11	110	90	0.000001	0.714286	0.000000	0.0	0.2

Analytic Method Example

System 2, Condition 2

Units Out	Capacity Out MW	Capacity In MW	Probability	% of Hours	LOLP	LOLE Hours / Year	LOEE MWh/Year
				Total:	**0.015673**	**137.3**	**1,755.7**
0	0	200	0.598737	0.000000			
1	20	180	0.315125	0.000000			
2	40	160	0.074635	0.158730	0.011847	103.8	1,037.8
3	60	140	0.010475	0.317460	0.003325	29.1	582.6
4	80	120	0.000965	0.476190	0.000459	4.0	120.7
5	100	100	0.000061	0.634921	0.000039	0.3	13.6
6	120	80	0.000003	0.793651	0.000002	0.0	0.9

Analytic Method Example

System 3, Condition 2

				Total:	0.030972	271.3	6,064.6
Units Out	**Capacity Out MW**	**Capacity In MW**	**Probability**	**% of Hours**	**LOLP**	**LOLE Hours / Year**	**LOEE MWh/Year**
0	0	400	0.074251	0.000000			
1	25	375	0.209650	0.000000			
2	50	350	0.277478	0.000000			
3	75	325	0.228511	0.000000			
4	100	300	0.131058	0.089286	0.011702	102.5	1,025.1
5	125	275	0.055507	0.200893	0.011151	97.7	2,197.9
6	150	250	0.017958	0.312500	0.005612	49.2	1,720.6
7	175	225	0.004527	0.424107	0.001920	16.8	798.9
8	200	200	0.000899	0.535714	0.000481	4.2	253.1
9	225	175	0.000141	0.647321	0.000091	0.8	58.0
10	250	150	0.000017	0.758929	0.000013	0.1	9.8
11	275	125	0.000002	0.870536	0.000001	0.0	1.3

Analytic Method Example

System 4, Condition 2

Units Out	Capacity Out MW	Capacity In MW	Probability	% of Hours	LOLP	LOLE Hours / Year	LOEE MWh/Year
				Total:	**0.021349**	**187.0**	**4,487.5**
0	0	400	0.470253	0.000000			
1	50	350	0.372068	0.000000			
2	100	300	0.128793	0.089286	0.011499	100.7	1,007.3
3	150	250	0.025475	0.312500	0.007961	69.7	2,440.9
4	200	200	0.003149	0.535714	0.001687	14.8	886.8
5	250	150	0.000249	0.758929	0.000189	1.7	140.8
6	300	100	0.000012	0.982143	0.000012	0.1	11.7

Analytic Method Example

Summary

System	Capacity	Peak Load	LOLP	LOLE (Days / Year)	LOEE (MWh / Year)
			Load Condition 1		
1	200	150	0.001345	11.8	87.4
2	200	150	0.001304	11.4	86.8
3	400	250	0.000975	8.5	151.9
4	400	250	0.001053	9.2	266.4
			Load Condition 2		
1	200	180	0.040739	356.9	3,627.3
2	200	180	0.015672	137.3	1,755.6
3	400	320	0.030972	271.3	6,064.6
4	400	320	0.021349	187.0	4,487.5

Analytic Method Example
Debrief

Systems 1&2 / Systems 3&4

- How were the systems similar?
- How were they different?
- How did the system reliabilities compare under Condition 1?
- How did the system reliabilities compare under Condition 2?
- How did reliability in each system change from Condition 1 to Condition 2?

Analytic Method Example
Debrief

Systems 1&2 / Systems 3&4

- How were the systems similar?
- How were they different?
- How did the system reliabilities compare under Condition 1?
- How did the system reliabilities compare under Condition 2?
- How did reliability in each system change from Condition 1 to Condition 2?

All Systems

How well does reserve margin reflect the relative reliabilities of your system?


Transmission Interconnection

Analytic Method

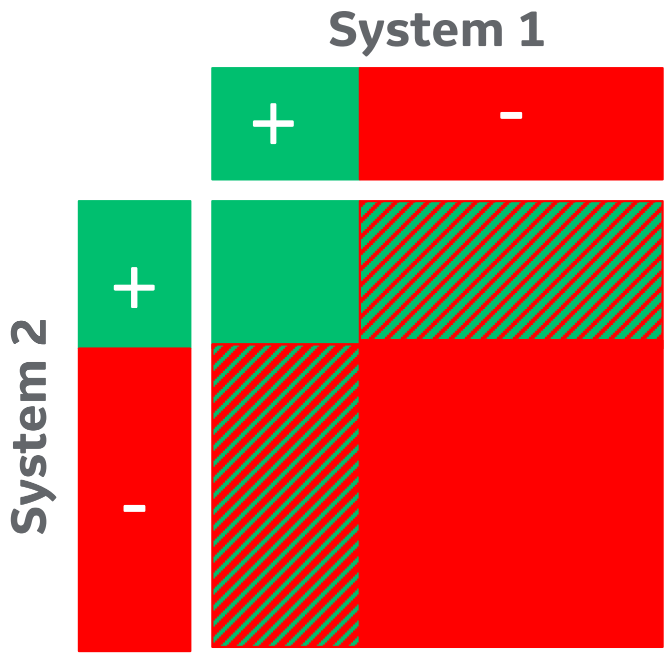
Extending to Multi-Area Analysis

Two methods are commonly used to represent transmission constraints and reliability when using an analytical approach

1) Probability Array Method
2) Equivalent Assisting Unit Method

Transmission Interconnection
Probability Array Method

The loss of load indices in each interconnected system is dependent on the simultaneous occurrences in both systems.

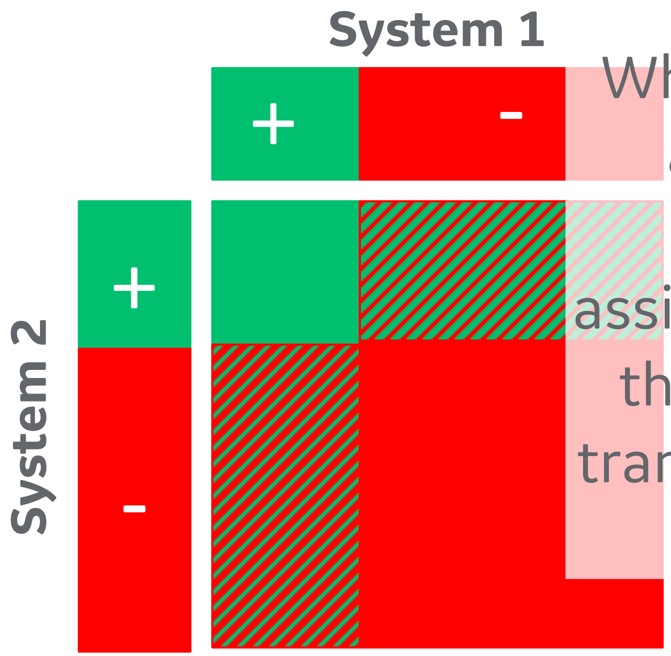


An n-dimensional probability array can be created which represents the probability that each system has a surplus, or deficit, of capacity

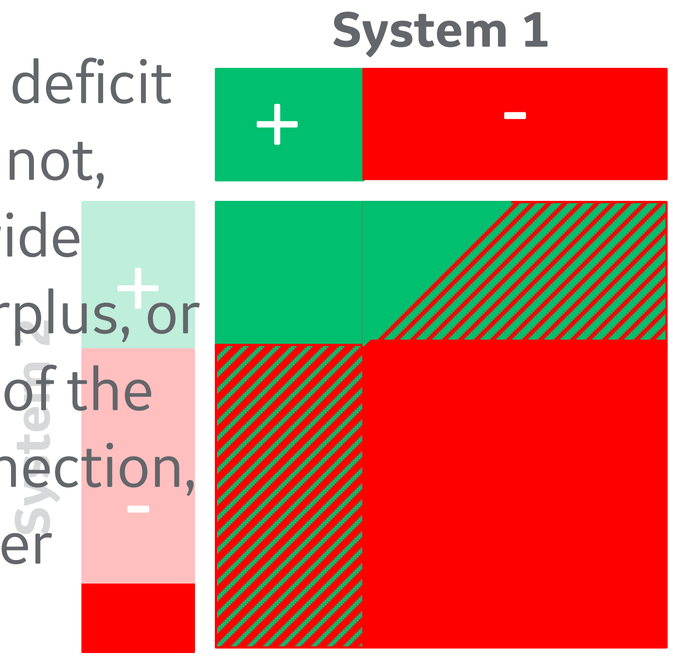
Transmission Interconnection

Probability Array Method

The loss of load indices in each interconnected system is dependent on the simultaneous occurrences in both systems.



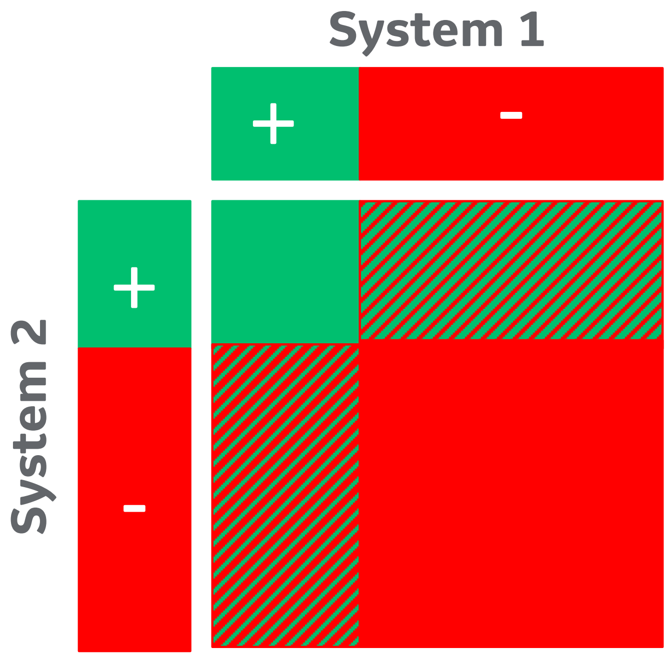
When system 1 has a deficit and system 2 does not, system 2 can provide assistance up to its surplus, or the maximum rating of the transmission interconnection, whichever is lesser

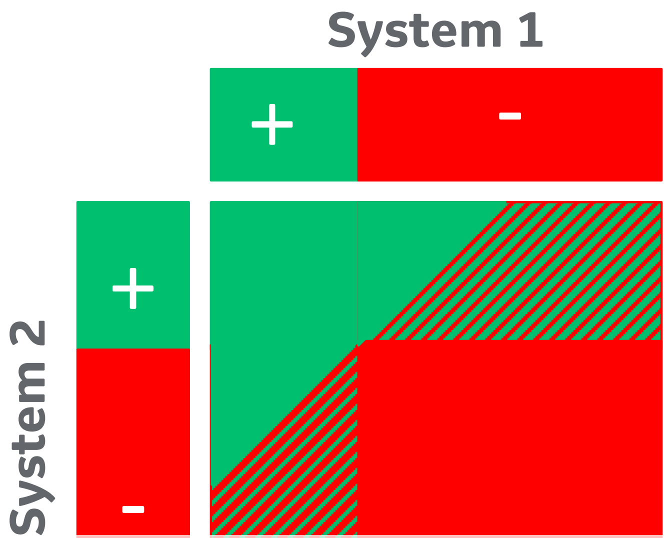


Transmission Interconnection

Probability Array Method

The loss of load indices in each interconnected system is dependent on the simultaneous occurrences in both systems.





Similarly, when system 2 has a deficit and system 1 does not, system 1 can provide assistance.

Transmission Interconnection
Probability Array Method

Systems 2 and 4 are connected by a perfect transmission interconnection with unlimited capacity

Each system provides support to the other, but only when they have excess reserve

System 2 Load is 180 MW, System 4 Load is 320 MW

	LOLP Isolated	**LOLP Interconnected**
System 2	0.0861	0.0179
System 4	0.1576	0.0806

Probability Array Method

System 4 Supporting System 2, Unlimited Interconnection

	Cap. Out MW	Reserve	Probability
System 2	0	20	0.598737
	20	0	0.315125
	40	-20	0.074635
	60	-40	0.010475
	80	-60	0.000965
	100	-80	0.000061
	120	-100	0.000003

Probability Array Method

System 4 Supporting System 2, Unlimited Interconnection

	Cap. Out MW	Reserve	Probability
System 2	0	20	0.598737
	20	0	0.315125
	40	-20	0.074635
	60	-40	0.010475
	80	-60	0.000965
	100	-80	0.000061
	120	-100	0.000003

Isolated LOLP **0.086138**

Probability Array Method

System 4 Supporting System 2, Unlimited Interconnection

				System 4						
	Cap. Out MW			0	50	100	150	200	250	300
		Reserve		80	30	-20	-70	-120	-170	-220
			Probability	0.470253	0.372068	0.128793	0.025475	0.003149	0.000249	0.000012
System 2	0	20	0.598737							
	20	0	0.315125							
	40	-20	0.074635							
	60	-40	0.010475							
	80	-60	0.000965							
	100	-80	0.000061							
	120	-100	0.000003							

Isolated LOLP **0.086138**

Probability Array Method

System 4 Supporting System 2, Unlimited Interconnection

				System 4						
	Cap. Out MW			0	50	100	150	200	250	300
		Reserve		80	30	-20	-70	-120	-170	-220
			Probability	0.470253	0.372068	0.128793	0.025475	0.003149	0.000249	0.000012
System 2	0	20	0.598737	0.281558	0.222771	0.077113	0.015253	0.001886	0.000149	0.000007
	20	0	0.315125	0.148188	0.117248	0.040586	0.008028	0.000992	0.000079	0.000004
	40	-20	0.074635	0.035097	0.027769	0.009612	0.001901	0.000235	0.000019	0.000001
	60	-40	0.010475	0.004926	0.003897	0.001349	0.000267	0.000033	0.000003	0.000000
	80	-60	0.000965	0.000454	0.000359	0.000124	0.000025	0.000003	0.000000	0.000000
	100	-80	0.000061	0.000029	0.000023	0.000008	0.000002	0.000000	0.000000	0.000000
	120	-100	0.000003	0.000001	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000

Isolated LOLP **0.086138**

Probability Array Method

System 4 Supporting System 2, Unlimited Interconnection

				System 4						
	Cap. Out MW			0	50	100	150	200	250	300
		Reserve		80	30	-20	-70	-120	-170	-220
			Probability	0.470253	0.372068	0.128793	0.025475	0.003149	0.000249	0.000012
System 2	0	20	0.598737	0.281558	0.222771	0.077113	0.015253	0.001886	0.000149	0.000007
	20	0	0.315125	0.148188	0.117248	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	40	-20	0.074635	0.035097	0.027769	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	60	-40	0.010475	0.004926	0.003897	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	80	-60	0.000965	0.000454	0.000359	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	100	-80	[illegible]	0.000029	0.000023	0.000008	0.000002	0.000000	0.000000	0.000000
	120	-100	[illegible]	[illegible]	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000
						20	20	20	20	20
						0	0	0	0	0
						-20	-20	-20	-20	-20
						-40	-40	-40	-40	-40
						-60	-60	-60	-60	-60
						-80	-80	-80	-80	-80
						-100	-100	-100	-100	-100

When System 4 reserve is negative it will not provide support to System 2, so the System 2 reserve stays the same.

Isolated LOLP **0.086138**

Probability Array Method

System 4 Supporting System 2, Unlimited Interconnection

				System 4						
	Cap. Out MW			0	50	100	150	200	250	300
		Reserve		80	30	-20	-70	-120	-170	-220
			Probability	0.470253	0.372068	0.128793	0.025475	0.003149	0.000249	0.000012
System 2	0	20	[illegible]	0.281558	0.222771	0.077113	0.015253	0.001886	0.000149	0.000007
	20	0	0.315125	[illegible]	0.117248	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	40	-20	[illegible]	[illegible]	0.027769	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	60	-40	0.010475	[illegible]	0.003897	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	80	-60	0.000965	[illegible]	0.000359	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	100	-80	0.000061	[illegible]	0.000023	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	120	-100	0.000003	0.000001	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000

		100	50	20	20	20	20	20
Isolated LOLP	**0.086138**	80	30	0	0	0	0	0
		60	10	-20	-20	-20	-20	-20
		40	-10	-40	-40	-40	-40	-40
		20	-30	-60	-60	-60	-60	-60
		0	-50	-80	-80	-80	-80	-80
		-20	-70	-100	-100	-100	-100	-100

When System 4 reserve is positive it will provide support to System 2 up to its available reserve, so the System 4 reserve will be added to the System 2 reserve .

Probability Array Method

System 4 Supporting System 2, Unlimited Interconnection

			System 4						
Cap. Out MW			0	50	100	150	200	250	300
	Reserve		80	30	-20	-70	-120	-170	-220
		Probability	0.470253	0.372068	0.128793	0.025475	0.003149	0.000249	0.000012
0	20	0.598737	0.281558	0.222771	0.077113	0.015253	0.001886	0.000149	0.000007
[illegible]	[illegible]	[illegible]	[illegible]	0.117248	0.040586	0.008028	0.000992	0.000079	0.000004
[illegible]	[illegible]	[illegible]	[illegible]	0.027769	0.009612	0.001901	0.000235	0.000019	0.000001
[illegible]	[illegible]	[illegible]	[illegible]	0.003897	0.001349	0.000267	0.000033	0.000003	0.000000
[illegible]	[illegible]	[illegible]	[illegible]	0.000359	0.000124	0.000025	0.000003	0.000000	0.000000
100	-80	0.000061	0.000029	0.000023	0.000008	0.000002	0.000000	0.000000	0.000000
120	-100	0.000003	0.000001	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000

The sum of the probabilities for each of System 2's new reserve conditions gives the interconnected LOLP.

100	50	20	20	20	20	20
80	30	0	0	0	0	0
60	10	-20	-20	-20	-20	-20
40	-10	-40	-40	-40	-40	-40
20	-30	-60	-60	-60	-60	-60
0	-50	-80	-80	-80	-80	-80
-20	-70	-100	-100	-100	-100	-100

Isolated LOLP **0.086138**

Interconnected LOLP **0.017864**
(Unlimited Interconnection)

Probability Array Method

System 2 Supporting System 4, Unlimited Interconnection

				System 2						
	Cap. Out MW			0	50	100	150	200	250	300
		Reserve		20	0	-20	-40	-60	-80	-100
			Probability	0.598737	0.315125	0.074635	0.010475	0.000965	0.000061	0.000003
System 4	0	80	0.470253	0.281558	0.148188	0.035097	0.004926	0.000454	0.000029	0.000001
	50	30	0.372068	0.222771	0.117248	0.027769	0.003897	0.000359	0.000023	0.000001
	100	-20	0.128793	0.077113	0.040586	0.009612	0.001349	0.000124	0.000008	0.000000
	150	-70	0.025475	0.015253	0.008028	0.001901	0.000267	0.000025	0.000002	0.000000
	200	-120	0.003149	0.001886	0.000992	0.000235	0.000033	0.000003	0.000000	0.000000
	250	-170	0.000249	0.000149	0.000079	0.000019	0.000003	0.000000	0.000000	0.000000
	300	-220	0.000012	0.000007	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000
				100	80	80	80	80	80	80
	Isolated LOLP		**0.157679**	50	30	30	30	30	30	30
				0	-20	-20	-20	-20	-20	-20
	Interconnected LOLP		**0.080566**	-50	-70	-70	-70	-70	-70	-70
	(Unlimited Interconnection)			-100	-120	-120	-120	-120	-120	-120
				-150	-170	-170	-170	-170	-170	-170
				-200	-220	-220	-220	-220	-220	-220

Probability Array Method

System 4 Supporting System 2, 50 MW Interconnection

				System 4						
	Cap. Out MW			0	50	100	150	200	250	300
		Reserve		80	30	-20	-70	-120	-170	-220
			Probability	0.470253	0.372068	0.128793	0.025475	0.003149	0.000249	0.000012
System 2	0	20	0.5[illegible]737	0.281558	0.222771	0.077113	0.015253	0.001886	0.000149	0.000007
	20	0	0.315125	.148188	0.117248	[illegible]	[illegible]	[illegible]	[illegible]	004
	40	-20	0.0746	035097	0.027769	[illegible]	[illegible]	[illegible]	[illegible]	001
	60	-40	0.01047	04926	0.003897	[illegible]	[illegible]	[illegible]	[illegible]	000
	80	-60	0.000965	54	0.000359	[illegible]	[illegible]	[illegible]	[illegible]	000
	100	-80	0.000061	029	0.000023	0.000008	0.000002	0.000000	0.000000	0.000000
	120	-100	0.000003	0.0[illegible]0001	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000

50 MW

When System 4 reserve is positive and greater than 50 MW, it will provide support to System 2 up to 50 MW, so the 50 MW will be added to the System 2 reserve .

70		20	20	20	20	20
50		0	0	0	0	0
30		-20	-20	-20	-20	-20
10		-40	-40	-40	-40	-40
-10		-60	-60	-60	-60	-60
-30		-80	-80	-80	-80	-80
-50		-100	-100	-100	-100	-100

Isolated LOLP **0.086138**

Interconnected LOLP **0.017864**
(Unlimited Interconnection)

Probability Array Method

System 4 Supporting System 2, 50 MW Interconnection

			System 4						
Cap. Out MW			0	50	100	150	200	250	300
	Reserve		80	30	-20	-70	-120	-170	-220
		Probability	0.470253	0.372068	0.128793	0.025475	0.003149	0.000249	0.000012
System 2 0	20	[illegible]	0.281558	0.222771	0.077113	0.015253	0.001886	0.000149	0.000007
20	0	0.315125	[illegible]	0.117248	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
40	-20	0.074635	[illegible]	0.027769	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
60	-40	0.010475	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
80	-60	0.000965	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
100	-80	0.000061	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
120	-100	0.000003	[illegible]	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000
			70	50	20	20	20	20	20
			50	30	0	0	0	0	0
			30	10	-20	-20	-20	-20	-20
			10	-10	-40	-40	-40	-40	-40
			-10	-30	-60	-60	-60	-60	-60
			-30	-50	-80	-80	-80	-80	-80
			-50	-70	-100	-100	-100	-100	-100

30 MW

When System 4 reserve is positive and greater than 0 MW, but less than 50 MW, it will provide support to System 2 up to its reserve, so the System 4 reserve will be added to the System 2 reserve .

Isolated LOLP **0.086138**

Interconnected LOLP **0.017864**
(Unlimited Interconnection)

Probability Array Method

System 4 Supporting System 2, 50 MW Interconnection

				System 4						
	Cap. Out MW			0	50	100	150	200	250	300
		Reserve		80	30	-20	-70	-120	-170	-220
			Probability	0.470253	0.372068	0.128793	0.025475	0.003149	0.000249	0.000012
System 2	0	20	0.598737	0.281558	0.222771	0.077113	0.015253	0.001886	0.000149	0.000007
	20	0	0.315125	0.148188	0.117248	0.040586	0.008028	0.000992	0.000079	0.000004
	40	-20	0.074635	0.035097	0.027769	0.009612	0.001901	0.000235	0.000019	0.000001
	60	-40	0.010475	0.004926	0.003897	0.001349	0.000267	0.000033	0.000003	0.000000
	80	-60	0.000965	0.000454	0.000359	0.000124	0.000025	0.000003	0.000000	0.000000
	100	-80	0.000061	0.000029	0.000023	0.000008	0.000002	0.000000	0.000000	0.000000
	120	-100	0.000003	0.000001	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000
				70	50	20	20	20	20	20
	Isolated LOLP		**0.086138**	50	30	0	0	0	0	0
				30	10	-20	-20	-20	-20	-20
	Interconnected LOLP		**0.017864**	10	-10	-40	-40	-40	-40	-40
	(Unlimited Interconnection)			-10	-30	-60	-60	-60	-60	-60
	Interconnected LOLP		**0.018346**	-30	-50	-80	-80	-80	-80	-80
	(50 MW Interconnection)			-50	-70	-100	-100	-100	-100	-100

Probability Array Method

System 2 Supporting System 4, 50 MW Interconnection

				System 2						
	Cap. Out MW			0	50	100	150	200	250	300
		Reserve		20	0	-20	-40	-60	-80	-100
			Probability	0.598737	0.315125	0.074635	0.010475	0.000965	0.000061	0.000003
System 4	0	80	0.470253	0.281558	0.148188	0.035097	0.004926	0.000454	0.000029	0.000001
System 4	50	30	0.372068	0.222771	0.117248	0.027769	0.003897	0.000359	0.000023	0.000001
System 4	100	-20	0.128793	0.077113	0.040586	0.009612	0.001349	0.000124	0.000008	0.000000
System 4	150	-70	0.025475	0.015253	0.008028	0.001901	0.000267	0.000025	0.000002	0.000000
System 4	200	-120	0.003149	0.001886	0.000992	0.000235	0.000033	0.000003	0.000000	0.000000
System 4	250	-170	0.000249	0.000149	0.000079	0.000019	0.000003	0.000000	0.000000	0.000000
System 4	300	-220	0.000012	0.000007	0.000004	0.000001	0.000000	0.000000	0.000000	0.000000
				100	80	80	80	80	80	80
	Isolated LOLP		0.157679	50	30	30	30	30	30	30
				0	-20	-20	-20	-20	-20	-20
	Interconnected LOLP		**0.080566**	-50	-70	-70	-70	-70	-70	-70
	(Unlimited Interconnection)			-100	-120	-120	-120	-120	-120	-120
	Interconnected LOLP		**0.080566**	-150	-170	-170	-170	-170	-170	-170
	(50 MW Interconnection)			-200	-220	-220	-220	-220	-220	-220

Transmission Interconnection

Equivalent Assisting Unit Method

Each radially interconnected system is treated as an equivalent generator in the neighboring system.

Transmission Interconnection

Equivalent Assisting Unit Method

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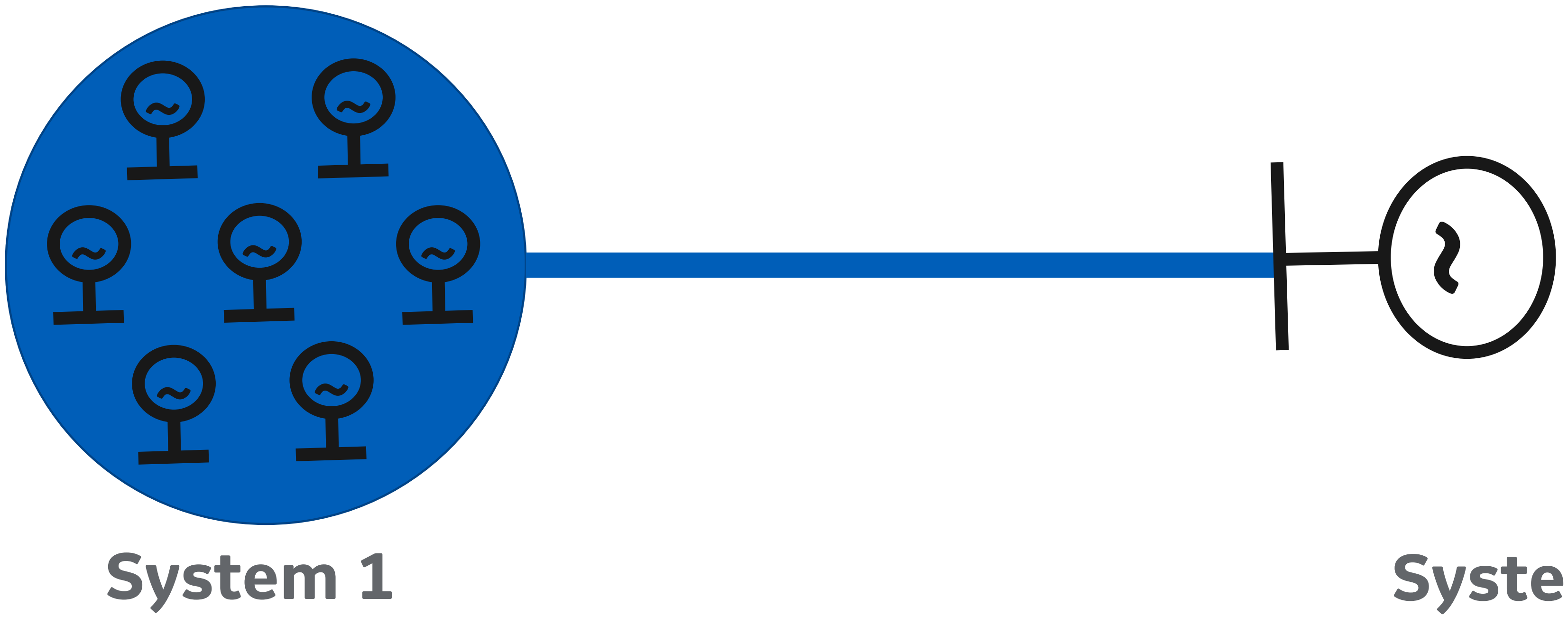

Equivalent Assisting Unit Method

System 4 Equivalent Unit

Capacity Out	Assistance	Probability
0	80	0.470253
50	30	0.372068
100	0	0.128793
150	0	0.025475
200	0	0.003149
250	0	0.000249
300	0	0.000012

Equivalent Assisting Unit Method

System 4 Equivalent Unit

Capacity Out	Assistance	Probability
0	80	0.470253
50	30	0.372068
100	0	0.128793
150	0	0.025475
200	0	0.003149
250	0	0.000249
300	0	0.000012

Unlimited Capacity	
Equivalent Probability	Equivalent Unit Capacity Out
0.470253	0
0.372068	50
0.157679	80

Equivalent Assisting Unit Method

System 4 Equivalent Unit

Capacity Out	Assistance	Probability
0	80	0.470253
50	30	0.372068
100	0	0.128793
150	0	0.025475
200	0	0.003149
250	0	0.000249
300	0	0.000012

Unlimited Capacity		30 MW Capacity	
Equivalent Probability	Equivalent Unit Capacity Out	Equivalent Probability	Equivalent Unit Capacity Out
0.470253	0	0.470253	0
0.372068	50	0.372068	0
0.157679	80	0.157679	30

Equivalent Assisting Unit Method

System 4 Equivalent Unit

Capacity Out	Assistance	Probability
0	80	0.470253
50	30	0.372068
100	0	0.128793
150	0	0.025475
200	0	0.003149
250	0	0.000249
300	0	0.000012

Unlimited Capacity	
Equivalent Probability	Equivalent Unit Capacity Out
0.470253	0
0.372068	50
0.157679	80

30 MW Capacity	
Equivalent Probability	Equivalent Unit Capacity Out
0.470253	0
0.372068	0
0.157679	30

0.842320	0
0.157679	30

Equivalent Assisting Unit Method

System 4 Equivalent Unit

System 2 Capacity Out	System 2 Probability	Equivalent Unit Capacity Out	Equivalent Unit Probability	Combined Capacity Out	Combined Probability
0	0.598737	0	0.84232	0	0.504328
20	0.315125	0	0.84232	20	0.265436
40	0.074635	0	0.84232	40	0.062867
60	0.010475	0	0.84232	60	0.008823
80	0.000965	0	0.84232	80	0.000813
100	0.000061	0	0.84232	100	0.000051
120	0.000003	0	0.84232	120	0.000003
0	0.598737	30	0.15768	30	0.094408
20	0.315125	30	0.15768	50	0.049689
40	0.074635	30	0.15768	70	0.011768
60	0.010475	30	0.15768	90	0.001652
80	0.000965	30	0.15768	110	0.000152
100	0.000061	30	0.15768	130	0.000010
120	0.000003	30	0.15768	150	0.000000

Equivalent Assisting Unit Method

System 4 Equivalent Unit

System 2 Capacity Out	System 2 Probability	Equivalent Unit Capacity Out	Equivalent Unit Probability	Combined Capacity Out	Combined Probability
0	0.598737	0	0.84232	0	0.504328
20	0.315125	0	0.84232	20	0.265436
40	0.074635	0	0.84232	40	0.062867
60	0.010475	0	0.84232	60	0.008823
80	0.000965	0	0.84232	80	0.000813
100	0.000061	0	0.84232	100	0.000051
120	0.000003	0	0.84232	120	0.000003
0	0.598737	30	0.15768	30	0.094408
20	0.315125	30	0.15768	50	0.049689
40	0.074635	30	0.15768	70	0.011768
60	0.010475	30	0.15768	90	0.001652
80	0.000965	30	0.15768	110	0.000152
100	0.000061	30	0.15768	130	0.000010
120	0.000003	30	0.15768	150	0.000000

Combined Capacity Out	Combined Probability
0	0.504328
20	0.265436
30	0.094408
40	0.062867
50	0.049689
60	0.008823
70	0.011768
80	0.000813
90	0.001652
100	0.000051
120	0.000003
110	0.000152
130	0.000010
150	0.000000

Equivalent Assisting Unit Method

System 4 Equivalent Unit

System 2 Capacity Out	System 2 Probability	Equivalent Unit Capacity Out	Equivalent Unit Probability	Combined Capacity Out	Combined Probability
0	0.598737	0	0.84232	0	0.504328
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40	0.074635	0	0.84232	40	0.062867
60	0.010475	0	0.84232	60	0.008823
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100	0.000061	30	0.15768	130	0.000010
120	0.000003	30	0.15768	150	0.000000

Combined Capacity Out	Combined Probability
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20	0.265436
30	0.094408
40	0.062867
50	0.049689
60	0.008823
70	0.011768
80	0.000813
90	0.001652
100	0.000051
120	0.000003
110	0.000152
130	0.000010
150	0.000000
Interconnected LOLP	**0.023262**

Simulation Method

Simulation Method

Monte-Carlo Simulation

Stochastic simulation, commonly referred to as Monte-Carlo simulation, is an alternative to the analytical method described thus far for ***estimating*** reliability indices.

Unlike the analytic approach, there is no set mathematical representation for Monte-Carlo Simulation - it is instead based on a series or random numbers generated by a computer.

By taking random samples of various system operating conditions, an estimate of the system reliability can be obtained without knowing an exact numerical formulation.

Simulation Method

$$Loss\ of\ Load\ Probability\ (LOLP) = \lim_{N \to \infty} \frac{1}{N} \sum_{N} Loss\ of\ Load$$

Using the simulation method the loss of load probability is the limit as the number of random samples, *N*, approaches infinity of the sum of loss of load events in each sample divided by the number of samples.

If the number of samples is sufficiently large, the simulation method should converge to a value very near the analytic.

Simulation Method
Expected Value

The expected value of simulated reliability indices (LOLP, LOLE, LOEE) can be calculated as follows:

$$\bar{I} = \frac{1}{N}\sum_{i=1}^{N} I_i$$

Simulation Method

Standard Error

The standard error of simulated reliability indices (LOLP, LOLE, LOEE) can be calculated as follows:

$$Standard\ Error\ of\ \bar{I} = \frac{S\bar{I}}{\bar{I}}$$

Where:

$$S\bar{I} = \sqrt{\frac{S^2}{N}} \qquad\qquad S^2 = \frac{1}{N}\sum_{i=1}^{N}\left(I_i - \bar{I}\right)^2$$

Monte-Carlo Simulation

Random vs Chronological

Random

Simulates time intervals at random and does not consider time correlated events

Will typically take less time than a sequential simulation of the same system

Cannot be used to generate frequency and duration distributions

Chronological

Simulates time intervals chronologically accounting for events which are dependent on past events

The more robust of the two simulation models

Monte-Carlo Simulation
Random vs Chronological

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Chronological

Simulates time intervals chronologically accounting for events which are dependent on past events

The more robust of the two simulation models

GE MARS is a Chronological Monte-Carlo Simulation

Monte-Carlo Simulation

Random

Step 1: Generate a uniform random number, U, in the range 0-1 for each random variable in the system

Step 2:

If U_i < Forced outage rate for generator G_i, the generator is unavailable

Based on the Daily Peak Load Variation Curve, or load duration curve, and U, calculate the system load for the current interval

Step 3:

If Load > Generation, a Loss of Load has occurred

Chronological Monte-Carlo Simulation

Mean Time to Repair and Mean Time to Failure

$$Forced\ Outage\ Rate = \frac{\lambda}{\lambda + \mu} = \frac{r}{m + r}$$

$\lambda = Time\ Unavailable$

$\mu = Time\ Available$

$r = Mean\ Time\ to\ Repair = 1 / \mu$

$m = Mean\ Time\ to\ Failure = 1 / \lambda$

Chronological Monte-Carlo Simulation

Time to Failure and Time to Repair

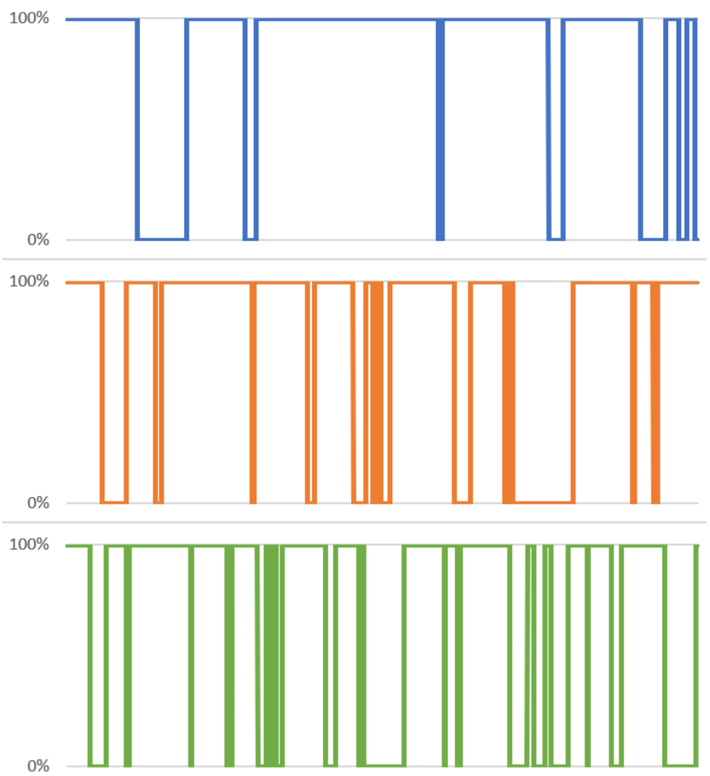
Time to Failure (TtF) and Time to Repair (TtR) can be estimated by transforming uniform random numbers into an exponential distribution around the mean time to failure (m), and mean time to repair (r).

$$TtF = -m \ln(U_1)$$

$$TtR = -r \ln(U_2)$$

Chronological Monte-Carlo Simulation
Two State Units

1. Assume the unit starts at full rated capacity
2. Generate a uniform random number (U_1) in the range 0-1
3. Determine the Time to Failure (TtF)
$$TtF = -m\ln(U_1)$$
4. After the time to failure has elapsed, generate another uniform random number (U_2) in the range 0-1
5. Determine the Time to Repair (TtR)
$$TtR = -r\ln(U_2)$$
6. After the time to repair has elapsed, go to step 2



Chronological Monte-Carlo Simulation

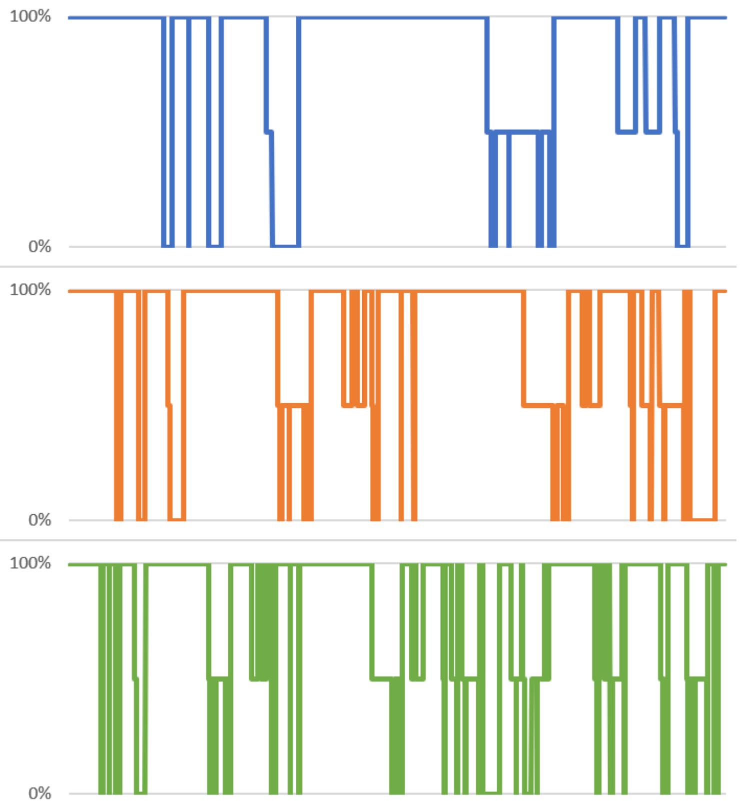
Multi State Units

1. Assume the unit starts at full rated capacity (state i)
2. Generate uniform random numbers in the range 0-1 for each state the unit may transition to ($U_{i,n}$, $i \neq n$)
3. Determine the Time to Transition from the current state t each other state ($TtT_{i,n}$) based on the transition rate $T_{i,n}$ from the current state to each other state

$$TtT_{i,n} = -\frac{1}{T_{i,n}} \ln(U_{i,n}) \;\; for\ all\ n$$

4. Transition to the next state after the shortest time to transition has elapsed

6. Go to step 2



Chronological Monte-Carlo Simulation

1. Generate random operating histories for all units in the system
2. Compare the total available capacity in each hour with a chronological demand profile
3. Aggregate statistics when load > available generation

GE

Introduction to GE MARS

GE's Multi Area Reliability Simulation (GE MARS)

GE MARS is a full sequential Monte Carlo simulation

Chronological system simulation performed by combining:

- Randomly generated operating histories of units through time
- Hourly chronological load cycles
- Transmission links

Years are simulated until a convergence criterion is met, or for a set number of samples

Monte Carlo Simulation

Random events to be considered

- Equipment forced outages
- Uncertainty in forecasted loads
- Transmission Interface Forced Outages
- Uncertainty in renewable output

System scenario created by randomly drawing availability of equipment

Each year is simulated with different sets of random events until statistical convergence is obtained

Reliability Indices Calculated

Expected value and distribution of

- Daily LOLE (days/year) calculated
- Hourly LOLE (hours/year)
- LOEE (MWh/year)
- Frequency (outages/year)
- Duration (hours/outage)

Calculation of Indices

Basic calculations are done at the area level

- Load is defined by area, units are assigned to areas, and transfer limits are specified between areas
- Area load is compared to available area generation plus assistance from other areas
- If load exceeds generation plus assistance, area is counted as being deficient

Pool indices are derived from areas in that pool

- If one or more areas in the pool are deficient, the pool is counted as being deficient

Simulation Process

Determine capacity available each hour from each unit in the system based on:

- Unit rating and capacity states
- Scheduled planned outages
- Random forced outages
- Renewable unit output

Determine area margins for each hour

- Margin = Available Capacity – Load

Accumulate statistics for isolated indices

Calculate flows between areas (if needed) and resulting area margins

Accumulate statistics for interconnected indices

Basic Unit Types

- Thermal
- Cogeneration
- Energy Limited
- Hourly modifier (DSM)

Cogeneration Units

Thermal units with associated hourly load demand

Type 1 – system will back up cogen loads if cogen not available

Type 2 – system will not back up cogen loads if cogen not available

Energy Limited Units

Type 1 – thermal unit with an energy probability distribution

Type 2 – unit with specified capacity and available monthly energy scheduled deterministically

Type 3 – unit with specified capacity and available monthly energy scheduled as-needed

Resource Allocation Among Areas

First step in calculating the reliability indices is to compute the isolated area margins for each hour

Margin = (Total Available Capacity) – (Load Demand)

- Total available capacity is adjusted for the net firm contracts; if margin is negative, the area is in loss of load situation
- If area has negative margin, adjust for curtailable contracts, MARS then tries to cover these deficiencies with capacity from Positive margin area

Resource Allocation Among Areas

Priority Order

- User specifies the order of receiving assistance using a single priority list to receive assistance for all areas in the system
- User can specify areas within a pool to have priority over outside areas

Proportional

- Share surplus among deficient areas in proportion to the size of their shortfalls
- Preference can be given to areas within the same pool
- Account for the transfer limits into and out of each area
- Effects of transfer limitations are further considered by grouping together those areas with the same sign that are directly interconnected

Resource Allocation Among Areas

Assistance Passes

Pass 1 – Assistance within Pool

- Assist deficient areas within the same pool
- Limit flows to only those interface paths within each pool, or allow assistance to flow through outside pools

Pass 2 – Assistance Between Pools

- User identifies the order in which pools with excess capacity will provide assistance to deficient areas in other pools
- Can control whether to allow flow through pools that are not part of the particular pool sharing arrangement

Pass 3 – System Wide Assistance

System-wide pass, without regard to the pools to which the areas have been assigned

Resource Allocation Among Areas

Transportation Model

MARS uses a transportation model to determine if areas with negative margins can be served by areas having positive margins, while being constrained by the capacity transfer limits between area

- The logic is a “nearest neighbor policy” which implies that if an area is deficient in capacity, it will look for assistance by way of the shortest path possible
- An area will provide assistance to other areas only up to the limit of its excess resources; no “Loss Sharing” is modeled

Simulation Convergence

Reliability Indices

I_i = Value of reliability index obtained from simulation data for year i

N = Number of times year has been simulated

$$\bar{I} = \frac{\sum_{i=1}^{N} I_i}{N} = \text{Estimate of expected value of index I}$$

$$S^2 = \frac{\sum_{i=1}^{N} (I_i - \bar{I})^2}{N} = \text{Sample variance}$$

$$S_{\bar{I}} = \sqrt{\left(\frac{S^2}{N}\right)} = \text{Standard deviation of estimate } \bar{I}$$

$$\frac{S_{\bar{I}}}{\bar{I}} = \text{Standard error of estimate } \bar{I}$$

Convergence

Degree of statistical convergence of reliability index measured by standard deviation of estimate of reliability index calculated from simulation

Simulation Convergence

Convergence

Index

- Daily or Hourly LOLE
- LOEE

Area, pool, or area group

Isolated or interconnected

Convergence tolerance

Minimum and maximum number of replications

Fixed

MARS can be run to a fixed number of replications specified by the user.

When running with a fixed number of replications, the simulation can be parallelized.

Factors Influencing Convergence

Number of units and size of units relative to load

Many units small in comparison to load results in less year-to-year variation and faster convergence

Strength of transmission network between interconnected areas

Strong ties reduce yearly variations

Level of reliability

Highly reliable systems converge more slowly

GE MARS Python Application Programming Interface (snappy)

snappy
Introduction

snappy is a python library, designed to interact with MAPS and MARS

Started as an application programming interface (API) to programmatically read MAPS results

It has evolved to include reading MARS, reading/writing model inputs, launch simulations and prepare reports

Currently supports python 2.7, but support for python 3 is in the works (expected later this year)

Reading Results

snappy.MARSH5, snappy.MarsScenarios

snappy.MARSH5 object defines the methods available to extract data from a single MARS output h5 file. Takes an h5 file as an input and outputs arrays of data.

snappy.MarsScenarios object manages multiple h5 file objects simultaneously to allow for easy extraction of data from multiple years / simulations simultaneously. Takes a list of folders containing h5 files as an input and outputs a structured tabular ***snappy.Data*** object.

Manipulation of Tabular Data

snappy.Data

- A tabular data object designed to work across snappy modules
- Can read and write load and modifier shape csv / eei / h5 files
- Master Input File data can be output to a ***snappy.Data*** object
- H5 file results can be output to a ***snappy.Data*** object
- snappy Tables and Plots take ***snappy.Data*** objects as an input
- Provides convenient data manipulation functions – *i.e.* pivot, unpivot, summarize, concatenate, filter, etc.

Reading and writing Master Input Files

snappy.InputTable

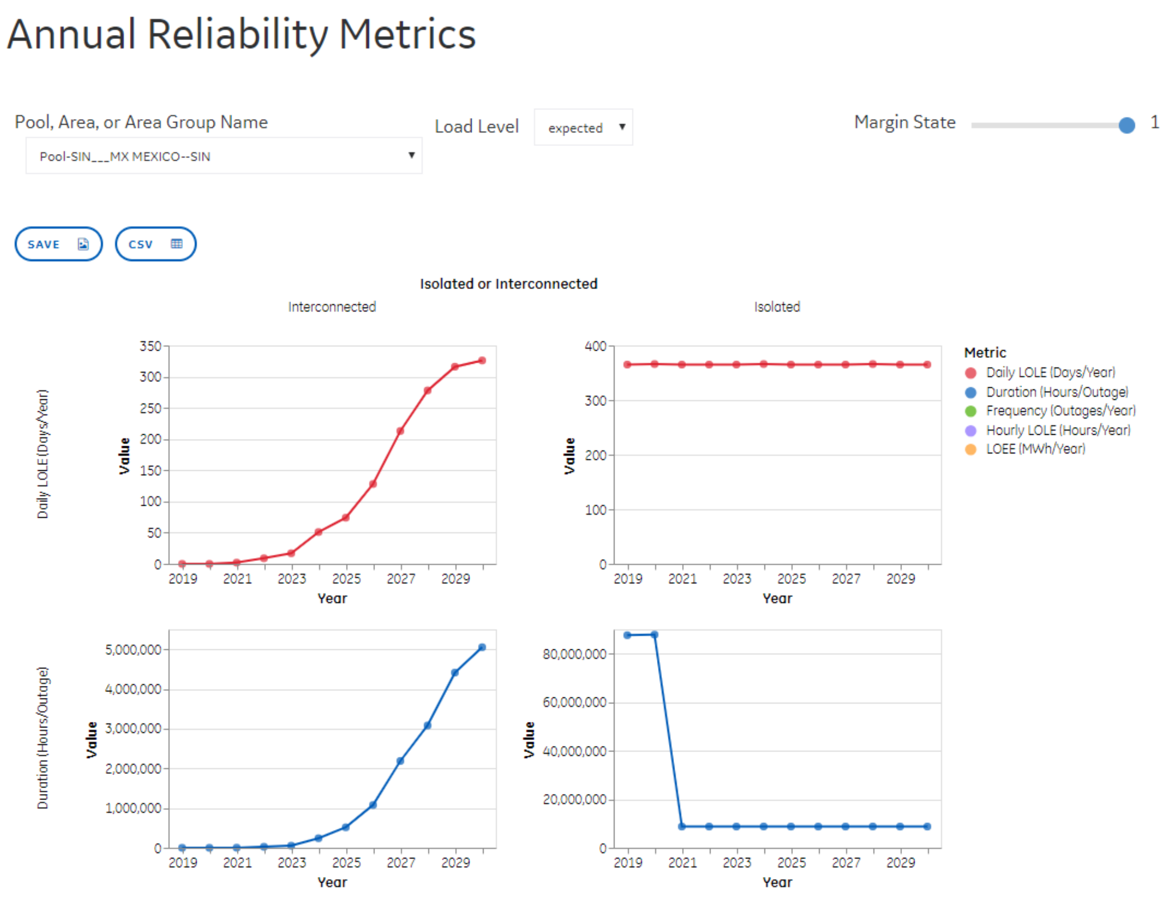
Read input data from a source MIF, csv file, or outputs of a previous case and write properly formatted input tables.

Can optionally apply overrides similar to MARS to give final data which will be used in the simulation.

```
python
Python 2.7.14 |Anaconda, Inc.| (default, Oct 15 2017, 03:34:40) [MSC v.1500 64 b
it (AMD64)] on win32
Type "help", "copyright", "credits" or "license" for more information.
>>> import snappy
>>> table = snappy.InputTable('mars', 'UNT-MXCP-00')
>>> print table
&UNT-MXCP-00       UMC
*         THERMAL-UNIT-MAXIMUM-CAPACITY
*-----------------------------------------------
*      EFFECTIVE     UNIT NAME     MAXIMUM RATING
*         DATE                          (MW)
*-----------------------------------------------
*                                      .CAP.
*-----------------------------------------------
*       MMMYYYY       AAAAAAAA       ##########
*       -------       --------       ----------

;;;; END OF UNT-MXCP-00 ;;;;

>>>
>>>
>>> table.add_row(None, 'UNIT_1', 100)
>>> print table
&UNT-MXCP-00       UMC
*         THERMAL-UNIT-MAXIMUM-CAPACITY
*-----------------------------------------------
*      EFFECTIVE     UNIT NAME     MAXIMUM RATING
*         DATE                          (MW)
*-----------------------------------------------
*                                      .CAP.
*-----------------------------------------------
*       MMMYYYY       AAAAAAAA       ##########
*       -------       --------       ----------
                     "UNIT_1  "          100.00

;;;; END OF UNT-MXCP-00 ;;;;

>>> _
```

Creation of rich, HTML reports

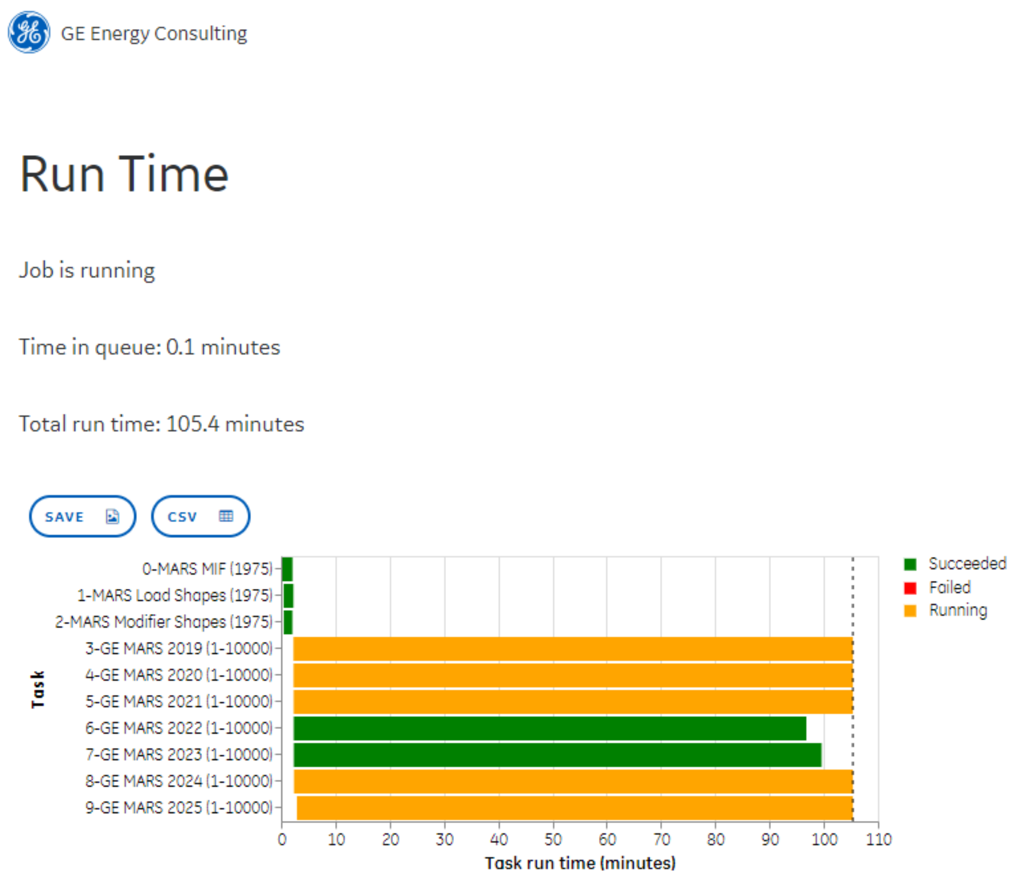
snappy.Report, snappy.Plot, snappy.Table



- Automate output report creation
- Automate input data visualization
- Creates interactive HTML files with a variety of data visualization options

Running Jobs

snappy.MARSJob, snappy.remote



- Automates simulation execution with options to add user defined post processing steps
- Parallelizes simulation across the number of workers specified by the user
- Logs errors during simulation
- Can be configured to run on a remote server with remote workers

GE MARS User Interface

GE MARS User Interface

Introduction

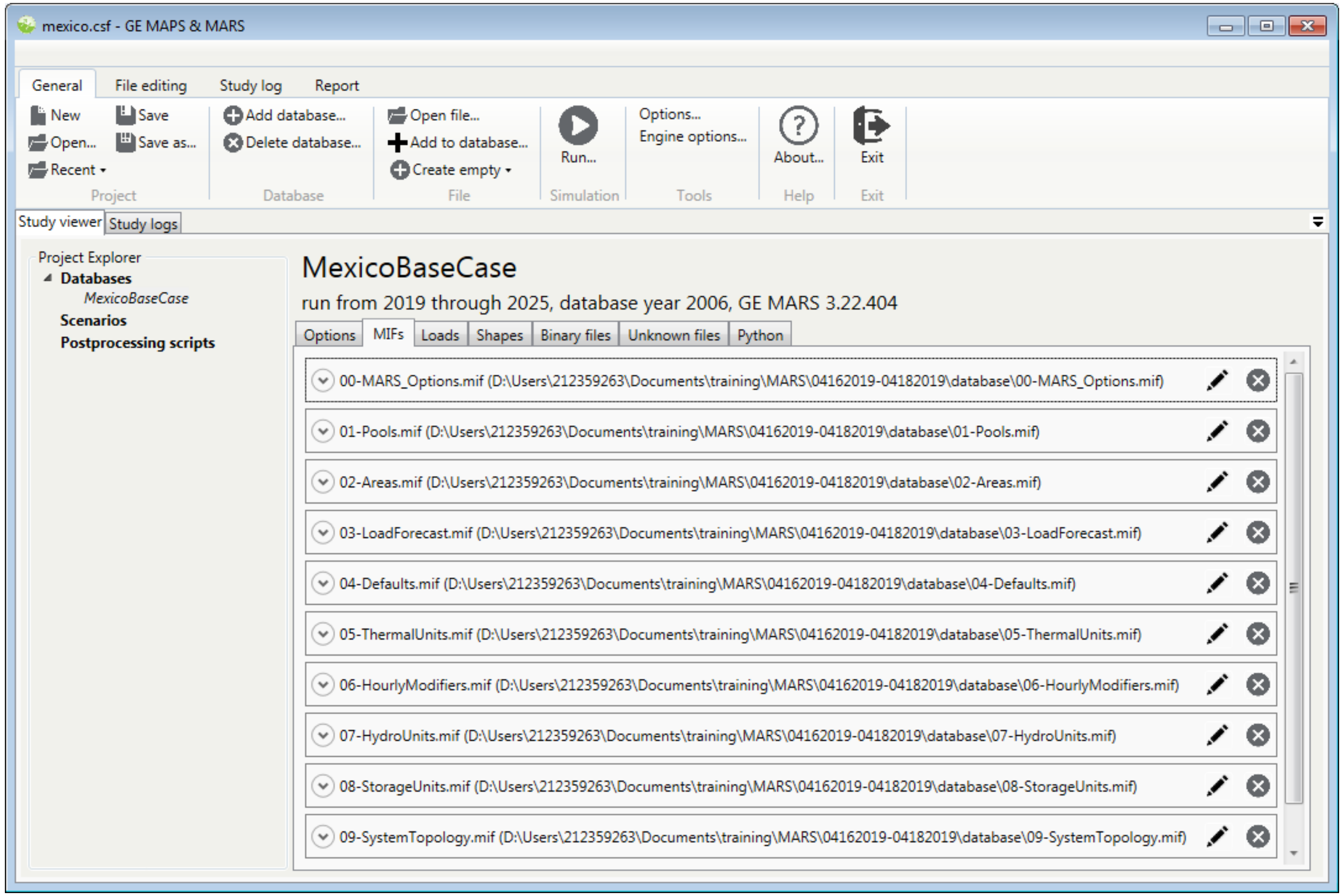
GE has developed a user interface for the GE MAPS and MARS simulation tools which manages input data, scheduling simulations, and viewing output data.

The user interface acts as a client using the snappy python API as a backend. This architecture allows for simple scaling to a parallel processing environment.

The user interface will be officially released to all GE MARS customers at the conclusion of this training.

GE MARS User Interface

Study Viewer

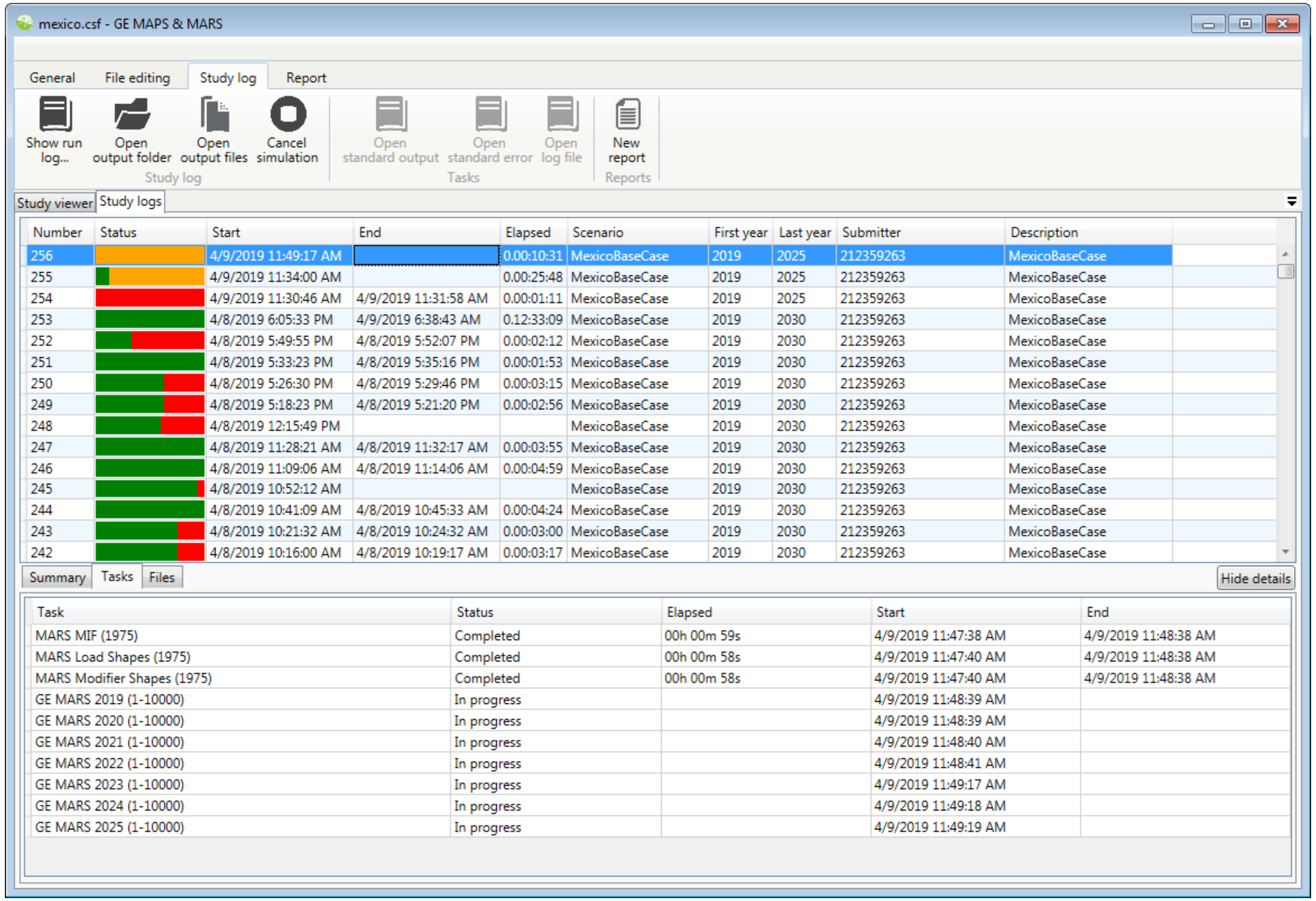


- Manages input files and simulation options
- Organizes inputs into ***Databases*** and ***Scenarios***
- Is the gateway for running simulations and editing data

GE MARS User Interface

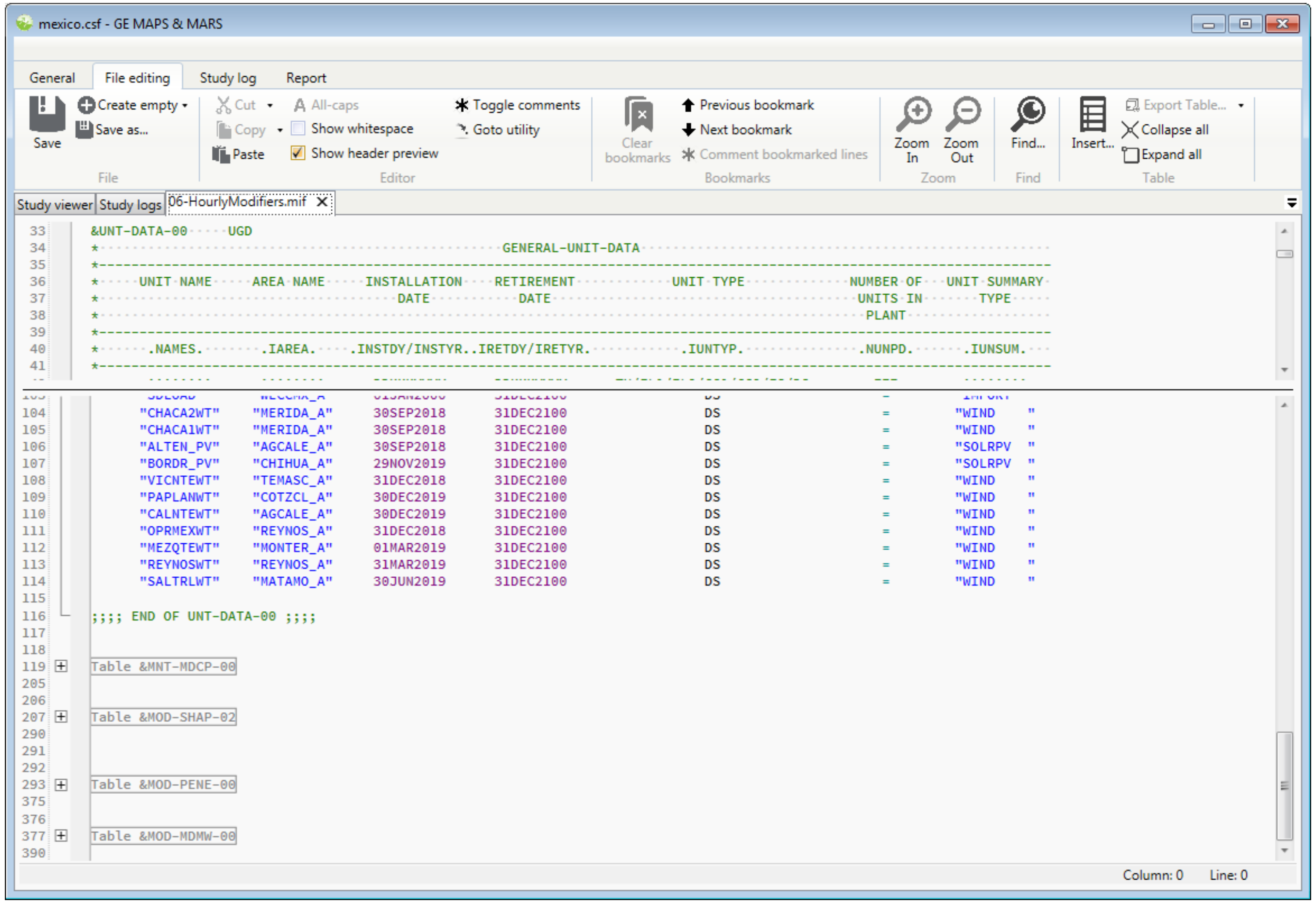
Study Logs

- Displays information about the status of a simulation as well as detailed information about the tasks in the simulation
- Provides access to standard error and output files
- Is the gateway for creating reports based on the results of the simulation



GE MARS User Interface

File Editor

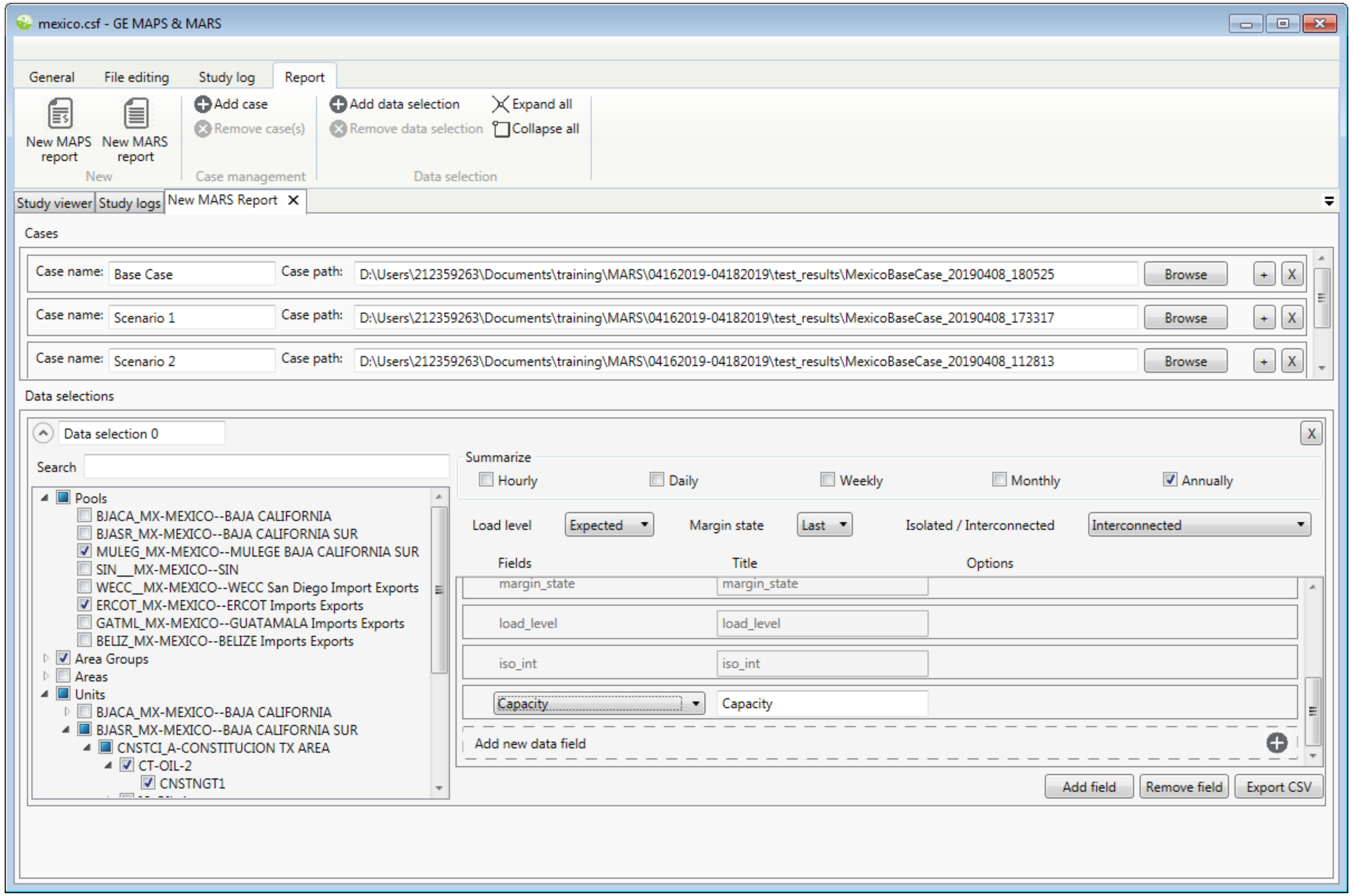


- Interface for editing Input Data Files
- Provides convenient tools to simplify editing for the user
- Has basic syntax highlighting to help decrease data errors

GE MARS User Interface

Output Reporting

- Graphical interface to the snappy API
- Allows the user to extract results from multiple simulations and years



GE

Introduction to the Sample System

Mexico Electricity Deregulation

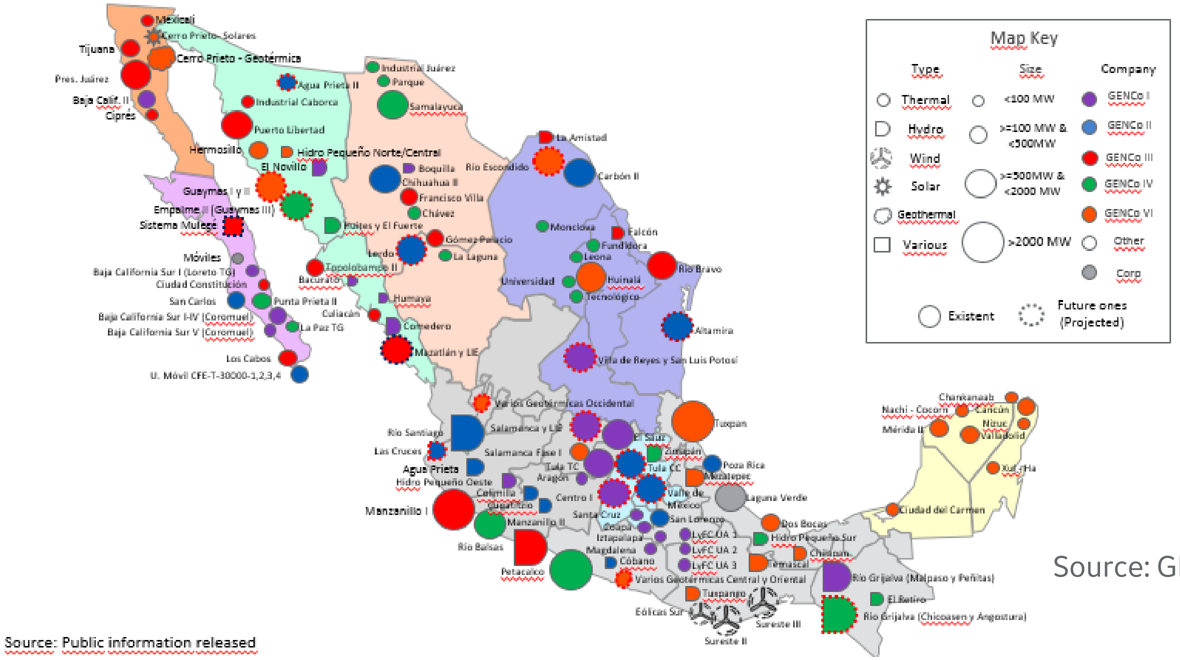
In August 2014, the Electric Industry Law was promulgated as part of the energy reforms in Mexico. This changed the market from a centralized and highly regulated market with a single monopoly entity, Comison Federal de Electricidad (CFE), into the deregulated market that has been operating for the past two years.

In 2016 CFE was unbundled vertically between its network, generation and retailing activities.

In 2017 CFE generation was unbundled horizontally, split into 6 separate generating companies (GENCOs or ESBs) to encourage competition at the generator level. GENCO V manages the IPP projects.

The reforms are also intended to remove existing subsidies for electricity as well as the fuels markets.

The CFE horizontal split was done both geographically as well as by technology or fuel type. Each generation company should be able to stand on it's own financially. This separation would achieve the best competitive outcomes for the new market place.



Source: GE

Mexico / US Energy Market Comparison

Energy Market Development: Mexico vs US Implemented = ● In Progress = ◐ Not Implemented = ○	**Mexico**	**US ISO / RTO**	**US Non ISO / RTO**
Electric Markets Development			
Day Ahead Hourly Spot Market	●	●	○
Real Time Spot Market	●	●	○
Hour Ahead Market	○	◐	○
Capacity Market	◐	●	○
Ancillary Services	●	●	○
Renewable Energy Certificates (RECs)	●	●	●
Natural Gas	◐	●	●
Commodity Markets (Futures & Forwards)	◐	●	●
Locational Pricing (Basis) at Liquid Trading Hubs	◐	●	●

Source: **GE Energy Consulting**

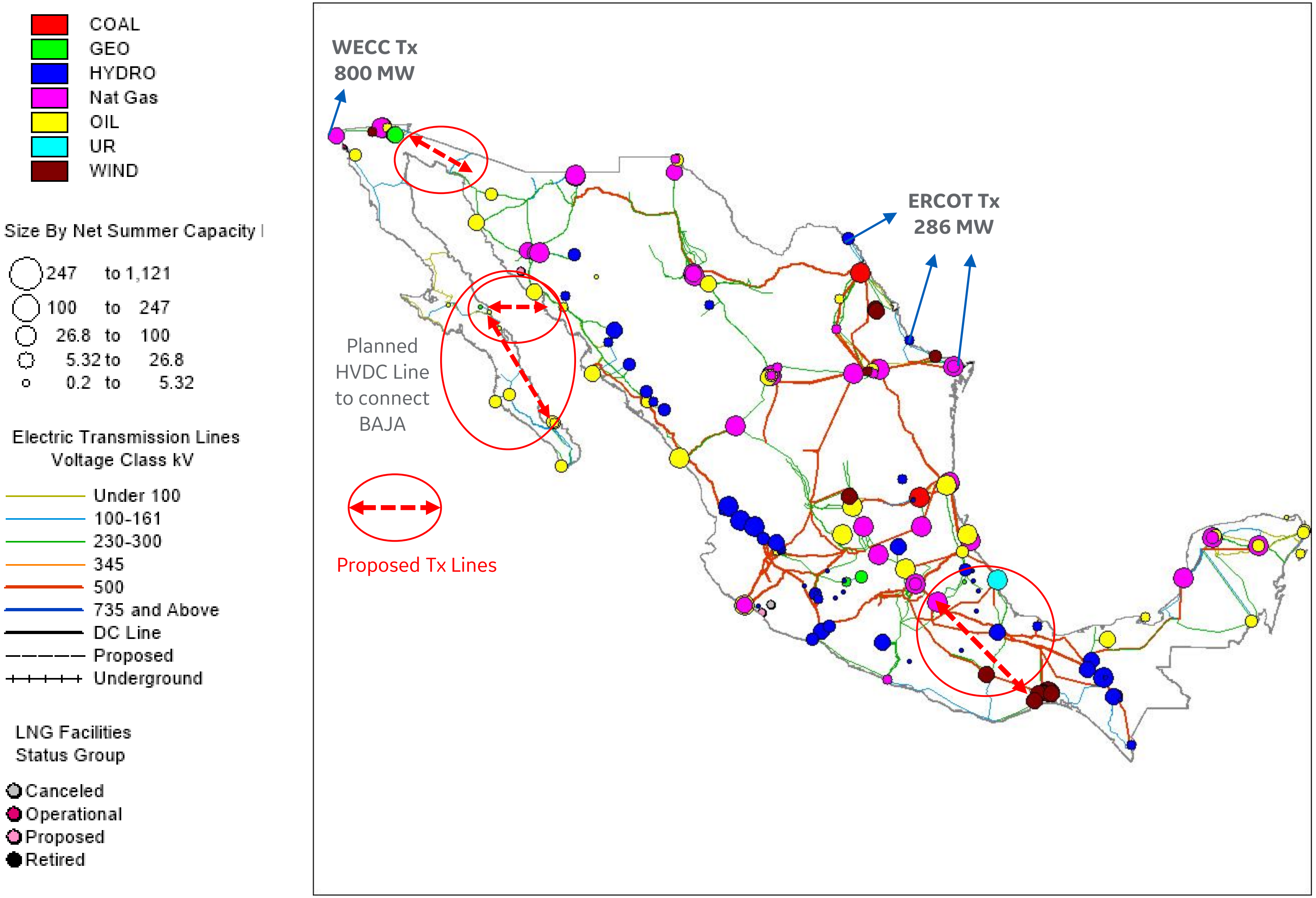
Energy Market

- 108 load and price nodes published by CENACE for both Day-ahead and Real Time Results. Total of 2000 nodes.
- Day-ahead Market (DAM)
  - ✓ Operating since February 2016.
- Real Time Market (RT)
  - ✓ Operating since January 2017.
- Hour-ahead Market (HA)
  - ✓ Has not yet been introduced.

Source: Ventyx

Mexico Energy Sector

Mexico Electric Infrastructure

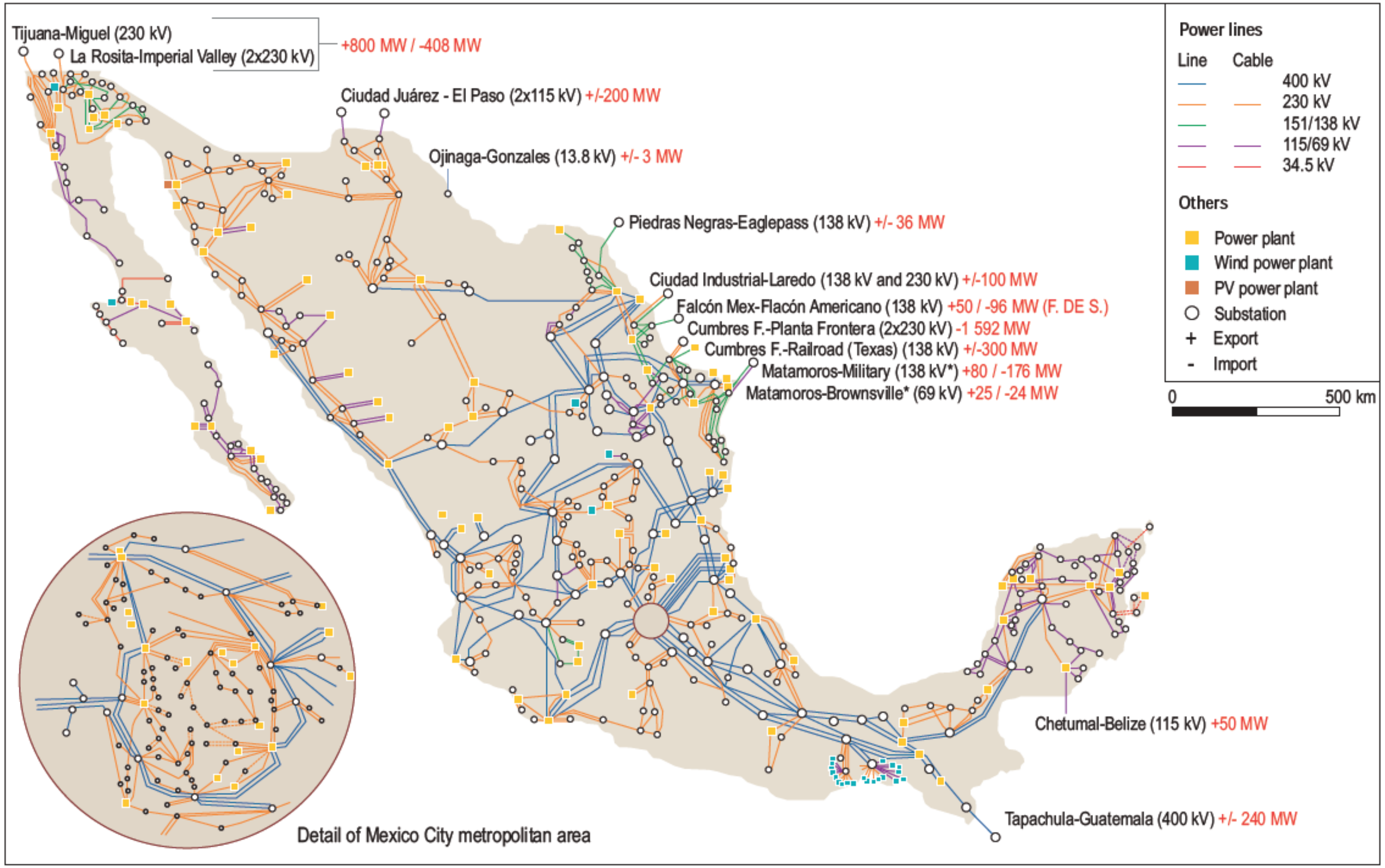


Mexico Power Indicators (Prodesen)	2016
Installed Capacity	69.9 GW
Generation (TWh)	315.4 TWh
Peak Demand (GW)	47.2 GW
Operating Reserve Margin*	25%
Annual Demand Growth	3.7%
Retirements by 2020 (GW)	27.5 GW
Installations for 2016-2020 (GW)	24.1 GW
Tx Interconnects to US (operating)	1086 MW
Net Annual Tx Flow to US 2015	6900 GWh

*Operating margin includes expected capacity at time of peak, after adjusting for seasonal availability and forced outages.

Source: GE Energy Consulting and ABB Velocity Suite

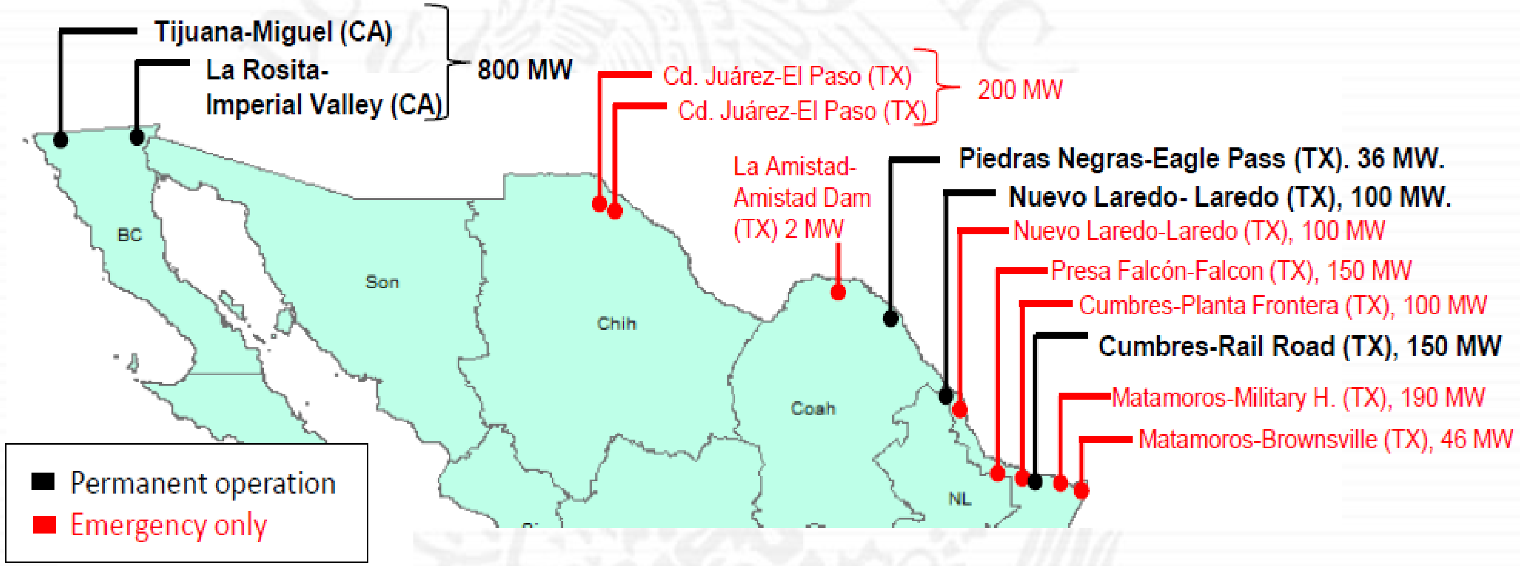
Transmission Network and Interconnections



- In 2014 total length of the high voltage Mexico transmission network is 52,815 km (from 230 to 400 kV) and the low voltage network (from 69 kV to 161 kV) is 58,660 km.
- CFE forecasts US $19.3 billion in transmission projects including 19,555 circuit-km of new transmission lines.
- CRE (Regulator) plans to allow tenders (ex-ante competition) to cooperate with CFE to develop new transmission links.

Mexico Electric Interfaces with US

- Current Mexico-US interconnections:
  - 5 interconnections (1086 MW) in permanent operation.
  - 8 interconnections (788 MW) for emergency backup.

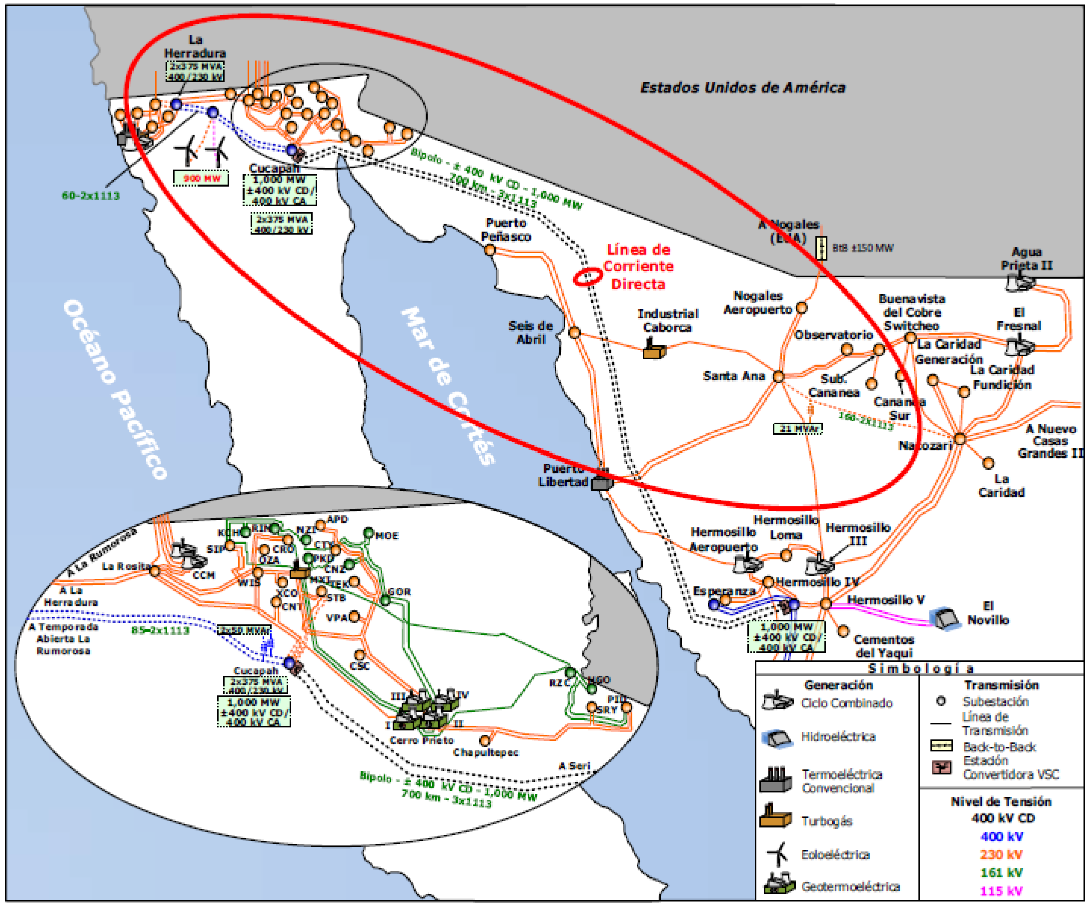


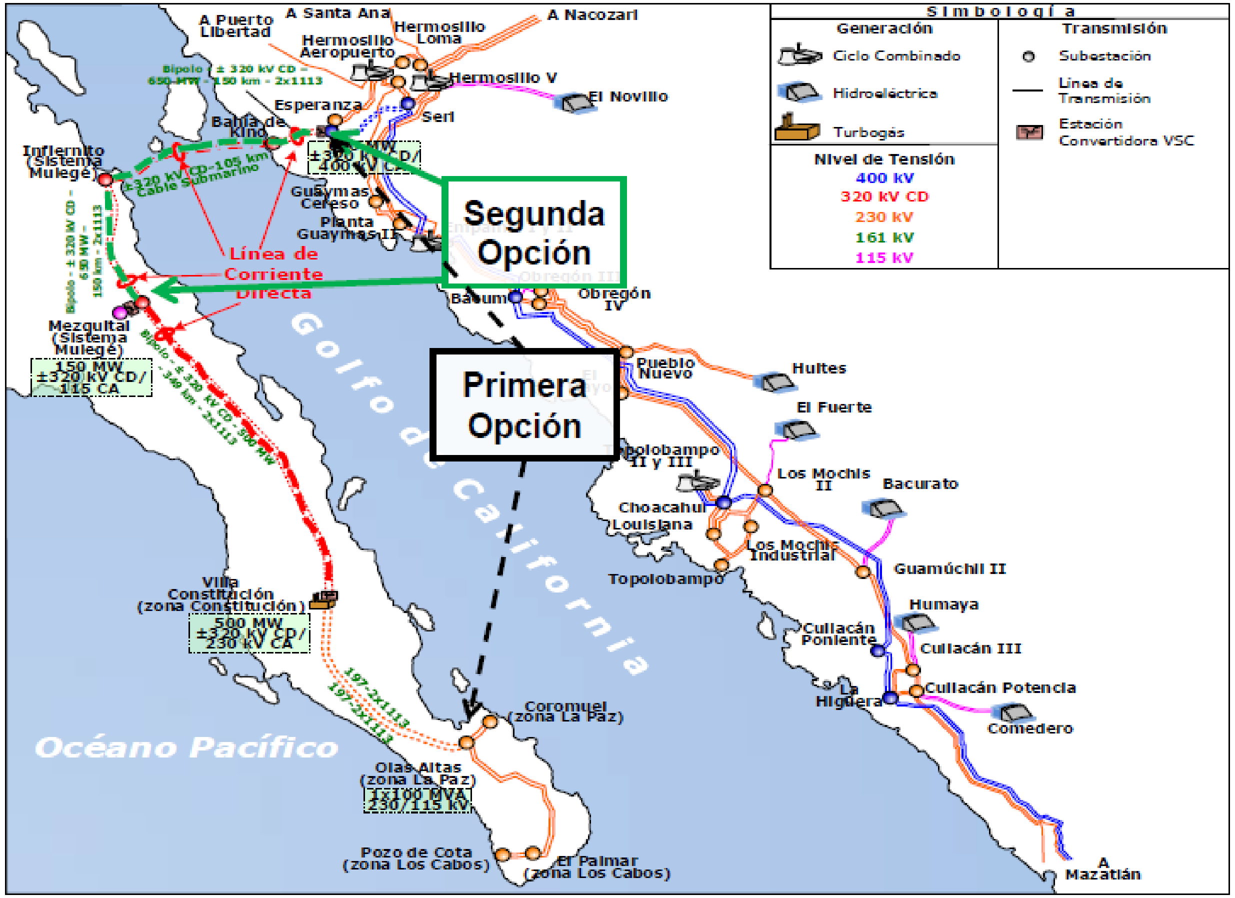
- Electrical Interconnections to the US from WECC & ERCOT
- 5 interconnection (1086 MW) operate economically and 8 interconnections (788 MW) are for reliability only.
- Largest economic interface (operational) ties into CAISO (WECC).
- Mexico transitioned to a net *exporter* of electricity in 2003 however the volume of exports are not significant.

Source: Jeff Pavlovic, SENER

Mexico Proposed Transmission Expansions

MAJOR PLANNED TRANSMISSION WORKS BAJA CALIFORNIA

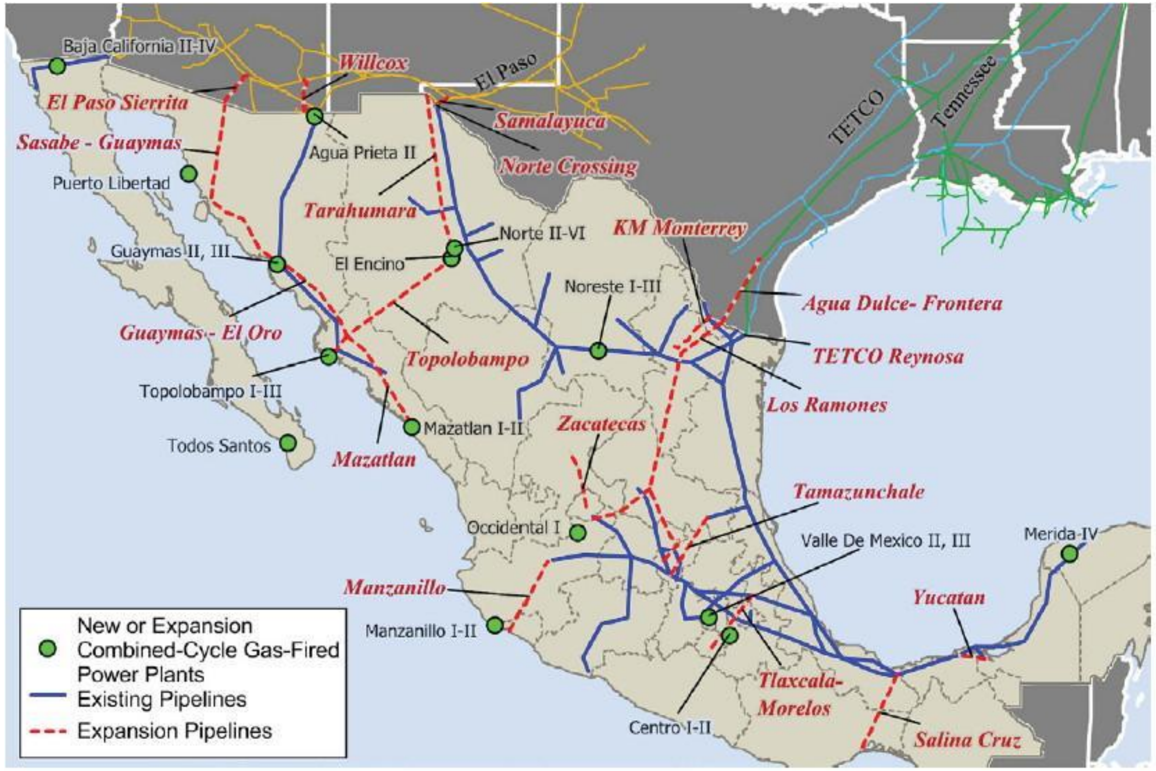


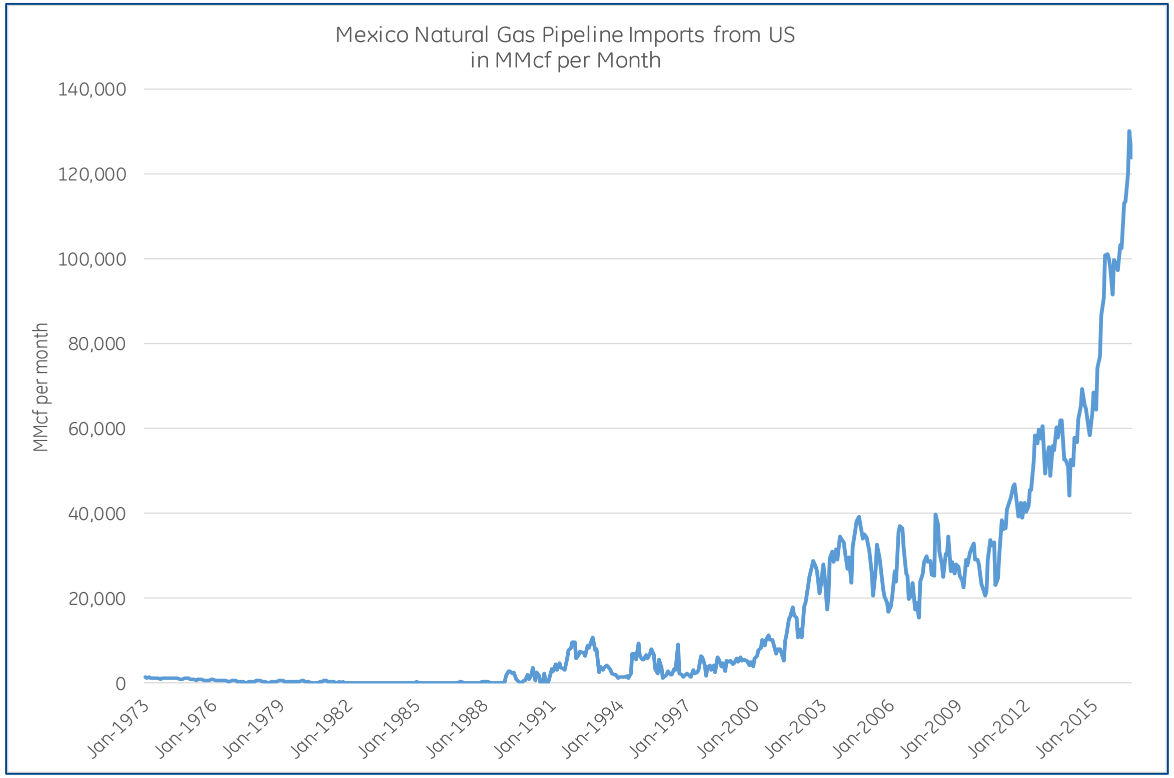


Baja, Mulege and Baja Sur are three islanded systems from the Mexico grid (Baja is connected to WECC but not remainder of Mexico). Proposals above to interconnect these three systems to the rest of Mexico (SEN).

Source: PRODESEN

Mexico Natural Gas Pipeline Infrastructure

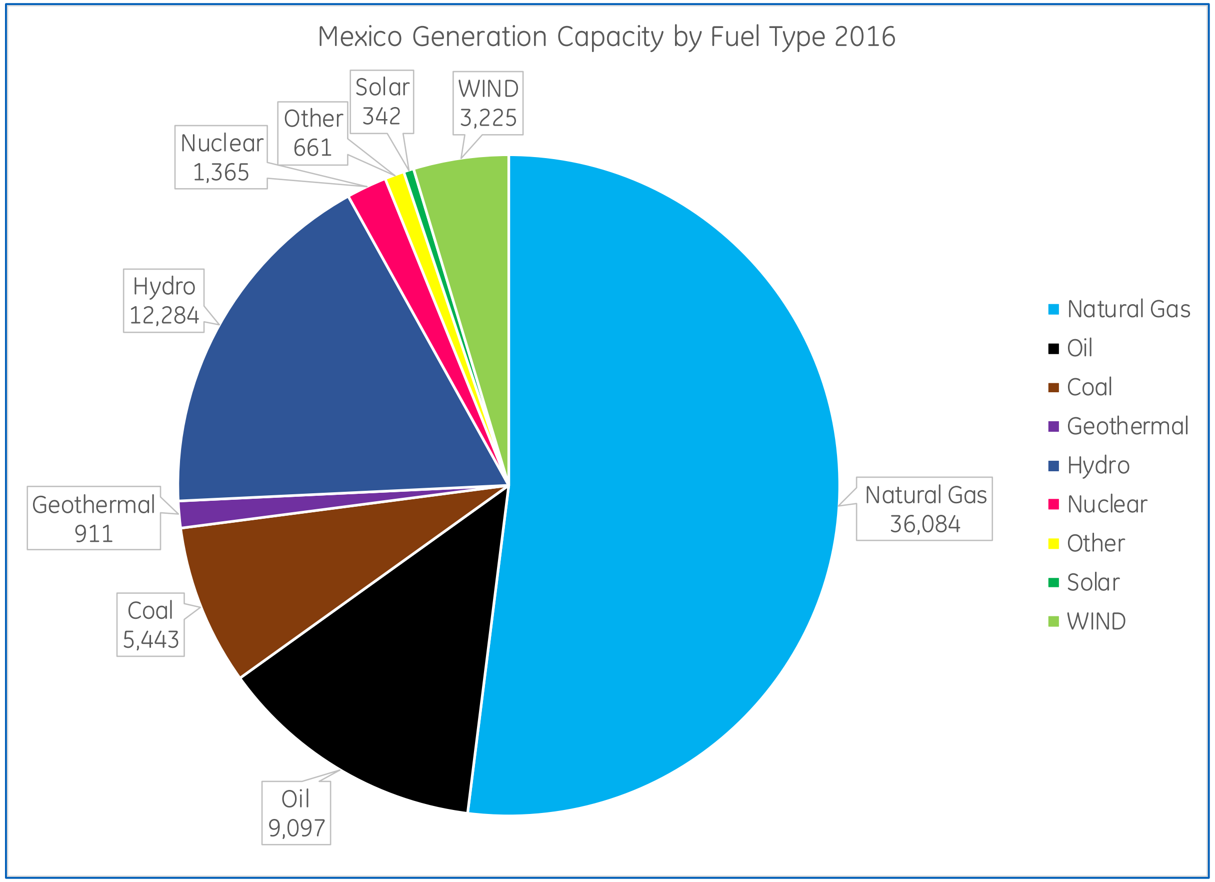




- Mexico has a declining domestic natural gas production capability and is unable to meet the growing demand, particularly from the power generation sector.
- With introduction of competitive electricity markets, imported natural gas from the US is expected to grow substantially.
- This will also require significant new pipeline infrastructure to accommodate these natural gas growth demands.

Source: Platts and EIA and GE Energy Consulting

Mexico Capacity Mix 2016

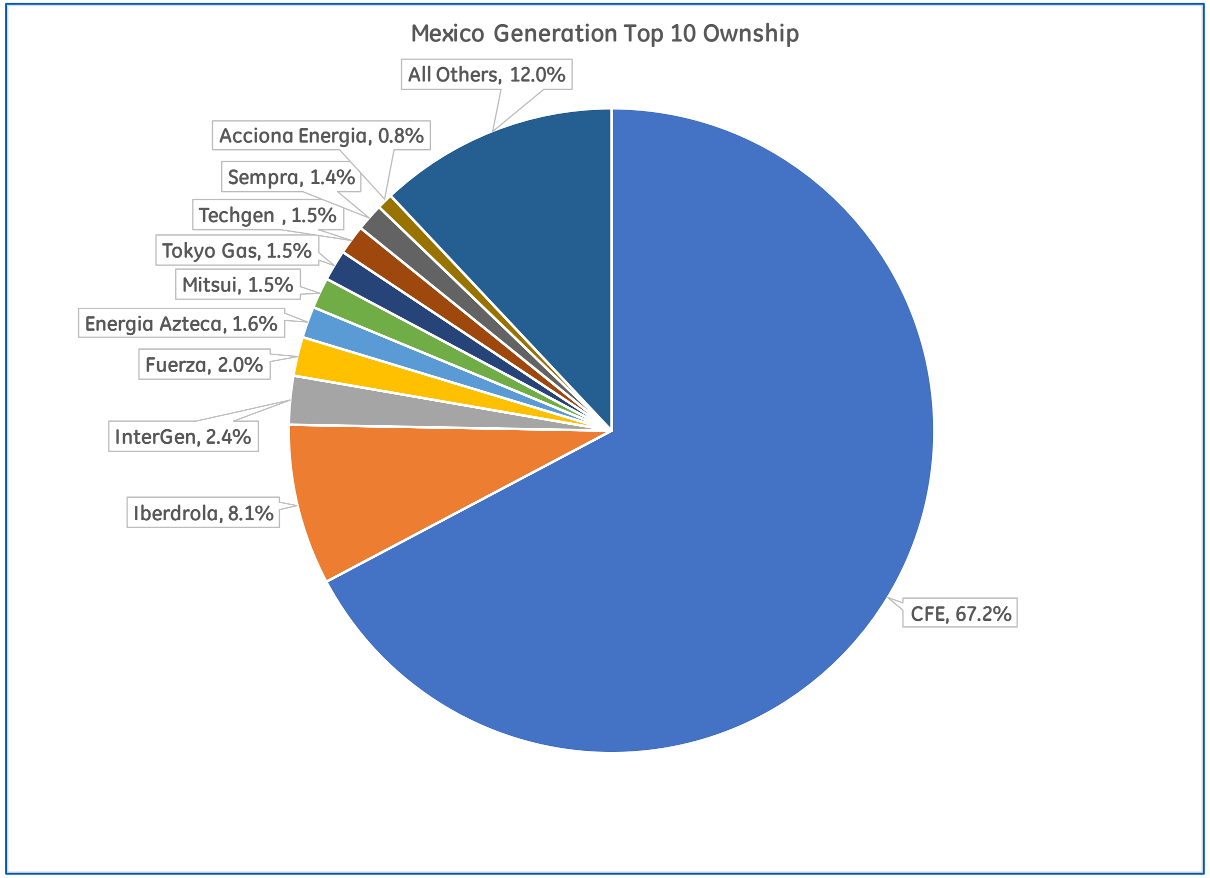


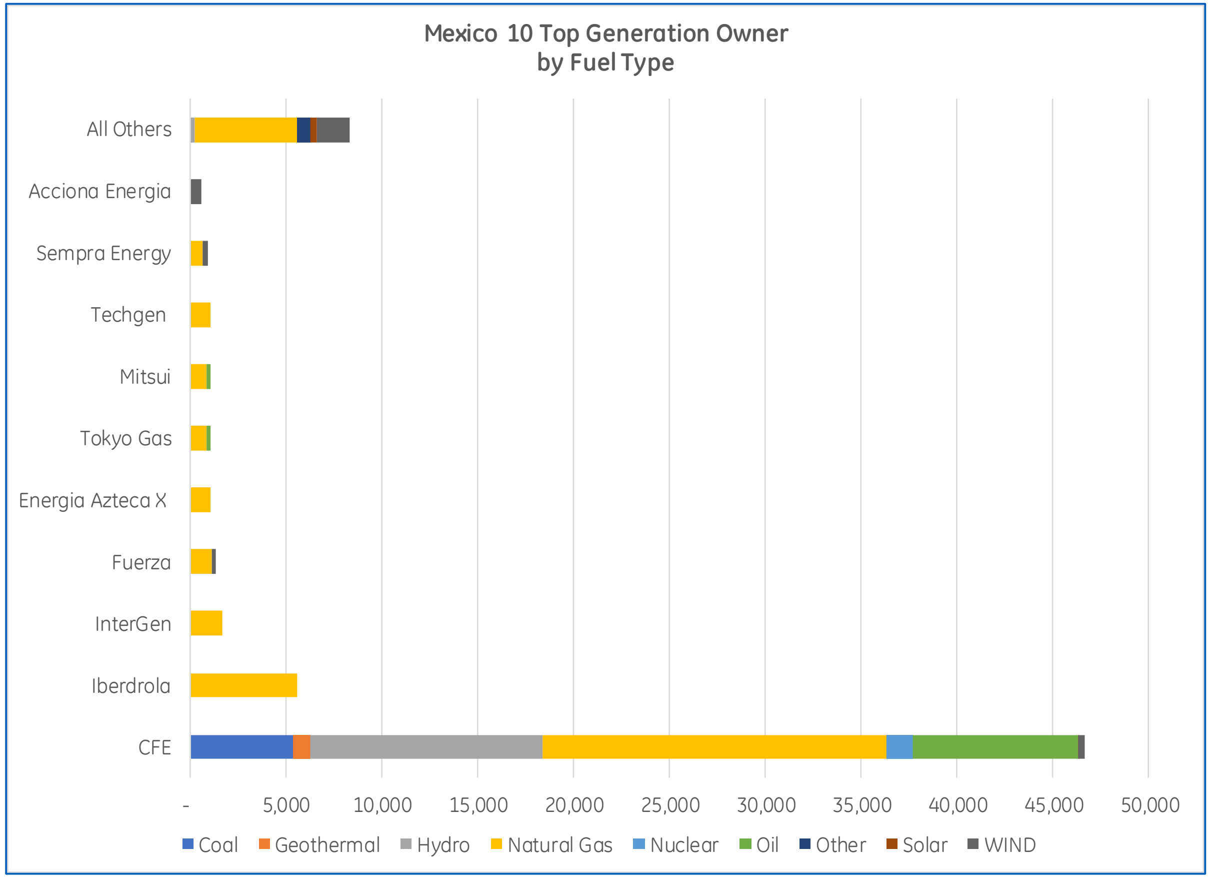
Existing Generation Capacity

- Mexico has a good mix of generation technologies. It has several base load coal primarily located in the southwest; nuclear generation fleet; a substantial geothermal fleet on the west coast; natural gas fleet; and growing wind and solar.
- In 2016, 83% of total generation capacity is owned by CFE, the existing electric utility. This includes private IPPs that currently offer all of their generation to CFE.
- CFE has since been disaggregated into several GENECO's (ESB's) in 2017.
- The remaining 17% of capacity belongs to private investors including independent power producers (IPPs); self-supply for industrial load; cogeneration; small production and export projects.
- Renewable capacity concentrated in hydro-electric, geothermal, wind and solar.

Source Ventyx

Mexico Top 10 Generation Owners 2016

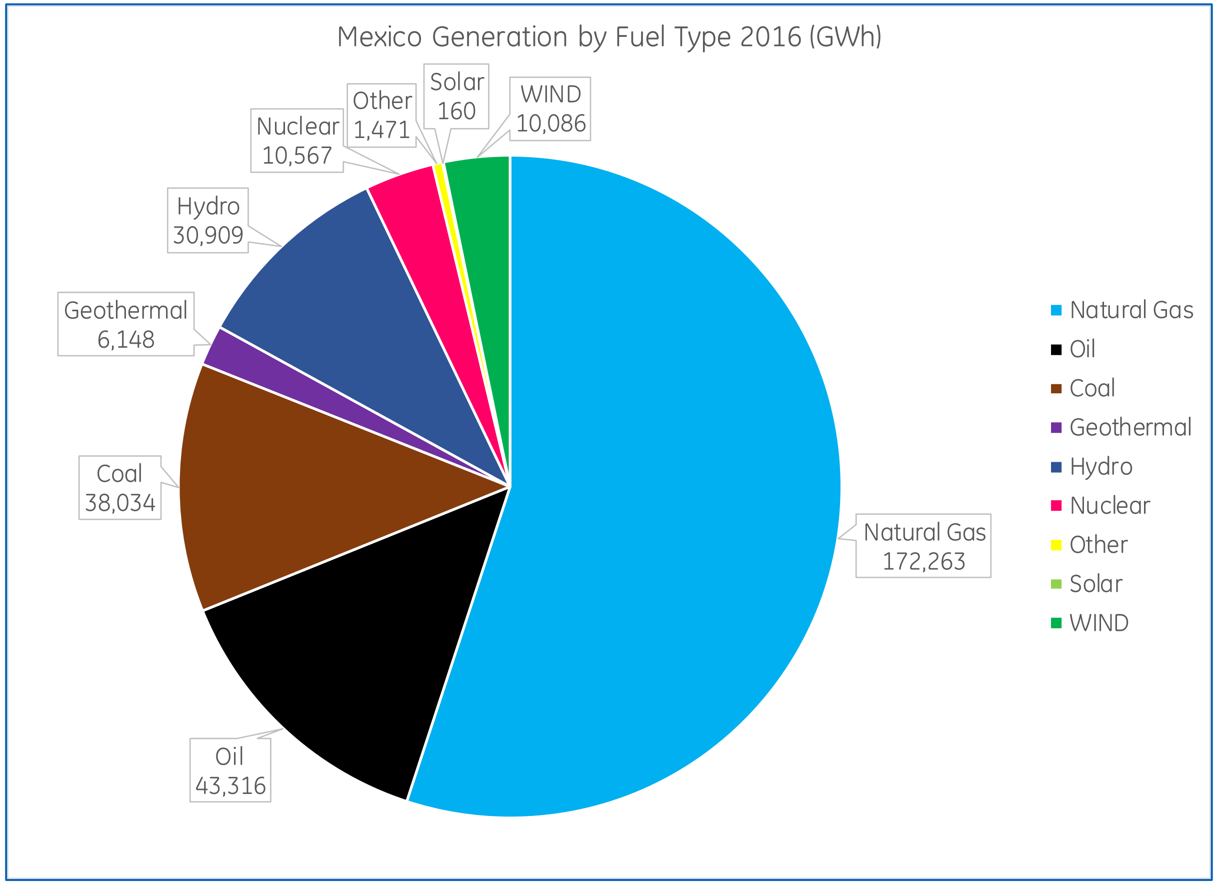




- CFE was the largest owner of generation prior to its breakup in different GENCO's (see Market Developments below)

Source Ventyx

Mexico Energy Mix 2016

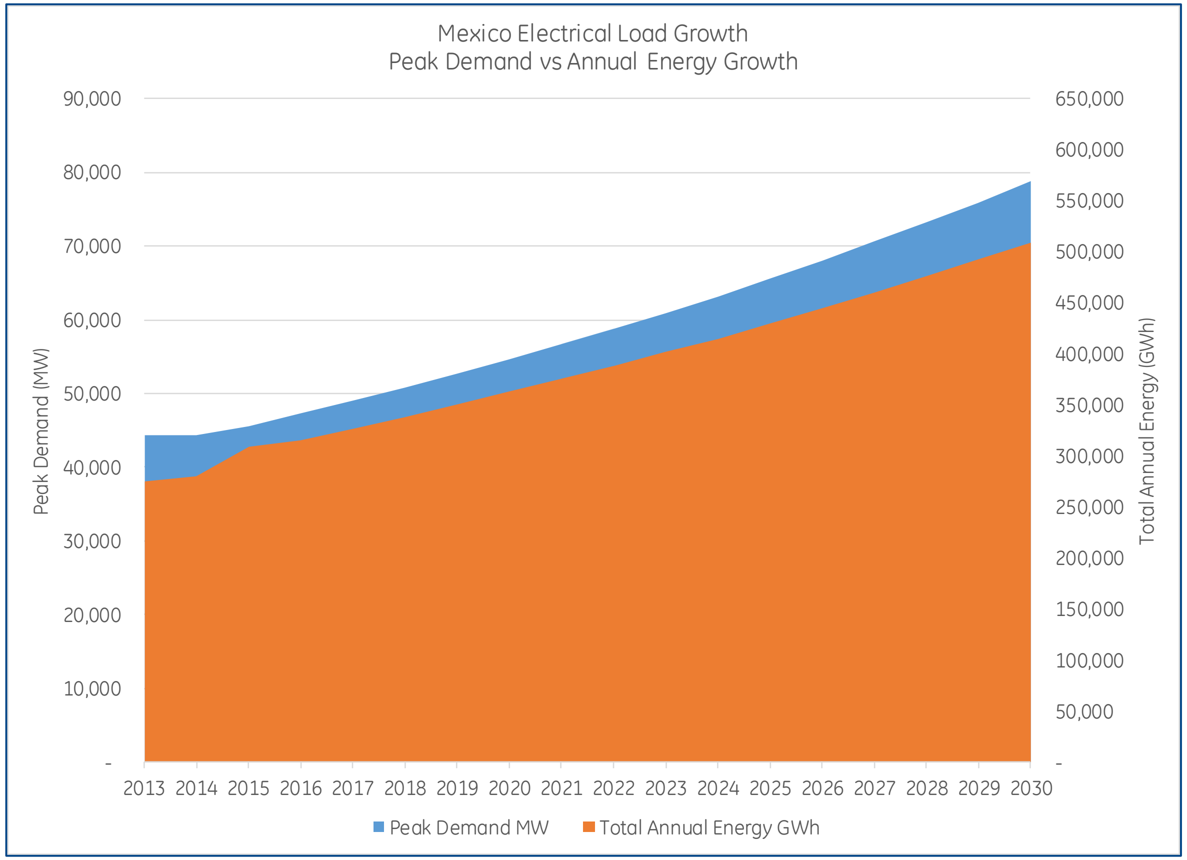


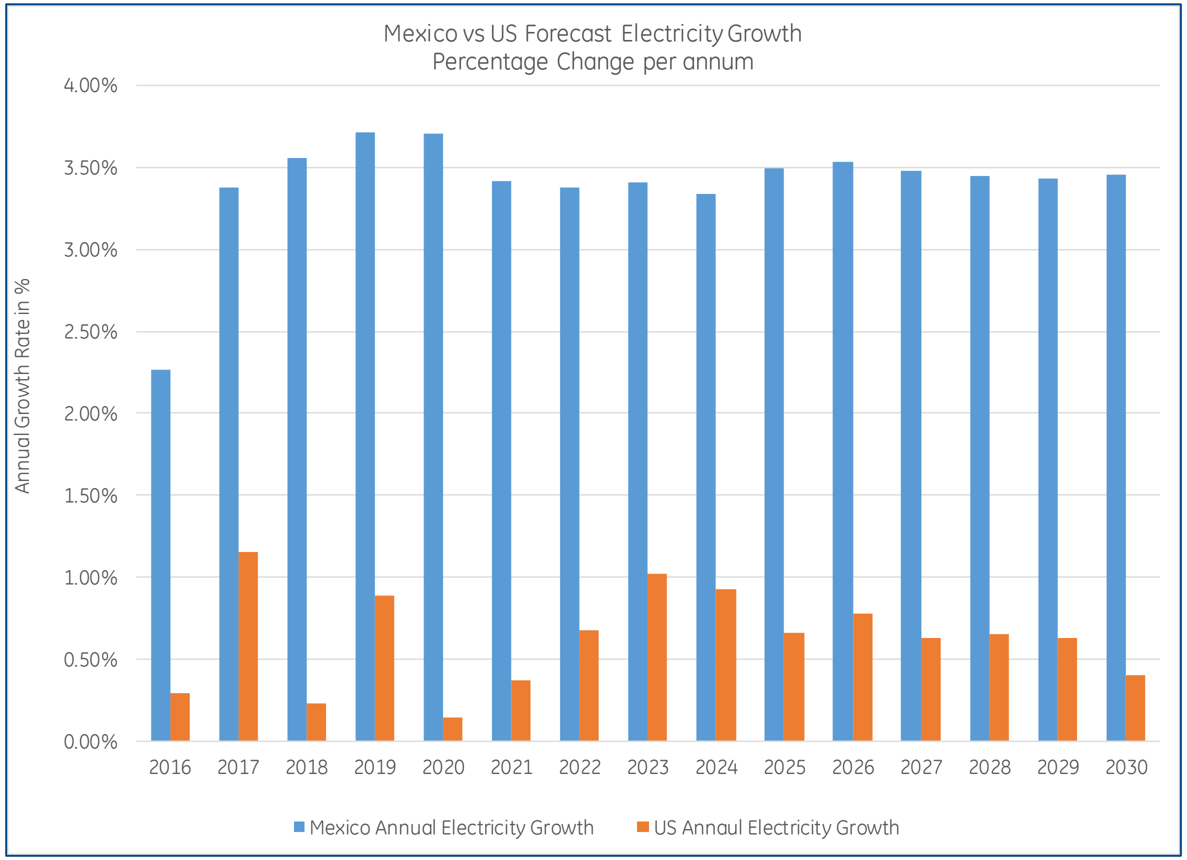
Existing Generation

- Natural gas is an increasing share of the total generation mix.
- Oil generation includes dual fuel thermal steam units and internal combustion turbines.
- Part of the reforms of the energy sector is to decrease the dependence oil generation and improve the sector's overall efficiencies.
- As such, oil will see a declining share of generation except in some pockets with limited natural gas infrastructure (notably Baja California Sur and to some extent in Peninsula).
- As oil generation declines, LMP prices will also decline. This is consistent with experiences in the early histories of other newly regulated electricity markets, including NYISO and ISONE.

Source PRODESEN

Strong Electric Forecast Growth

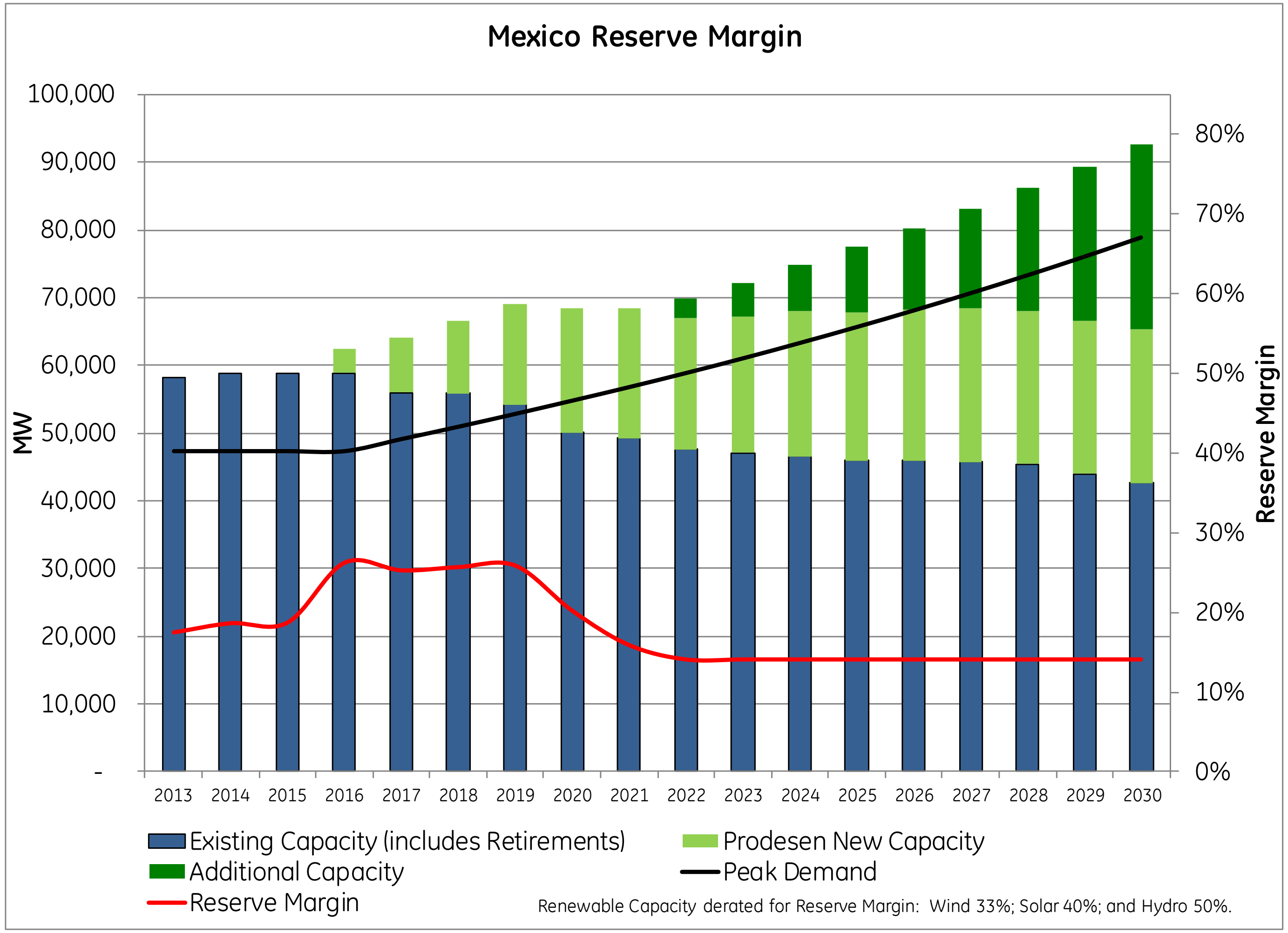




Mexico has strong electrical growth in the past decade and forecast compound annual growth rate is 3.7% compared to 0.7% in the US from 2016 to 2030.

Source: PRODESEN, EIA and GE Energy Consulting

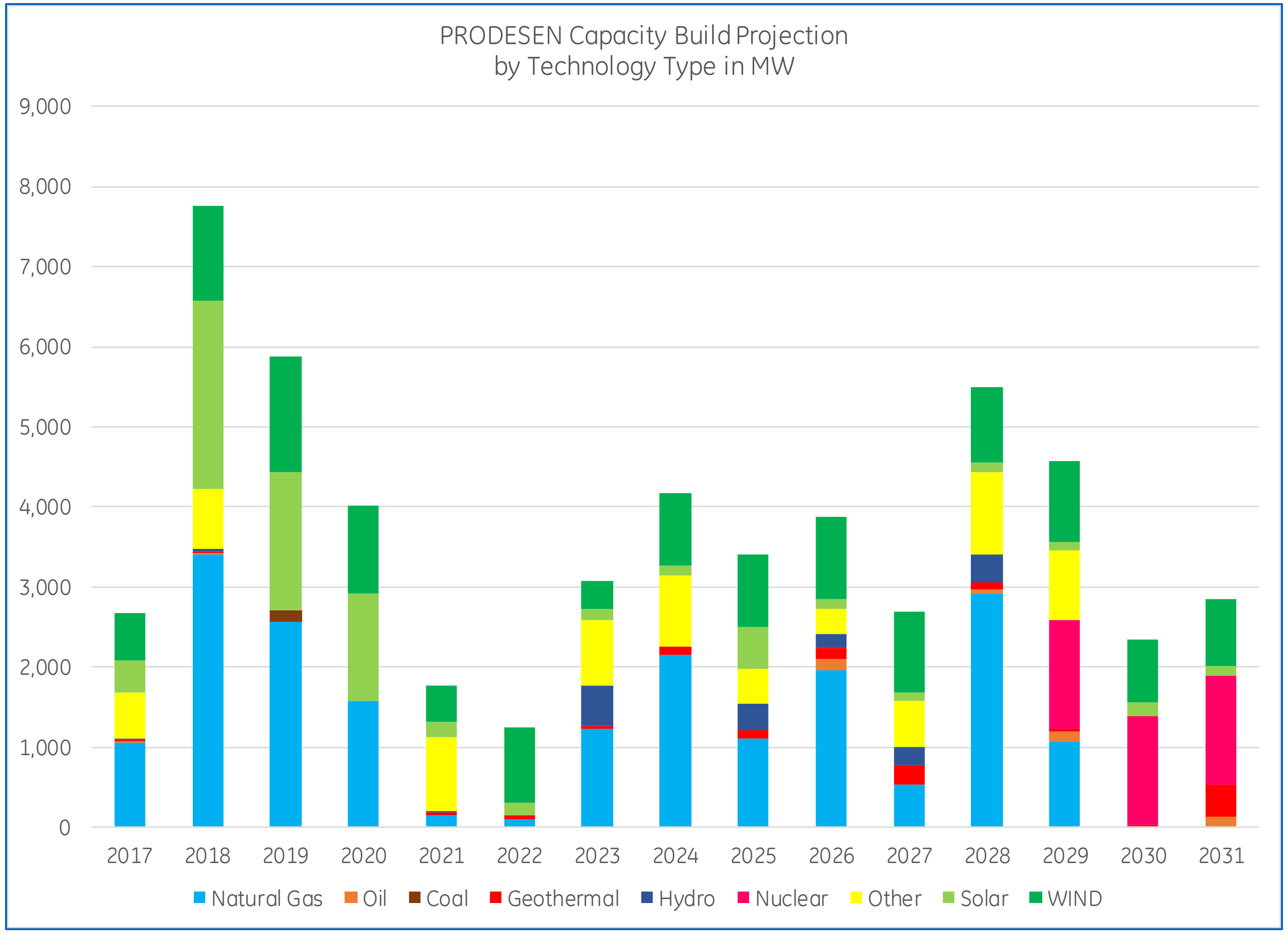
Mexico Reserve Margin Forecast



- Older and inefficient generation, including conventional steam plants fired by gas or oil and smaller simple cycle and internal combustion generation, are expected to retire over time. This contributes to the decline in existing capacity.
- We have included PRODESEN generation builds through 2023. Thereafter, we have included additional economic generation capacity expansions to meet load growth.
- Reserve Margin is assumed to be 15%.

Data Source: PRODESEN Analysis: GE Energy Consulting

Mexico Forecast Generation Capacity (MW)

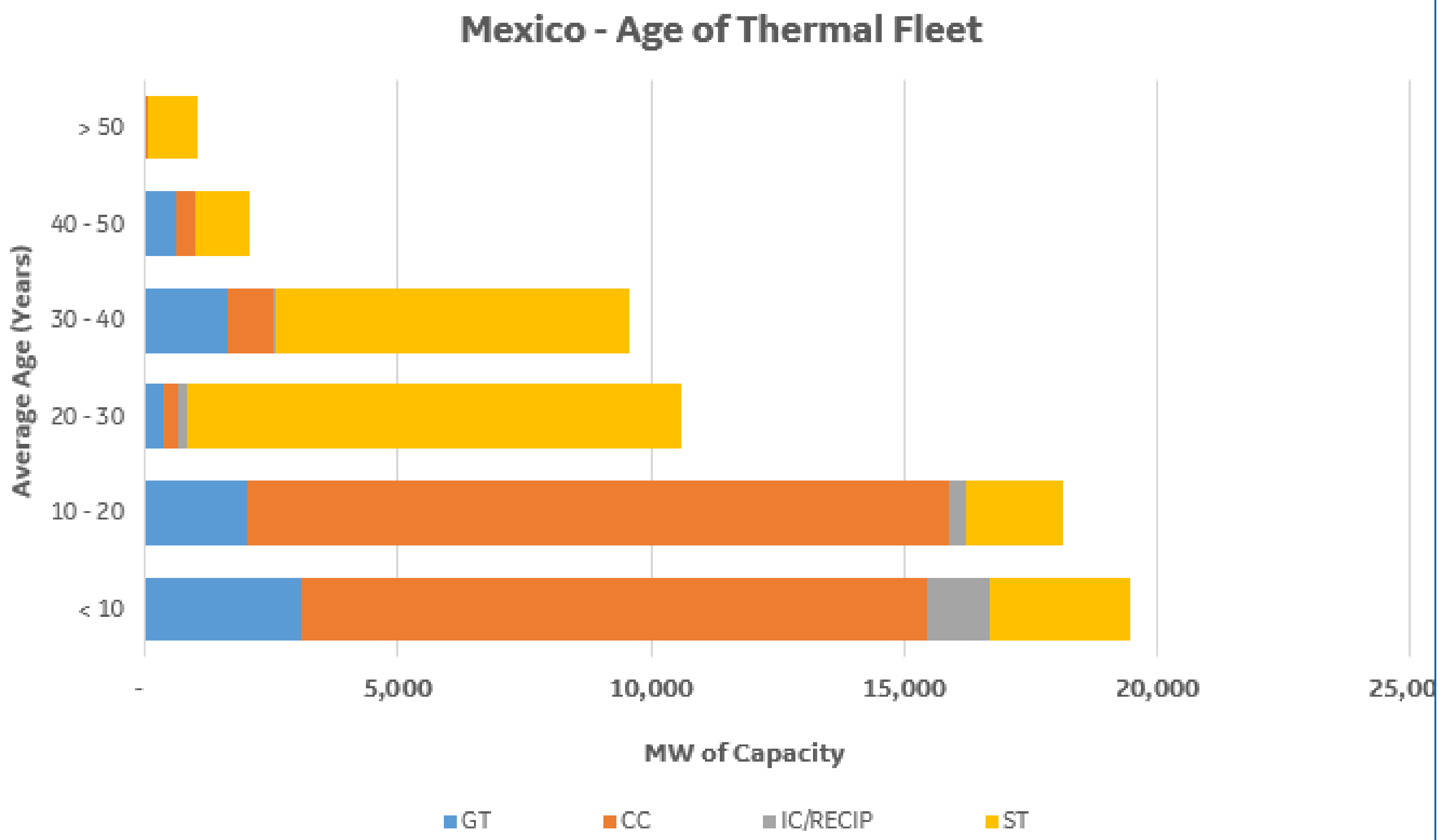


New Generation Capacity

- PRODESEN (SENER) projection of 55,840 MW of additional generation capacity for 2017-2031.
- Thermal technologies capacity expansion 32,962 MW over the same period, or 59.0% of the total.
- Renewable technologies capacity expansion is projected to be 22,878 MW or 40.1% of the total.

Source PRODESEN

Mexico Age of Generation Fleet

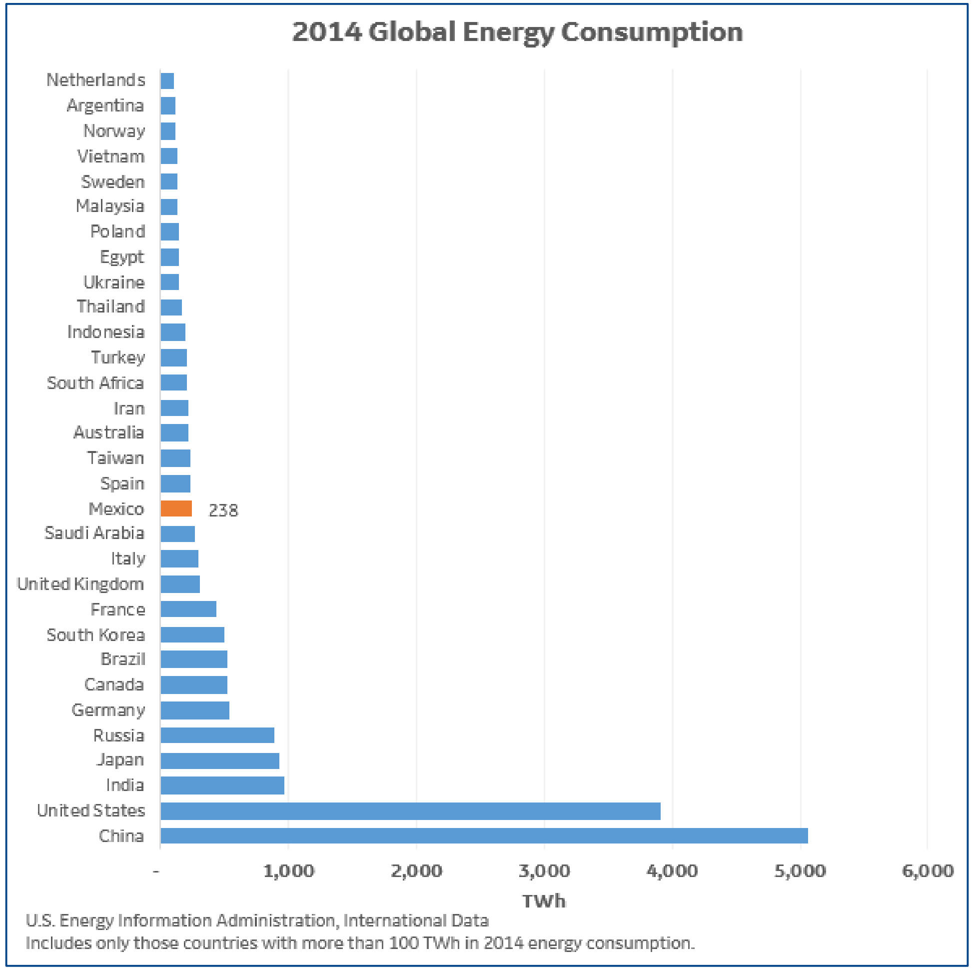


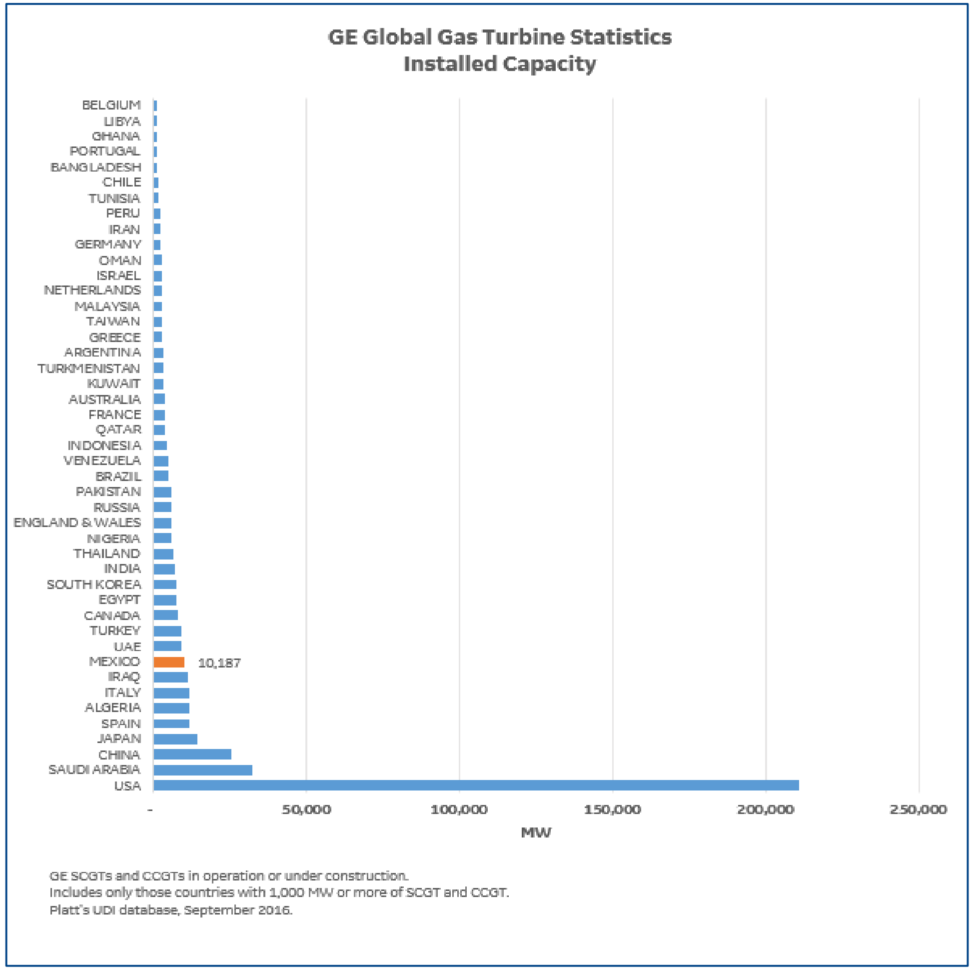
Includes thermal units in operation or under construction.
Platt's UDI database, September 2016.

- Large proportion of older and inefficient steam (ST) units which will likely retire in the coming years and replaced with efficient combined cycle units as well as renewables.

Source: Prodesen 2016   Analysis GE Energy Consulting

Mexico Ranking Energy and GE turbine fleet





Mexico is ranked within top 15 countries in terms of total energy consumption and within the top 10 in terms of GE Gas Turbines installations.

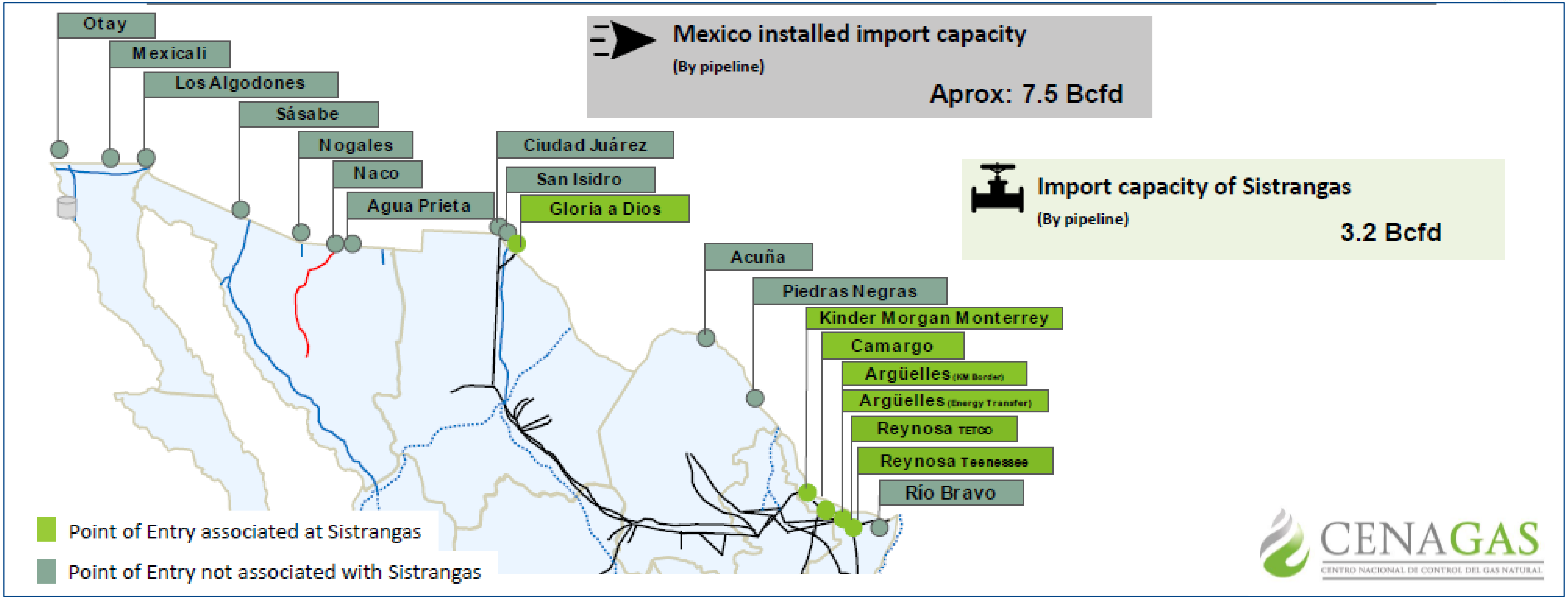
Source: EIA and Platts UDI

Natural Gas Developments

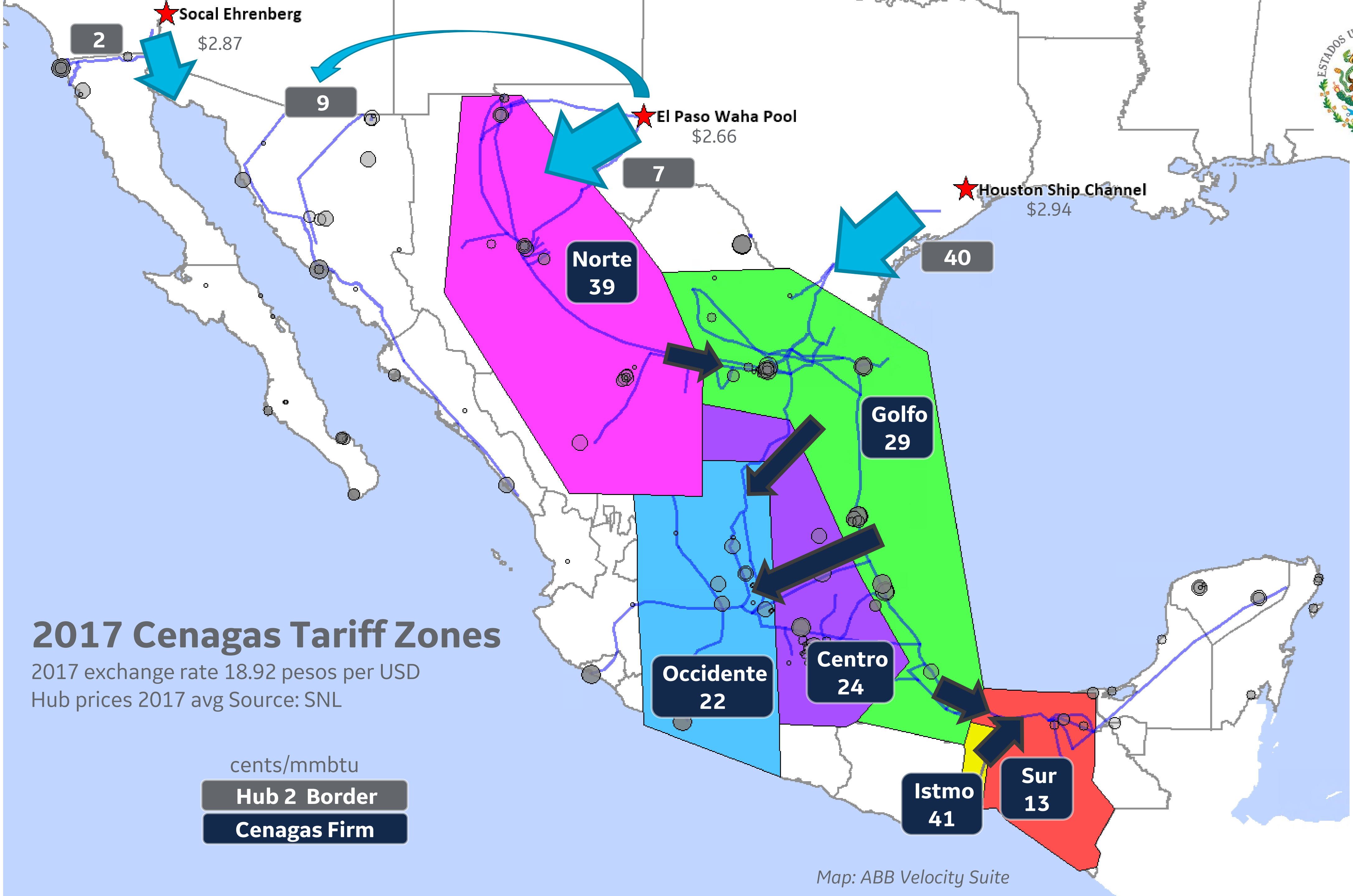
Mexico Natural Gas Grid & Sistrangas

Source: David Suarez, CENAGAS

Mexico Natural Gas Import Capacity



Source: David Suarez, CENAGAS



2017 Cenagas Tariff Zones

2017 exchange rate 18.92 pesos per USD
Hub prices 2017 avg Source: SNL

cents/mmbtu

Hub 2 Border

Cenagas Firm

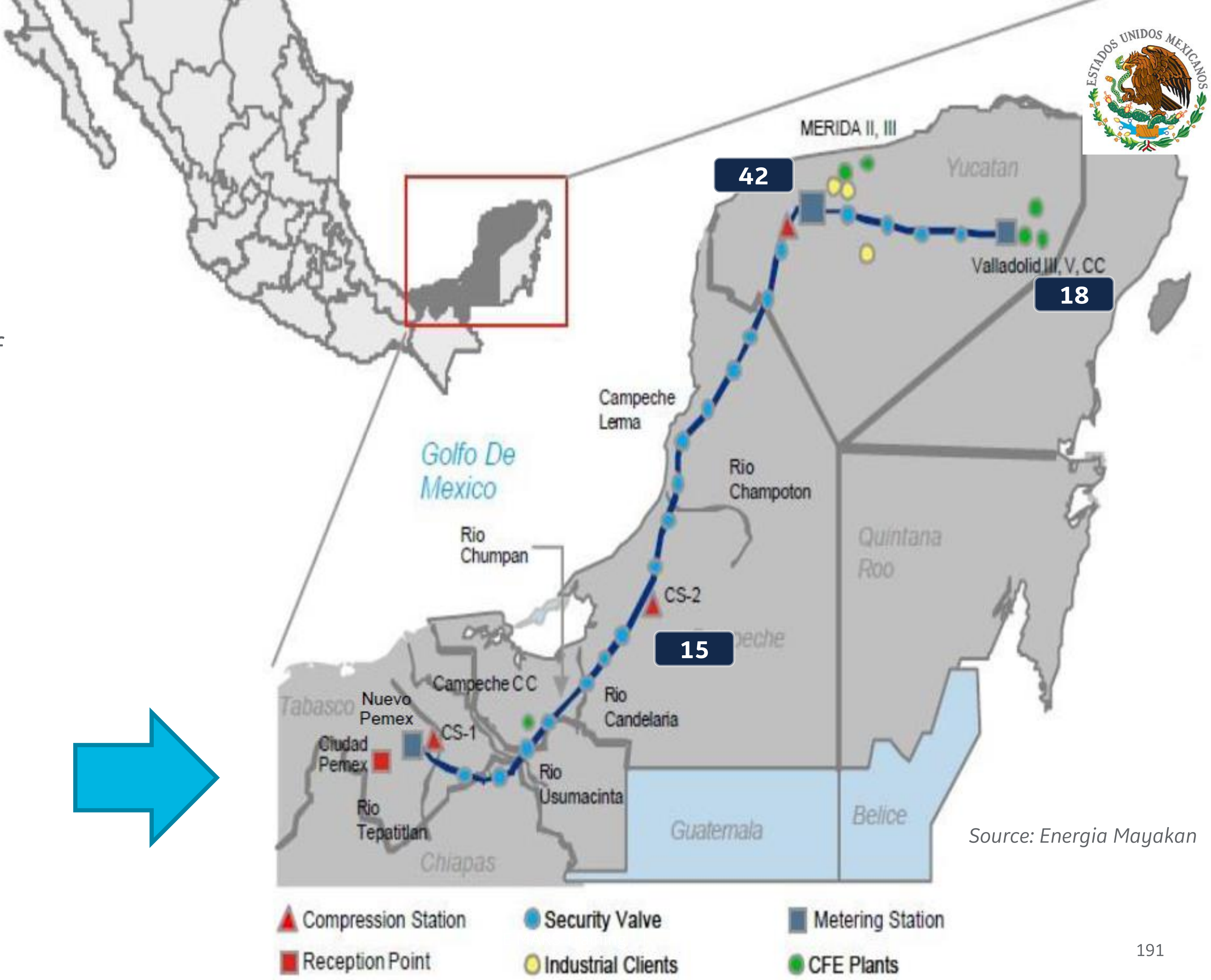
Energia Mayakan

Private Pipeline

Cents per MMbtu

Source: 2017 Mayakan Tariff

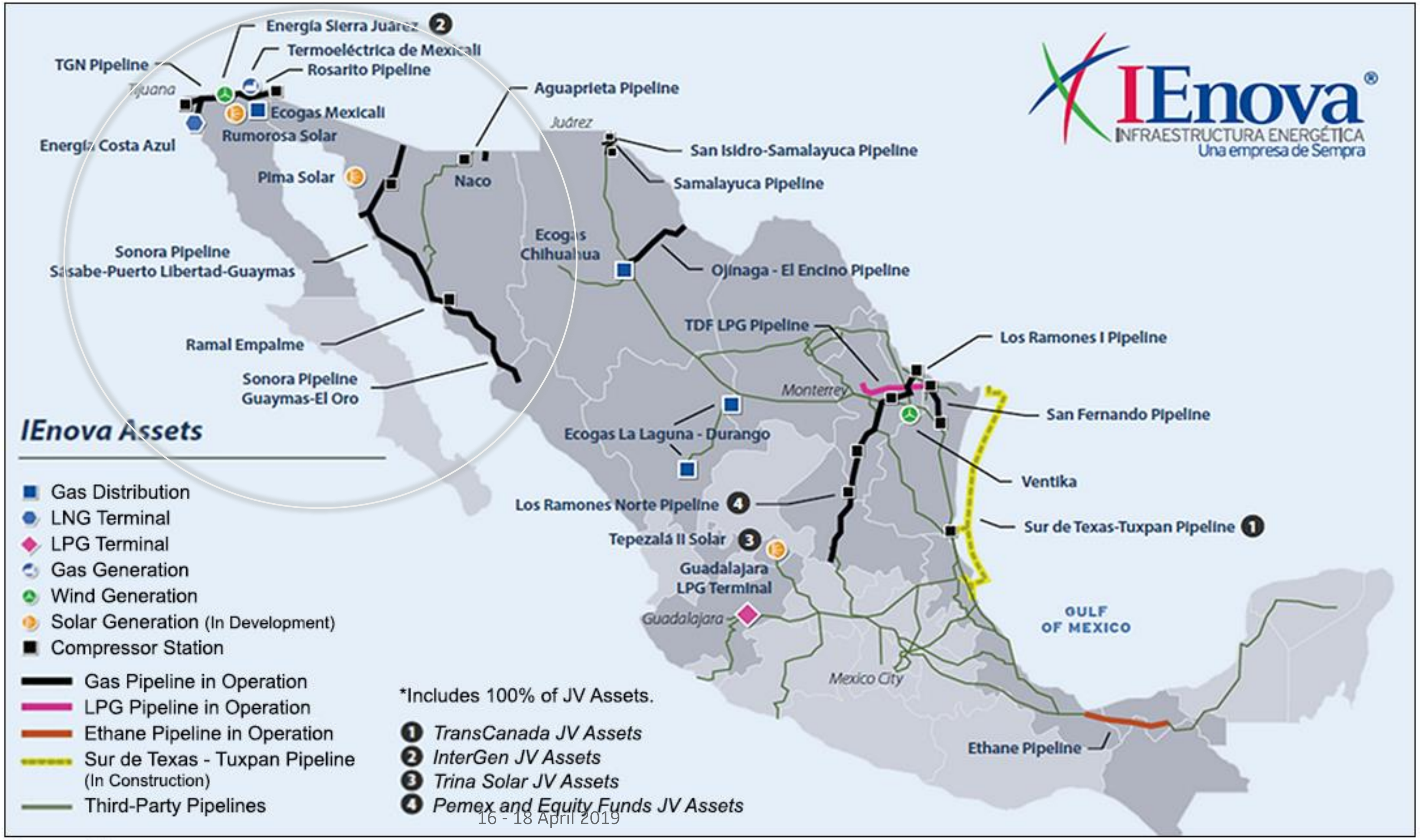
PEMEX Sur



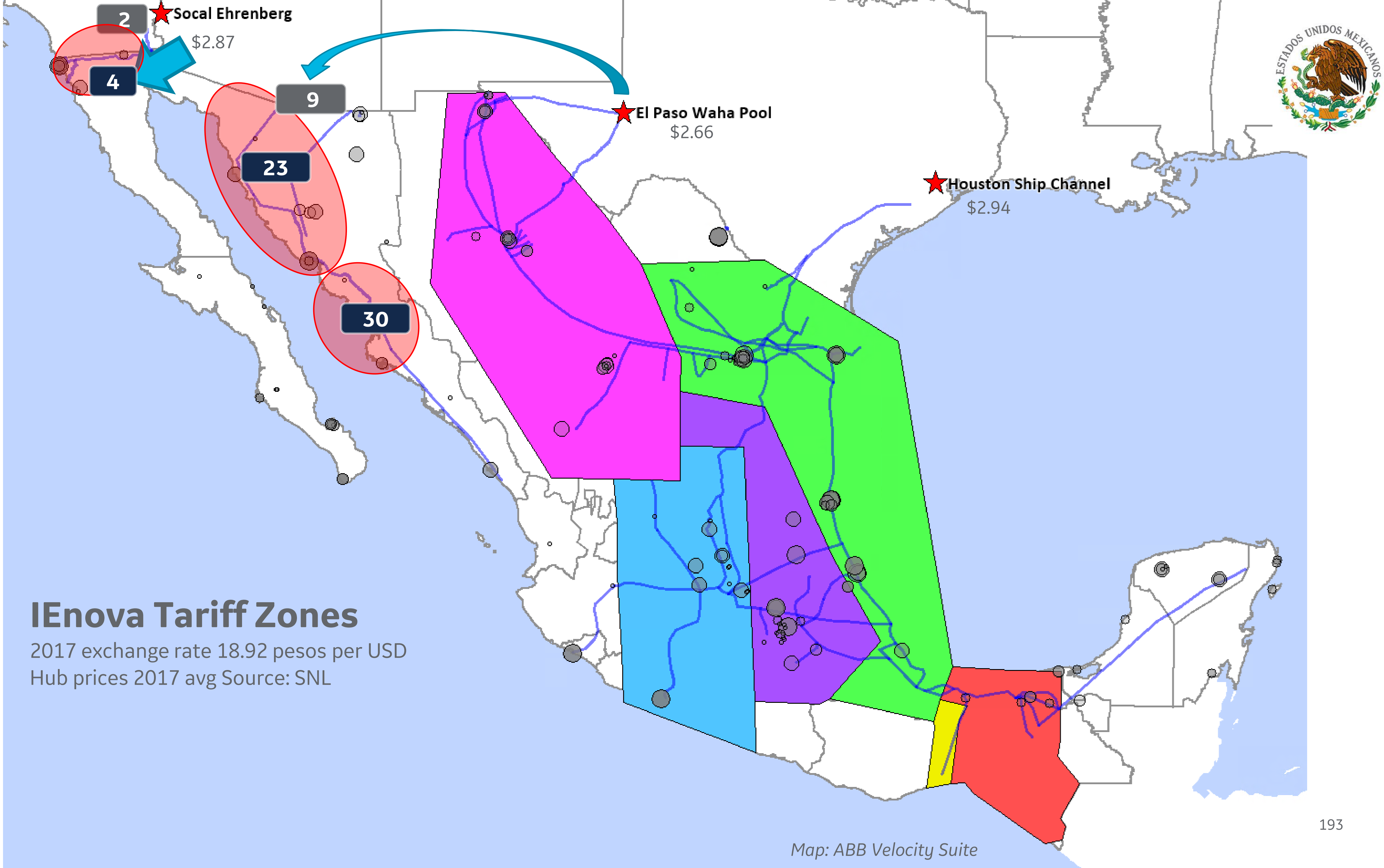
Source: Energia Mayakan

IEnova Second Quarter Natural Gas Project Updates

Project	Ownership	CapEx (Million $US)	Target In-Service Date	Contract Term	Status
Sonora Pipeline (Guaymas-El Oro Segment)	Wholly-Owned	$1,000	2Q2017	25 Years	In Operation
Ojinaga-El Encino Pipeline	Wholly-Owned	$300	2Q2017	25 Years	In Operation
Empalme Lateral	Wholly-Owned	$11	2Q2017	21 Years	In Operation
Texas-Tuxpan Marine Pipeline	Joint Venture	$2,100	4Q2018	25 Years	Under Construction



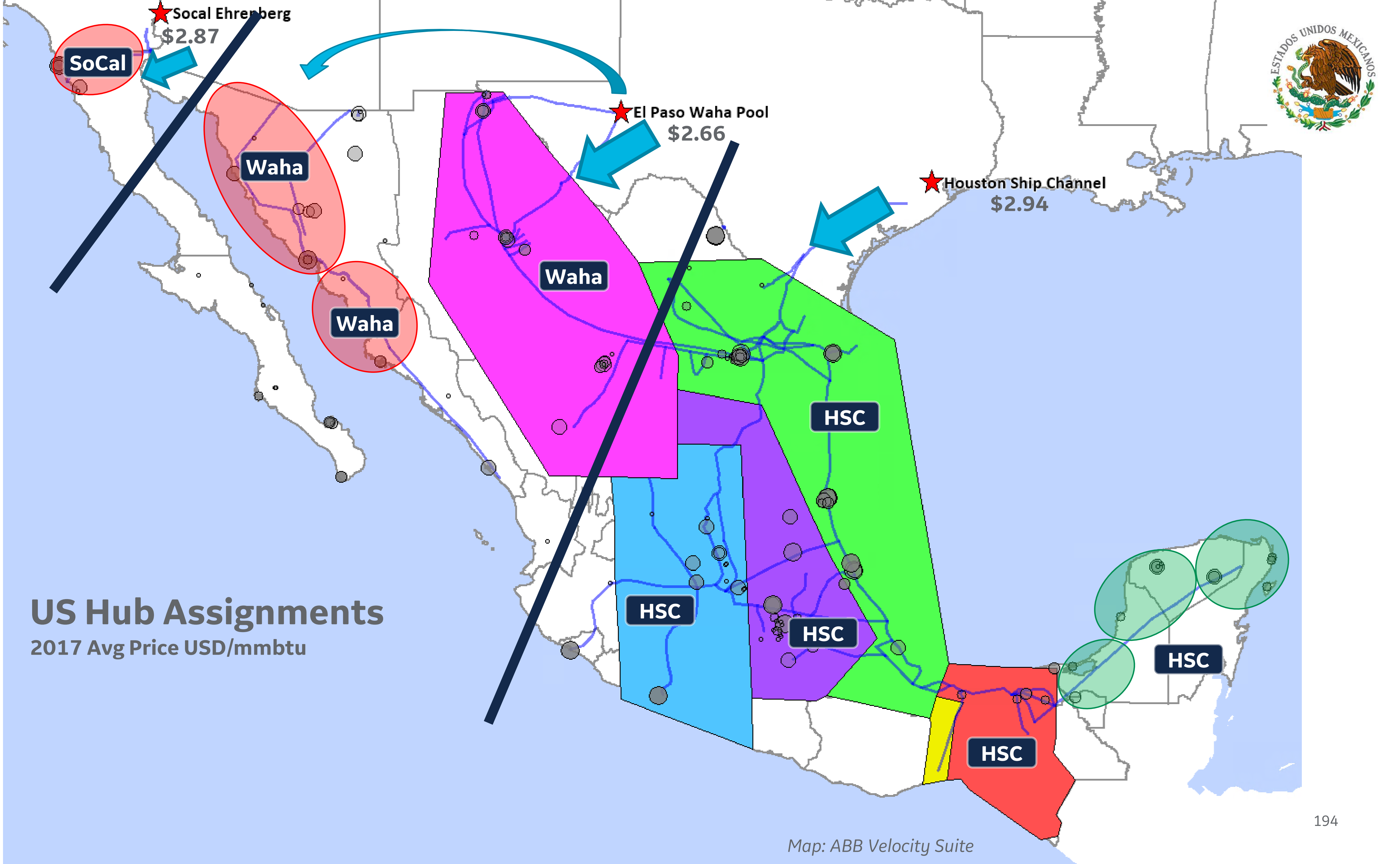
Source: IEnova



IEnova Tariff Zones

2017 exchange rate 18.92 pesos per USD
Hub prices 2017 avg Source: SNL

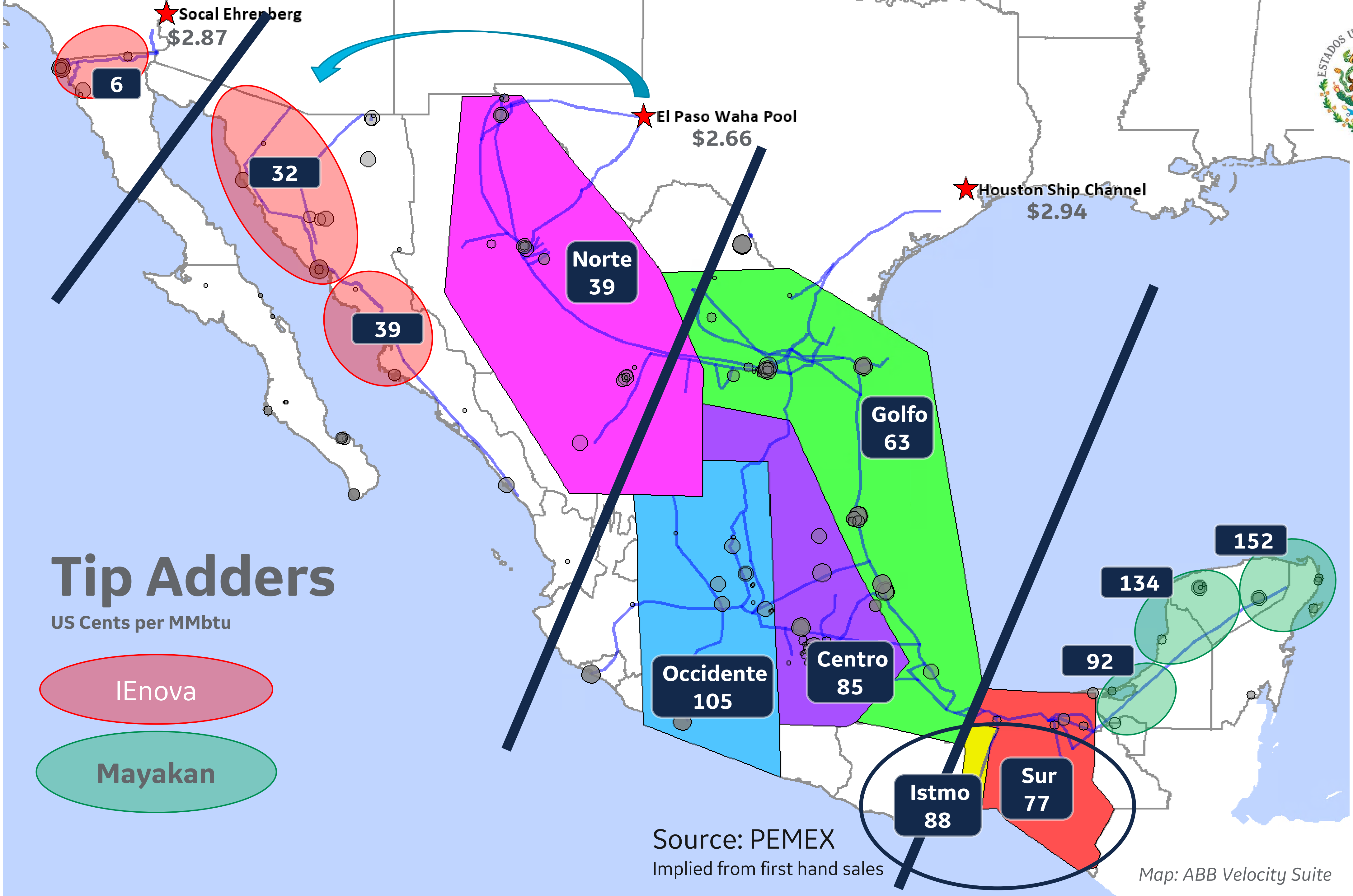
Map: ABB Velocity Suite



US Hub Assignments

2017 Avg Price USD/mmbtu

Map: ABB Velocity Suite



Socal Ehrenberg
$2.87
El Paso Waha Pool
$2.66
Houston Ship Channel
$2.94
6
32
39
Norte
39
Golfo
63
Centro
85
Occidente
105
Istmo
88
Sur
77
92
134
152
Tip Adders
US Cents per MMbtu
IEnova
Mayakan
Source: PEMEX
Implied from first hand sales
Map: ABB Velocity Suite

Renewables

Mexico Clean Energy Targets

Energy Transition Law (*Ley de Transición Energética*) published in December 24, 2015

Clean Energy Goals is to establish an energy matrix diversification program, requiring companies to produce clean energy with specific goals of clean energy production by

- 25% by 2018,
- 30% by 2021; and
- 35% by 2024; and
- 50% by 2050 (indicative)

The goals are for generation to be met by clean energy, including the following generation types:

- Wind;
- Solar;
- Nuclear;
- Biomass and biogas;
- Geothermal;
- Tidal;
- Hydro; and
- Cogeneration

GE RECAST Model Overview

RECAST is a capacity expansion model. It seeks to estimate how state and national renewable policies will be achieved through the addition of new renewable generation.

It was originally developed to model & forecast U.S. Renewable Portfolio Standards (RPS)

The model mimics the investment decision making process, using a profit maximization algorithm

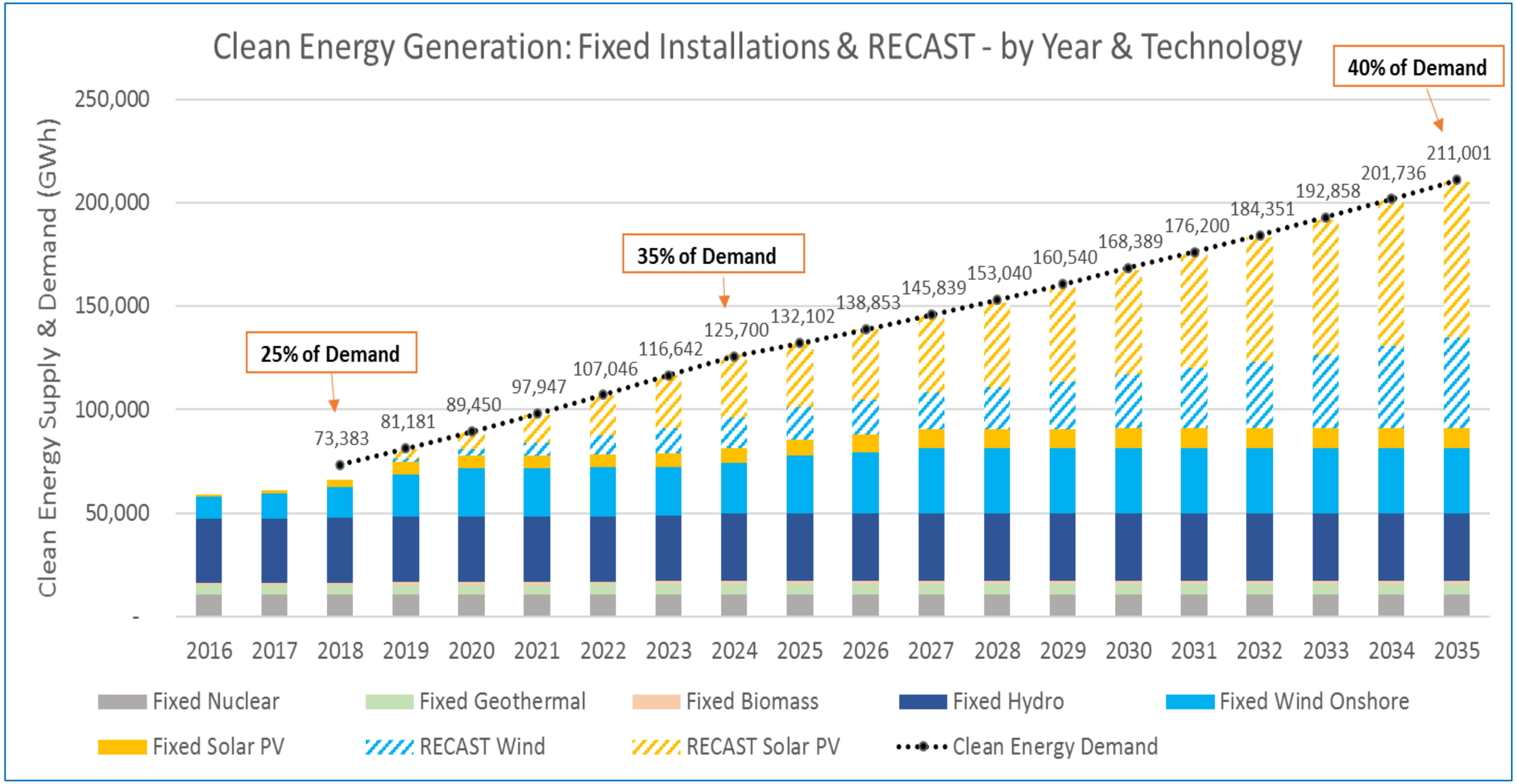
It selects the optimal mix of resources based on technology cost, prices, geography, and system constraints

RECAST Model Formulation

Maximize Profits (Energy Revenue + Capacity Revenue – LCOE)

- Subject to:
  - -Demand by RPS program
  - -Transmission Capacity Constraints
  - -Renewable Resource Availability Constraints
  - -Year-Tech-State Annual Build Constraints
  - -Import Eligibility Constraints
  - -Alternative Compliance Penalties
  - -Regional Prices
- Decision Variables:
- -Renewable Plants Built by Tech, Resource, Year over Horizon
- -Renewable Energy Transported Across States over Horizon
- -Penalties Paid for Under-Compliance

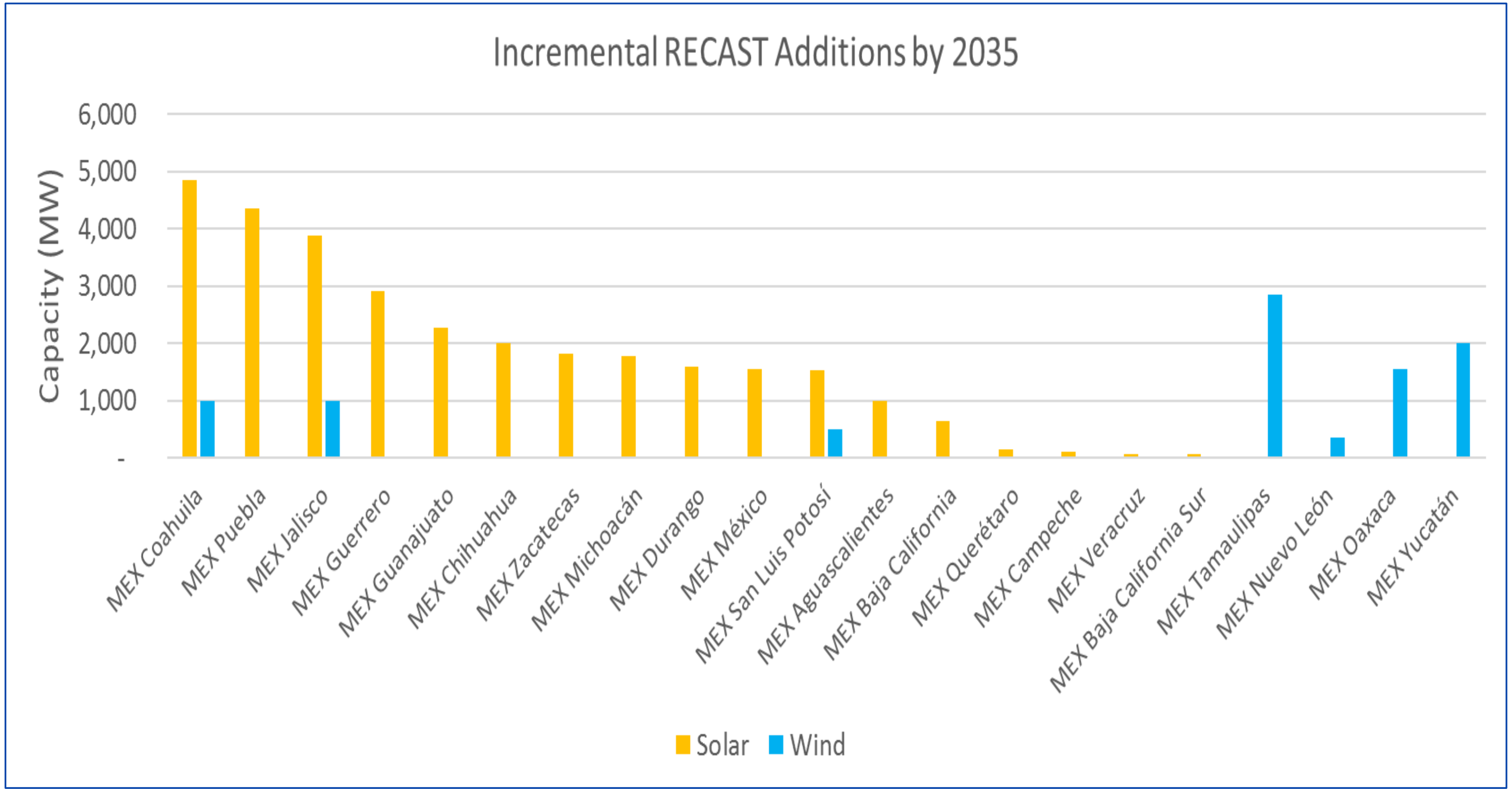
Clean Energy Generation Forecast



- RECAST fills in the gap between what existing generation provides, and what is needed to meet our targets
- Share of solar grows through time, due to faster CapEx decline

Source: GE Energy Consulting

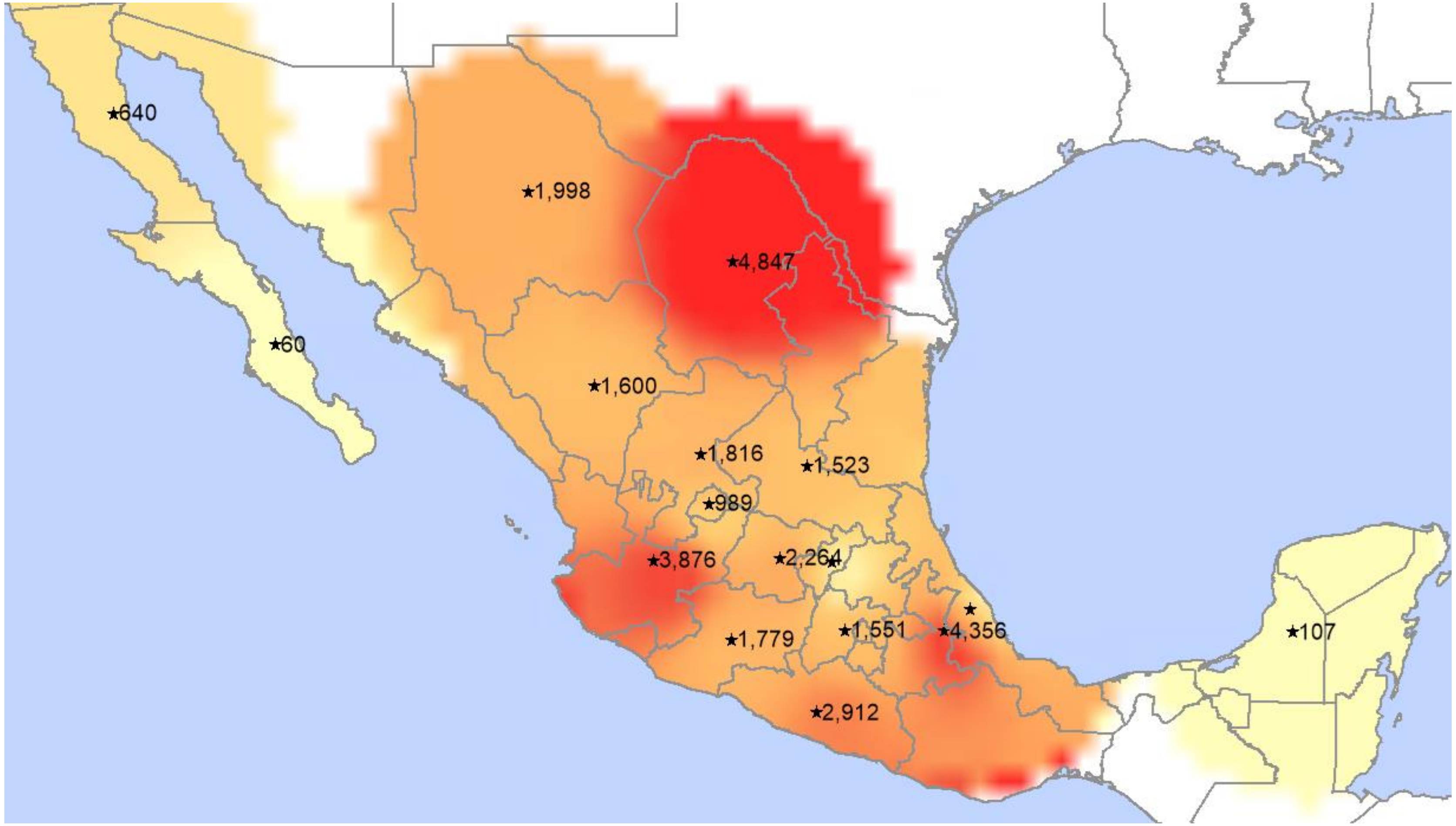
Geographic Distribution of New Resources



- 30.5GW of solar added by 2035, 9.3GW of wind
- Resources are built in regions with a mix of high available capacity factors & high prices (MAPS)

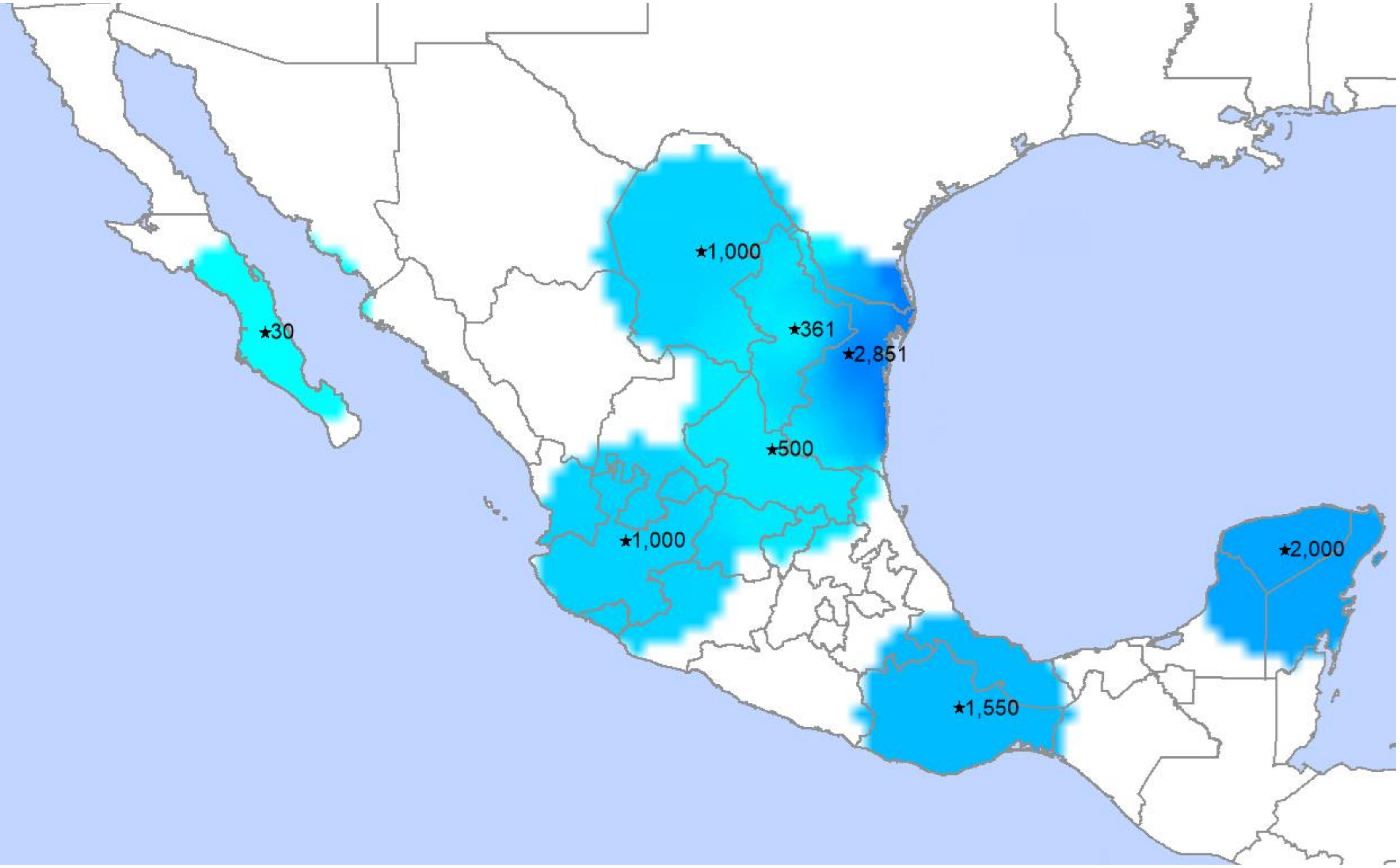
Source: GE Energy Consulting

Solar Buildout Map



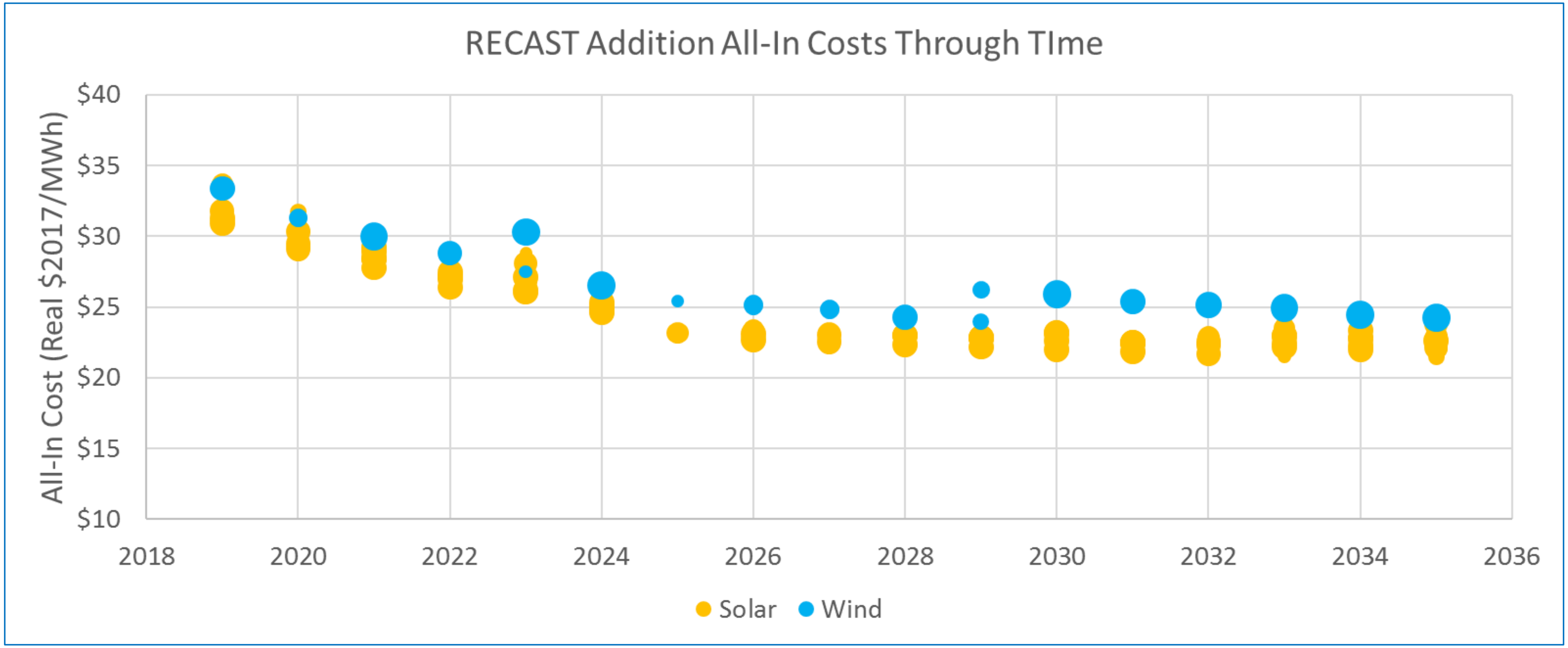
Source: GE Energy Consulting

Wind Buildout Map



Source: GE Energy Consulting

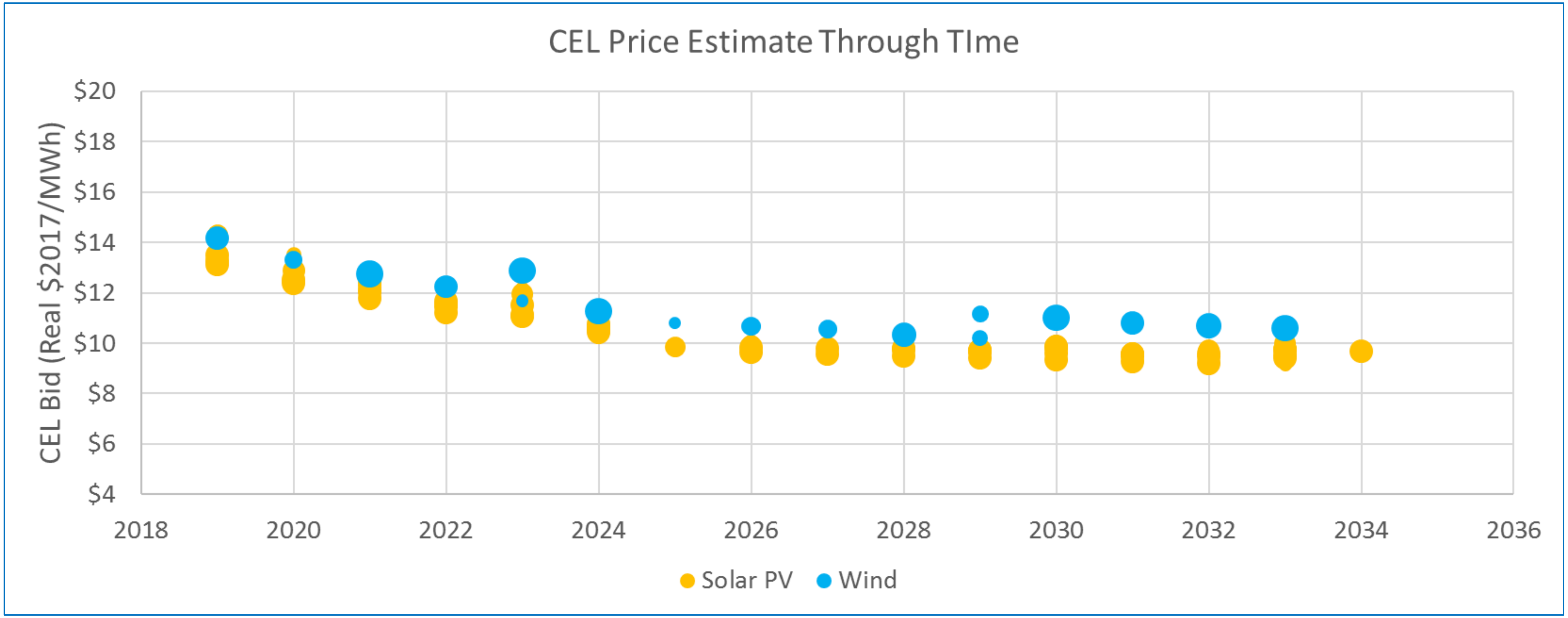
All-In Bid Forecast (2017 $/MWh)



- Sized by unit capacity, most units in 200MW-500MW range
- These values represent the before-tax revenue requirement needed to make the project whole after accounting for tax benefits

Source: GE Energy Consulting

CEL Bid Forecast (2017 $/CEL)



- Sized by unit capacity most units in 200MW-500MW range
- Represents 42.5% of the All-In cost

Source: GE Energy Consulting

MAPS / MARS Modelling

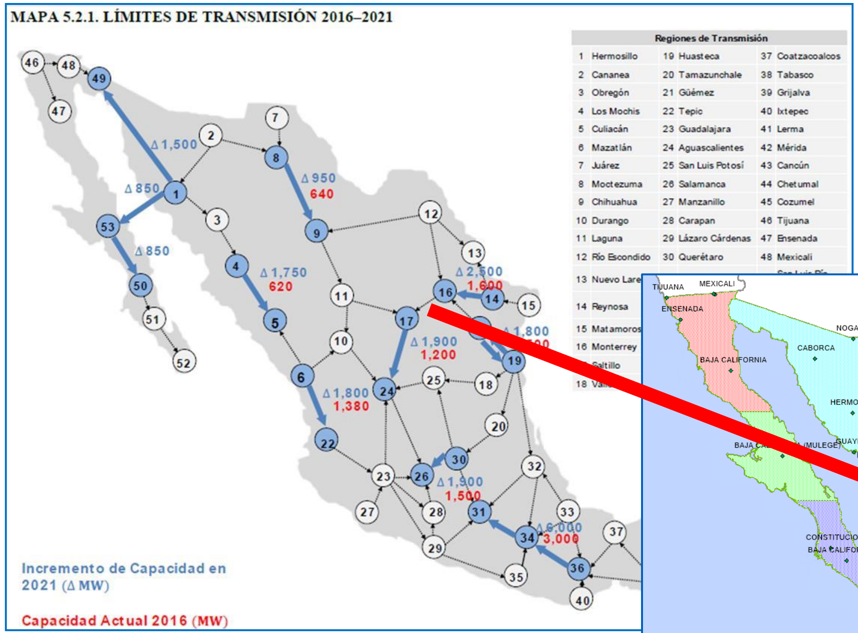
MAPS Mexico Model

First created using GE MAPS production cost software in 2015 to assist GE internal risk review.

- Incorporate public data to the extent available in all of our models.
- Started with POISE data release. Assumed 9 zones (based on transmission zones).
- In June 2016 updated with PRODESEN. Updated load profiles and fuel forecasts.
- In October 2016 expanded from 9 zones to 53, increasing fidelity of the modelling.
- March 2017 included Mexico modelling with our GPCM natural gas model for North America. This effort is currently being benchmarked.
- August 2017 started RECAST modelling of the renewables market.

Source: GE Energy Consulting

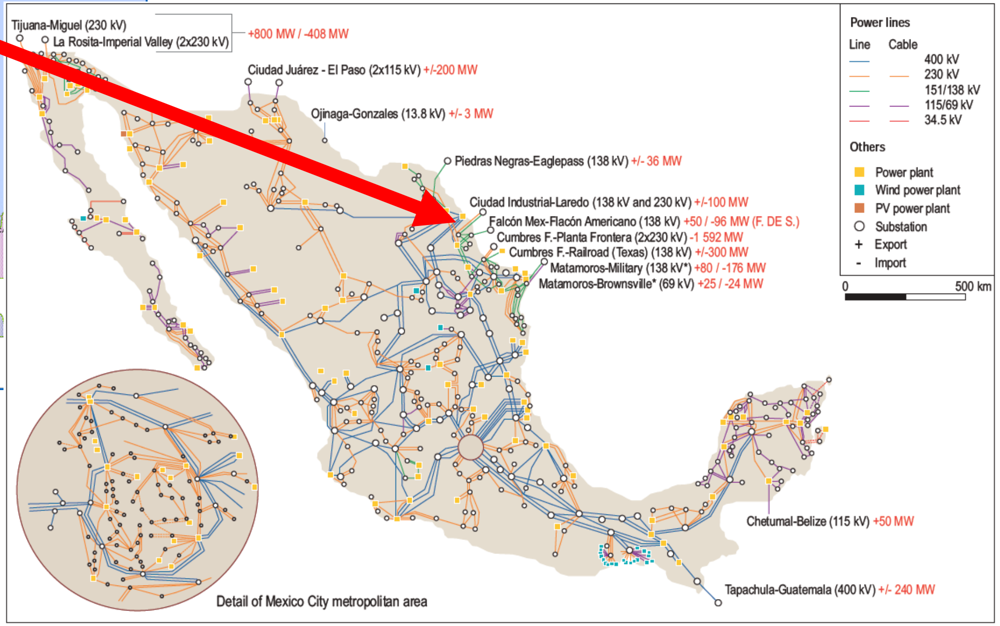
GE MAPS Mexico Topology



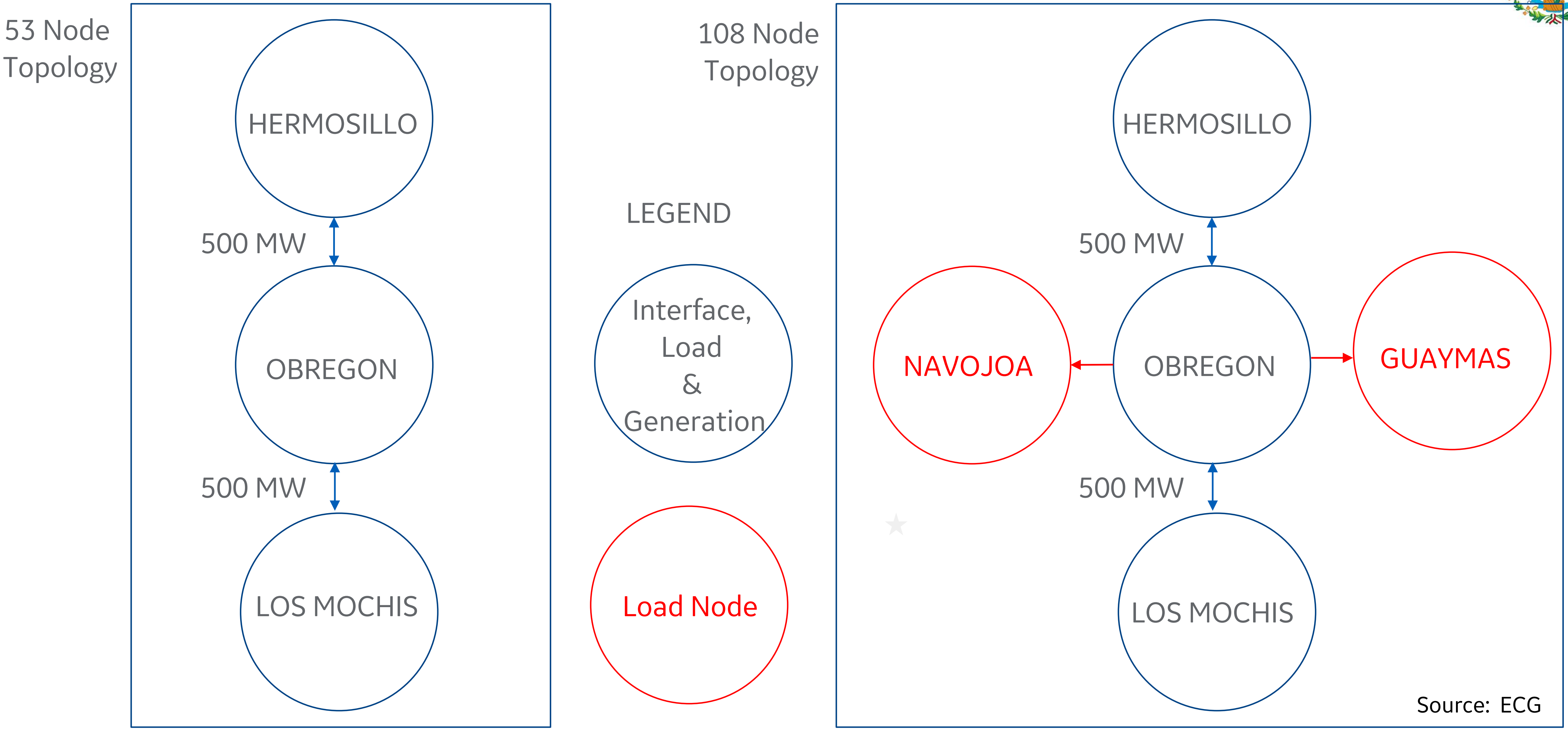
53 Zones Based on Transmission Interfaces

108 Zones Based on Transmission Interfaces & Load Zones

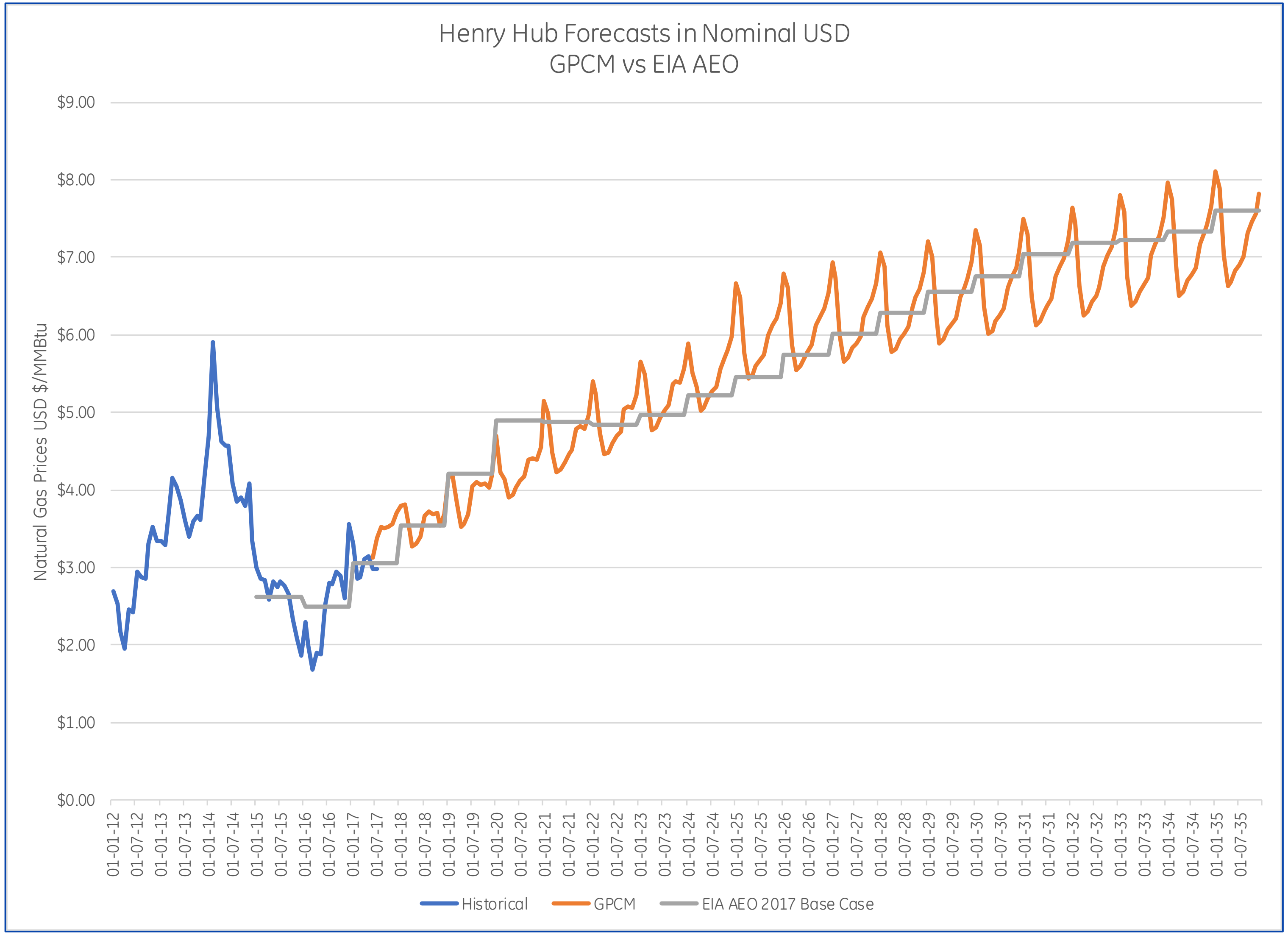
Full Node System



GE MAPS Mexico Topology

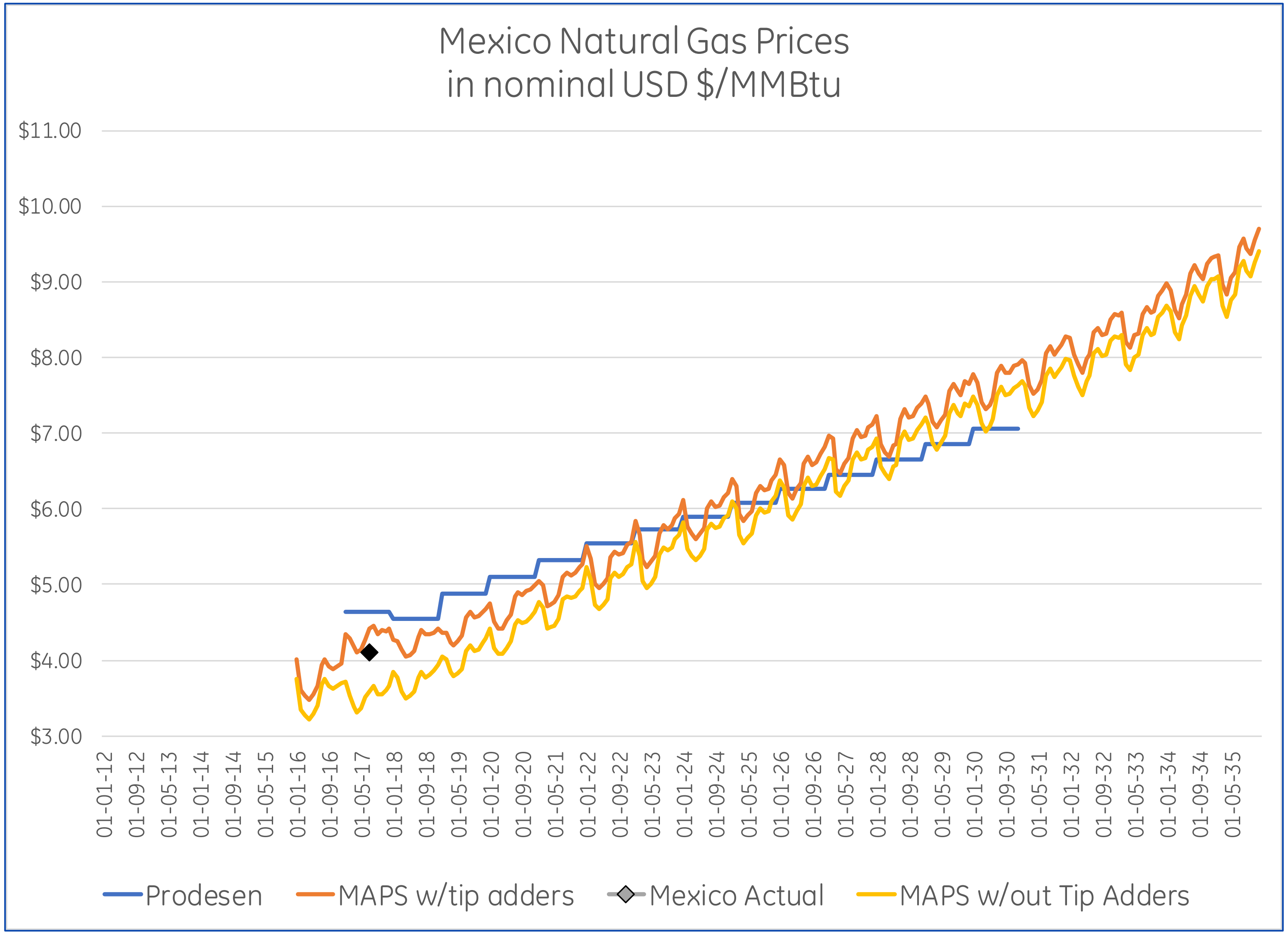


GE-MAPS – Natural Gas



Source: EIA and GE Energy Consulting

GE-MAPS – Benchmarking



Source: Actual Prices CENACE; MAPS GE Energy Consulting

Mexico Sources & References

Source	Description	web-site
CENACE	El Centro Nacional de Control de Energía (The National Center for Energy Control)	https://www.gob.mx/cenace
SENER	Secretario de Energía (Ministry of Energy)	https://www.gob.mx/sener
PRODESEN	Programa de Desarrollo del Sistema Eléctrico Nacional (PRODESEN) (Program for the Development of the National Electricity System	https://www.gob.mx/sener/acciones-y-programas/programa-de-desarrollo-del-sistema-electrico-nacional-33462?idiom=es
CFE	Comisión Federal de Electricidad (Federal electricity commission -- existing electric utilty)	http://www.cfe.gob.mx/paginas/Home.aspx
CRE	Comisión Reguladora de Energía (Energy Regulatory Commission)	http://www.gob.mx/cre
IEA	Energy Policies Beyond IEA Countries: MEXICO 2017	
SENER	Jeff Pavlovic	
ICIS	James Fowler	
CENAGAS	David Suarez	
AUROA	Auctions for Renewable Energy Support, Report D4.4-MX, IEA Mexco 2017	

GE

GE MARS Master Input File

Master Input File (MIF)

- GE MARS uses the Master Input File (MIF) to input all of the study data except for the hourly area loads and the modifier shapes
- We will review the general format of the MIF and the rules that govern its use
- The MIF is a set of input tables
  - With the exception of the table GEN-CASE, which is always first, the order the tables appear doesn't impact it's functionality. The order the data appears in the tables however is important
  - Tables may be duplicated and some may be omitted
- Each line can be up to 132 characters long
- The first and second characters on each line are reserved for reserved characters

Basics

The first two characters of each line are scanned for special characters

- **Header** – An ampersand (&) or a percent sign (%) indicates the beginning of a table
- **Footer** – A semicolon (;) or a colon (:) indicates the end of a table
- **Comments** – An asterisk (*) denotes a comment within a MIF table.

The lines between table footer and next table header may be used for commenting purposes (between ; and &)

Example

```
&GEN-POOL-00     PID
*                          POOL-IDENTIFICATION
*--------------------------------------------------------------------------
*    ABBREVIATED                          FULL POOL NAME
*     POOL NAME
*--------------------------------------------------------------------------
*      .NMPOOL.                              .NMP048.
*--------------------------------------------------------------------------
*      AAAAAAAA      AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
*      --------      ------------------------------------------------
      "BJACA_MX"    "MEXICO--BAJA CALIFORNIA                          "
      "BJASR_MX"    "MEXICO--BAJA CALIFORNIA SUR                      "
      "MULEG_MX"    "MEXICO--MULEGE BAJA CALIFORNIA SUR               "
      "SIN___MX"    "MEXICO--SIN                                      "
      "WECC__MX"    "MEXICO--WECC San Diego Import Exports            "
      "ERCOT_MX"    "MEXICO--ERCOT Imports Exports                    "
      "GATML_MX"    "MEXICO--GUATAMALA Imports Exports                "
      "BELIZ_MX"    "MEXICO--BELIZE Imports Exports                   "

;;;; END OF GEN-POOL-00 ;;;;
```

Example

Table Header

```
&GEN-POOL-00     PID
*                          POOL-IDENTIFICATION
*-----------------------------------------------------------------------
*    ABBREVIATED                                 FULL POOL NAME
*     POOL NAME
*-----------------------------------------------------------------------
*      .NMPOOL.                                    .NMPO48.
*-----------------------------------------------------------------------
*      AAAAAAAA      AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
*      --------      ------------------------------------------------
      "BJACA_MX"    "MEXICO--BAJA CALIFORNIA                         "
      "BJASR_MX"    "MEXICO--BAJA CALIFORNIA SUR                     "
      "MULEG_MX"    "MEXICO--MULEGE BAJA CALIFORNIA SUR              "
      "SIN___MX"    "MEXICO--SIN                                     "
      "WECC__MX"    "MEXICO--WECC San Diego Import Exports           "
      "ERCOT_MX"    "MEXICO--ERCOT Imports Exports                   "
      "GATML_MX"    "MEXICO--GUATAMALA Imports Exports               "
      "BELIZ_MX"    "MEXICO--BELIZE Imports Exports                  "

;;;; END OF GEN-POOL-00 ;;;;
```

Example

Table Header

```
&GEN-POOL-00     PID
*                          POOL-IDENTIFICATION
*----------------------------------------------------------------------
*    ABBREVIATED                        FULL POOL NAME
*     POOL NAME
*----------------------------------------------------------------------
*      .NMPOOL.                            .NMPO48.
*----------------------------------------------------------------------
*      AAAAAAAA      AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
*      --------      ------------------------------------------------
      "BJACA_MX"    "MEXICO--BAJA CALIFORNIA                          "
      "BJASR_MX"    "MEXICO--BAJA CALIFORNIA SUR                      "
      "MULEG_MX"    "MEXICO--MULEGE BAJA CALIFORNIA SUR               "
      "SIN___MX"    "MEXICO--SIN                                      "
      "WECC__MX"    "MEXICO--WECC San Diego Import Exports            "
      "ERCOT_MX"    "MEXICO--ERCOT Imports Exports                    "
      "GATML_MX"    "MEXICO--GUATAMALA Imports Exports                "
      "BELIZ_MX"    "MEXICO--BELIZE Imports Exports                   "

;;;; END OF GEN-POOL-00 ;;;;
```

Table Footer

Example

Table Header

Comments

```

&GEN-POOL-00     PID
*                          POOL-IDENTIFICATION
*----------------------------------------------------------------------
*    ABBREVIATED                      FULL POOL NAME
*     POOL NAME
*----------------------------------------------------------------------
*      .NMPOOL.                          .NMPO48.
*----------------------------------------------------------------------
*      AAAAAAAA      AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
*      --------      ------------------------------------------------
      "BJACA_MX"    "MEXICO--BAJA CALIFORNIA                         "
      "BJASR_MX"    "MEXICO--BAJA CALIFORNIA SUR                     "
      "MULEG_MX"    "MEXICO--MULEGE BAJA CALIFORNIA SUR              "
      "SIN___MX"    "MEXICO--SIN                                     "
      "WECC__MX"    "MEXICO--WECC San Diego Import Exports           "
      "ERCOT_MX"    "MEXICO--ERCOT Imports Exports                   "
      "GATML_MX"    "MEXICO--GUATAMALA Imports Exports               "
      "BELIZ_MX"    "MEXICO--BELIZE Imports Exports                  "

;;;; END OF GEN-POOL-00 ;;;;

```

Table Footer

Data Types

- **Numerical**
  - Reals
  - Integers
- **String**
- **Date**
- **Enumerator**

Numerical

Reals

- Typically denoted by a # in the table heading
- Real values are expected
- 12 digits for the number, up to 10 decimal places
- No blanks or spaces

Integers

- Typically denoted by an I in the table heading
- Maximum of 8 digits in addition to sign
- No space between sign and digits

Strings

- Typically denoted by A in the table heading
- The number of A's typically indicates the maximum length of the string
- If a string contains a space it must be put in quotes. Single (') or double (") quotes are equally valid, but must match
- All strings do not need to be put in quotes, however it is recommended.
- String fields are case sensitive
- It is recommended that you do not use duplicate names for simulation components of different types (*i.e.* a pool and an area named "MYSYSTM")

Dates

Three supported date formats

- YYYY
- MMMYYYY
- DDMMMYYYY

The date format indicates how the data is read in

No spaces allowed

Month must be in uppercase

Day defaults to 01, Month defaults to JAN

Enumerators

Most commonly Y / N

Must be upper case

Must be a supported option

Typically the available options are indicated in the table heading

Types of Tables

- **Record Tables**
  - "Driver" Tables
- **Colon Tables**
- **Colon Array Tables**

Record Tables

- Data organized into columns
- Values input free-form, space delimited
- Columns to be skipped must be filled by “=“
- Fixed number of columns per line

```

&UNT-DATA-00     UGD
*                                                   GENERAL-UNIT-DATA
*------------------------------------------------------------------------------------------------------------------------
*     UNIT NAME     AREA NAME     INSTALLATION     RETIREMENT             UNIT TYPE              NUMBER OF   UNIT SUMMARY
*                                     DATE            DATE                                       UNITS IN        TYPE
*                                                                                                  PLANT
*------------------------------------------------------------------------------------------------------------------------
*      .NAMES.       .IAREA.    .INSTDY/INSTYR..IRETDY/IRETYR.             .IUNTYP.                .NUNPD.     .IUNSUM.
*------------------------------------------------------------------------------------------------------------------------
*      AAAAAAAA      AAAAAAAA      DDMMMYYYY       DDMMMYYYY     TH/EL1/EL2/CG1/CG2/ES/DS             III        AAAAAAAA
*      --------      --------      ---------       ---------     ------------------------             ---        --------
      "PRITA2CS"    "CANANE_A"     23SEP2015       31DEC2050                DS                         =        "SOLRPV  "
      "AURASOPV"    "LOSCAB_A"     26MAR2014       31DEC2050                DS                         =        "SOLRPV  "
      "ABSTCMPV"    "AGCALE_A"     17MAR2011       31DEC2050                DS                         =        "SOLRPV  "
      "CNTCABPV"    "HRMOSI_A"     31JAN2016       31DEC2050                DS                         =        "SOLRPV  "
      "CNTELCPV"    "HRMOSI_A"     27DEC2016       31DEC2050                DS                         =        "SOLRPV  "
      "CERROPPV"    "MEXICA_A"     08JAN2013       31DEC2050                DS                         =        "SOLRPV  "
      "COMENSPV"    "LOSCAB_A"     01NOV2013       31DEC2050                DS                         =        "SOLRPV  "
      "EJEVRDPV"    "MERIDA_A"     29NOV2017       31DEC2050                DS                         =        "SOLRPV  "
      "GRPTECPV"    "LOSCAB_A"     30JUN2015       31DEC2050                DS                         =        "SOLRPV  "
      "KAMBULPV"    "MERIDA_A"     29JAN2018       31DEC2050                DS                         =        "SOLRPV  "
      "LSANTSPV"    "CHIHUA_A"     06JUN2017       31DEC2050                DS                         =        "SOLRPV  "
      "DNJOSEPV"    "QURETE_A"     28MAY2018       31DEC2050                DS                         =        "SOLRPV  "
      "IGNACOPV"    "LERMA_A "     27APR2018       31DEC2050                DS                         =        "SOLRPV  "
      "RIVMYAPV"    "CHETUM_A"     29NOV2017       31DEC2050                DS                         =        "SOLRPV  "
      "TDRANGPV"    "DURANG_A"     22APR2016       31DEC2050                DS                         =        "SOLRPV  "
      "TRSVRGPV"    "MULEGE_A"     26MAR2013       31DEC2050                DS                         =        "SOLRPV  "
      "ACCNCNWT"    "CANCUN_A"     28NOV2010       31DEC2050                DS                         =        "WIND    "
      "BIINEEWT"    "IXTEPE_A"     01APR2010       31DEC2050                DS                         =        "WIND    "
      "OJUELSWT"    "SNPOTO_A"     11FEB2014       31DEC2050                DS                         =        "WIND    "
      "DEMOXCWT"    "IXTEPE_A"     31JAN2012       31DEC2050                DS                         =        "WIND    "
      "DOMNCAWT"    "SNPOTO_A"     28OCT2014       31DEC2050                DS                         =        "WIND    "
      "PORVNRWT"    "GUEMEZ_A"     14OCT2013       31DEC2050                DS                         =        "WIND    "
      "POALTOWT"    "AGCALE_A"     01NOV2016       31DEC2050                DS                         =        "WIND    "
      "SJUREZWT"    "MEXICA_A"     18JUN2015       31DEC2050                DS                         =        "WIND    "
      "DISTMOWT"    "IXTEPE_A"     12JAN2011       31DEC2050                DS                         =        "WIND    "
      "PACIFCWT"    "IXTEPE_A"     18FEB2014       31DEC2050                DS                         =        "WIND    "
      "COAHLAWT"    "REYNOS_A"     24JAN2017       31DEC2050                DS                         =        "WIND    "
      "ARBLTSWT"    "IXTEPE_A"     01DEC2014       31DEC2050                DS                         =        "WIND    "
      "RETIROWT"    "IXTEPE_A"     01MAY2014       31DEC2050                DS                         =        "WIND    "
      "PENSCOWT"    "OBREGO_A"     01DEC2014       31DEC2050                DS                         =        "WIND    "
      "CATRNAWT"    "MONTER_A"     25JUN2013       31DEC2050                DS                         =        "WIND    "
      "ZOPLPNWT"    "IXTEPE_A"     01JAN2013       31DEC2050                DS                         =        "WIND    "
```

Driver Tables

Defines Valid Names for use in other tables

- Names must match exactly including leading and trailing spaces
- Error messages printed from other tables if the name is not in the Driver table
- Driver table entries may be overridden if using the MIF-Preprocessor, but must be explicitly marked as an override by beginning the line with an at-sign (@) in the first two characters of the line

Colon Tables

```
&CNV-CRIT-00     CNC
 *                                           CONVERGENCE-CRITERIA
 *---------------------------------------------------------------------------------------------------------------

   AREA OR POOL TO DETERMINE HOUR OF DAILY PEAK  (.IPKARP.)                   AAAAAAAA : ALL

   AREA OR POOL TO CHECK FOR CONVERGENCE  (.ICNARP.)                          AAAAAAAA : "ALL_MEX "

   CONVERGENCE INDEX     1  =  LOEE (MWH/YR)        (.KVSTAT.)                       I : 3
                         2  =  LOLE (HOURS/YR)
                         3  =  LOLE (DAYS/YR)

   BASIS FOR CALCULATING CONVERGENCE INDEX   1  =  INTERCONNECTED   (.KVWHEN.)        I : 1
                                             2  =  ISOLATED

   CONVERGENCE TOLERANCE  (per unit)  (.CVPARM.)                                    #  : 0.025

   MARGIN STATE TO CALCULATE CONVERGENCE INDEX  (.KVEOP.)                           I  : 1

   MINIMUM NUMBER OF REPLICATIONS   (.MINREP.)                                      I  : 100

   MAXIMUM NUMBER OF REPLICATIONS   (.MAXREP.)                                      I  : 10000

   ASSISTANCE PRIORITY WITHIN POOL ?   (.IPRIPL.)   Y/N                           AAA  : YES

   SEED FOR RANDOM NUMBER GENERATOR   (.ISEED.)                                     I  : 1340983

   INDICES TO CALCULATE      A  =  ALL                           (.ICALC.)        AAA  :  A
                             I  =  INTERCONNECTED ONLY
                             D  =  DAILY INTERCONNECTED ONLY

   CALCULATE WEEKLY OR MONTHLY INDICES      N  =  NEITHER (ANNUAL ONLY)  (.ICWKMN.)   AAA :  N
                                            W  =  WEEKLY
                                            M  =  MONTHLY
                                            B  =  BOTH WEEKLY AND MONTHLY

   SHARE EXCESS RESERVES AMONG DEFICIENT AREAS ?   (.ILOSHR.)    Y/N               AAA :  YES

 ;;;; END OF &CNV-CRIT-00 ;;;;
```

- One input value per line
- Data read following the colon (:)
- Fixed number of rows per table

Colon Array Table

- Colon indicates where data begins
- Each line can contain more than one data item
- Fixed number of rows per table

```
&INF-DYLM-00    CONTINUATION
*         INTERFACE-DYNAMIC-TRANSFER-LIMITS
*-----------------------------------------------

  EFFECTIVE DATE                YYYY :  2015

  CONDITION SET NUMBER            II :  1

  NUMBER OF UNIT CONDITIONS       II :  1

  NUMBER OF LOAD CONDITIONS       II :  1

*-------------------------------------------------
*            UNIT NAME     STATUS
*-------------------------------------------------
*             AAAAAAAA      A/U
*             --------      ---
            'UNIT 1  '        U
+           'UNIT 2  '        U
+           'UNIT 3  '        U
+           'UNIT 4  '        U
*-------------------------------------------------
*            AREA OR POOL    LESS OR        MW
*              NAME OR       GREATER
*              "SYSTEM"
*-------------------------------------------------
*              AAAAAAAA       LT/GT      #######
*              --------       -----      -------
             'AREA_1  '         GT     10000.00
*--------------------------------------------------
*            INTERFACE OR    POSITIVE     NEGATIVE
*             GROUP NAME    DIRECTION    DIRECTION
*                           TIE LIMIT    TIE LIMIT
*                              (MW)         (MW)
*--------------------------------------------------
*              AAAAAAAA      #######      #######
*              --------      -------      -------
             "INTERFAC"      100.00       100.00

;;;; END OF INF-DYLM-00 ;;;;
```

Special Features

Continuation

- Allows a row of data to be continued on the next line
- Continuation indicated by a **+** in the first two characters of a line

```
&GEN-ARGP-00     AGP    CONTINUATION
*                                    AREA-GROUP-DEFINITION
*---------------------------------------------------------------------------------------------------------
*    ABBREVIATED       FULL AREA GROUP NAME      ABBREVIATED NAMES OF AREAS INCLUDED IN THE AREA GROUP
*     AREA GROUP
*        NAME
*---------------------------------------------------------------------------------------------------------
*      .NMARGP.              .NMAG24.                                   .IARGRP.
*---------------------------------------------------------------------------------------------------------
*      AAAAAAAA      AAAAAAAAAAAAAAAAAAAAAAAA      AAAAAAAA      AAAAAAAA      AAAAAAAA      AAAAAAAA
*      --------      ------------------------      --------      --------      --------      --------
      "ALL_MEX "    "All Mexico Areas        "    "ENSENA_A"    "MEXICA_A"    "RIOCLR_A"    "TIJUAN_A"
+                                                  "CNSTCI_A"    "LAPAZ_A "    "LOSCAB_A"    "MULEGE_A"
+                                                  "CENTRA_A"    "GUEMEZ_A"    "HUASTE_A"    "MATAMO_A"
+                                                  "MONTER_A"    "NUELAR_A"    "REYNOS_A"    "RIOESC_A"
+                                                  "SALTIL_A"    "TMZNCH_A"    "VALLES_A"    "CANANE_A"
+                                                  "CULIAC_A"    "HRMOSI_A"    "LOSMCH_A"    "MAZATL_A"
+                                                  "OBREGO_A"    "CHIHUA_A"    "DURANG_A"    "JUAREZ_A"
+                                                  "LAGUNA_A"    "MOCTZU_A"    "AGCALE_A"    "CARAPA_A"
+                                                  "GDALAJ_A"    "LAZCRD_A"    "MANZNI_A"    "QURETE_A"
+                                                  "SALMAN_A"    "SNPOTO_A"    "TEPIC_A "    "ACAPUL_A"
+                                                  "COTZCL_A"    "GRIJAL_A"    "IXTEPE_A"    "POZARI_A"
+                                                  "PUEBLA_A"    "TABASC_A"    "TEMASC_A"    "VERACR_A"
+                                                  "CANCUN_A"    "CHETUM_A"    "COZUME_A"    "LERMA_A "
+                                                  "MERIDA_A"

;;;; END OF GEN-ARGP-00 ;;;;
```

Special Features

Asterisk

- Used to assign the same value to successive input items
- No spaces allowed between a repetition factor (*) and value

```
&MOD-MDMW-00     ESD    CONTINUATION    ASTERISK
*                                 ENERGY-STORAGE-DSM-MOD-MW
*-------------------------------------------------------------------------------------------
*     EFFECTIVE    UNIT NAME        NET HOURLY LOAD MODIFICATION FOR TYPICAL WEEK (MW)
*        DATE
*-------------------------------------------------------------------------------------------
*                                                    .ESUMOD/DSMMOD.
*-------------------------------------------------------------------------------------------
*      MMMYYYY      AAAAAAAA      #########      #########      #########      #########
*      -------      --------      ---------      ---------      ---------      ---------
                   "SDLOAD  "      168*-738

;;;; END OF MOD-MDMW-00 ;;;;
```

Special Features
Overrides

- Frequency of override indicated by table date format
  - YYYY / MMMYYYY / DDMMMYYYY
- Any line with an effective date must begin with **@**
- Any fields input as **=** will be filled with the previously effective value
- ***n** immediately following a date indicates the data will be repeated on that date each year for n years
  - *i.e.* 01MAY2020*5 would repeat that line on May 1st 2020 – 2024
  - if n is ***** the value is repeated indefinitely (*i.e.* 01MAY2020**)

Special Features

Overrides

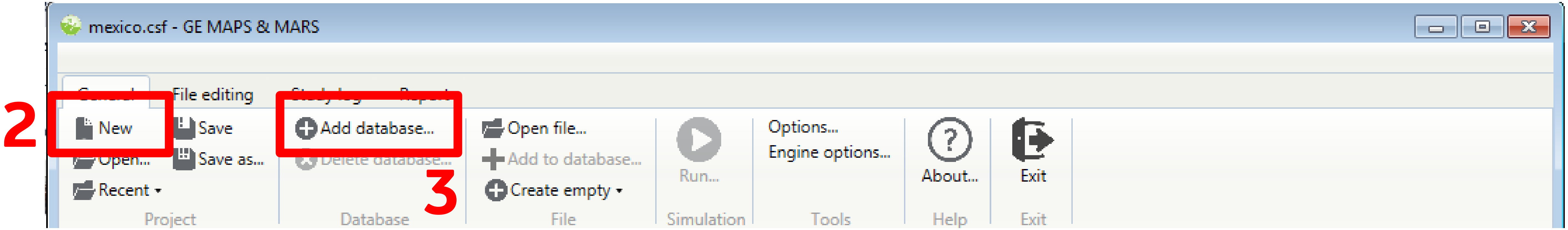
```
&MOD-ELMW-00     ELM
*                                           RATINGS-FOR-TYPE-2-ENERGY-LIMITED-UNITS
*-----------------------------------------------------------------------------------------------------------------------------
*     EFFECTIVE    UNIT NAME      MINIMUM     MAXIMUM      ENERGY     STORAGE     DAYS    DAYS   HOURS    HOURS    HOURS    ENERGY
*       DATE                        (MW)        (MW)        (MWH)      (MWH)       PER     PER    PER      PER      PER     PER DAY
*                                                                                  YEAR   MONTH   YEAR    MONTH     DAY
*-----------------------------------------------------------------------------------------------------------------------------
*                                .ELUMIN.    .ELUMAX.    .ELUENG.    .EL2STR.  .IEL2MD..IEL2MD..IEL2YH..IEL2MH..IEL2DH. .EEl2DH.
*-----------------------------------------------------------------------------------------------------------------------------
*      MMMYYYY     AAAAAAAA      ########    ########    ########    ########    III     III     IIII     III      III     ######
*                  --------      --------    --------    --------    --------    ---     ---     ----     ---      ---     ------
@      JAN2019**  "ELFUERTH"         5.86       59.10     5961.00           =      =       =       =        =        =          =
@      FEB2019**  "ELFUERTH"         5.86       59.10     5961.00           =      =       =       =        =        =          =
@      MAR2019**  "ELFUERTH"         5.86       59.10     5515.00           =      =       =       =        =        =          =
@      APR2019**  "ELFUERTH"         5.86       59.10     5515.00           =      =       =       =        =        =          =
@      MAY2019**  "ELFUERTH"         5.86       59.10     5515.00           =      =       =       =        =        =          =
@      JUN2019**  "ELFUERTH"         5.86       59.10     5515.00           =      =       =       =        =        =          =
@      JUL2019**  "ELFUERTH"         5.86       59.10     5107.00           =      =       =       =        =        =          =
@      AUG2019**  "ELFUERTH"         5.86       59.10     5107.00           =      =       =       =        =        =          =
@      SEP2019**  "ELFUERTH"         5.86       59.10     5107.00           =      =       =       =        =        =          =
@      OCT2019**  "ELFUERTH"         5.86       59.10     5107.00           =      =       =       =        =        =          =
@      NOV2019**  "ELFUERTH"         5.86       59.10     5961.00           =      =       =       =        =        =          =
@      DEC2019**  "ELFUERTH"         5.86       59.10     5961.00           =      =       =       =        =        =          =
@      JAN2019**  "AGUAMILH"        61.33      955.20    64526.00           =      =       =       =        =        =          =
@      FEB2019**  "AGUAMILH"        61.33      955.20    76295.00           =      =       =       =        =        =          =
@      MAR2019**  "AGUAMILH"        61.33      955.20   109879.00           =      =       =       =        =        =          =
@      APR2019**  "AGUAMILH"        61.33      955.20   149055.00           =      =       =       =        =        =          =
@      MAY2019**  "AGUAMILH"        61.33      955.20   203528.00           =      =       =       =        =        =          =
@      JUN2019**  "AGUAMILH"        61.33      955.20   182622.00           =      =       =       =        =        =          =
```

GE

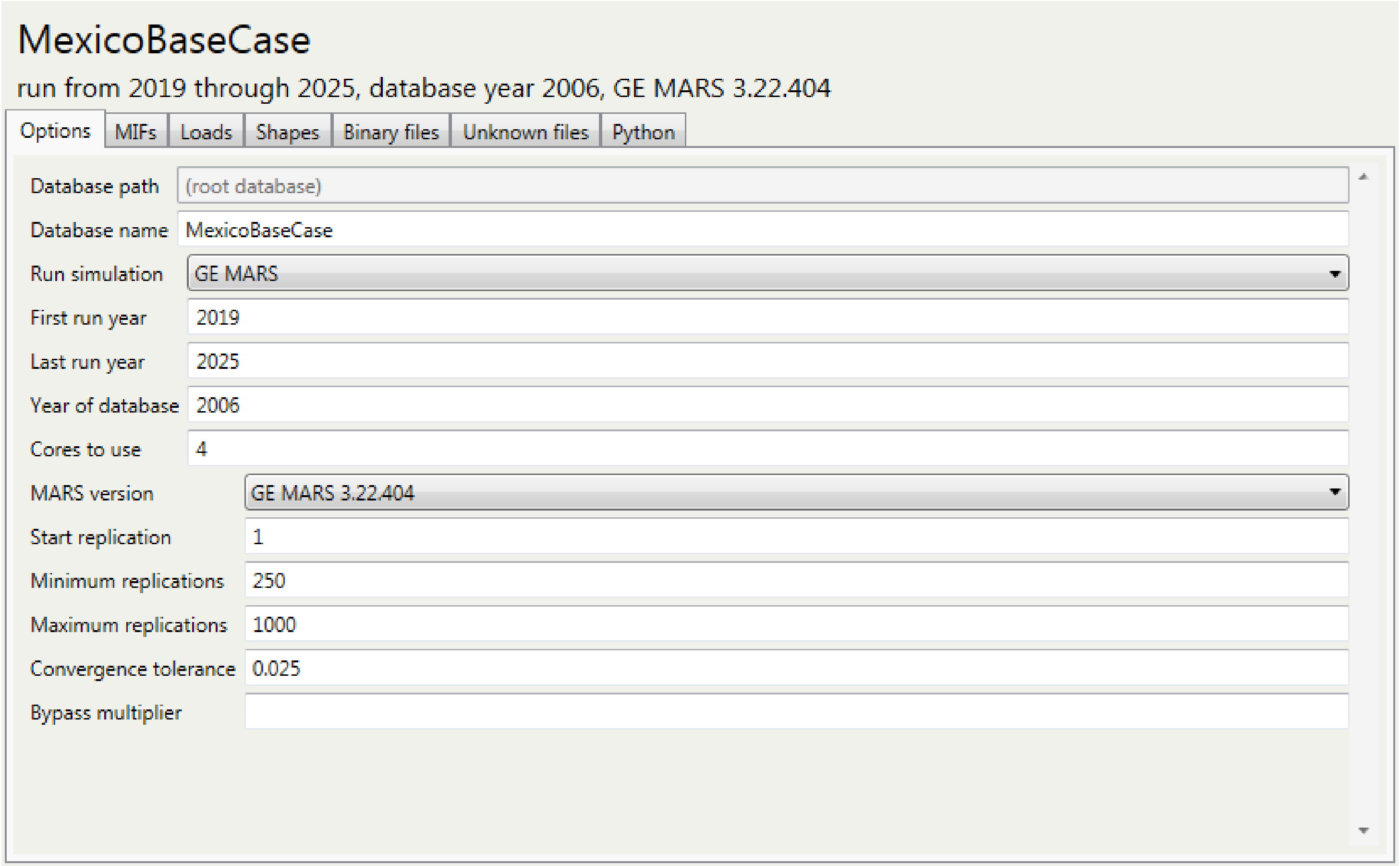
Starting our Database

Create a New Database

1) Open the GE MAPS and MARS User Interface
2) Create a new project file and save to your user directory (there is a shortcut on the desktop)
3) Create a new database in the project



Simulation Options



- Simulation type
  - GE MAPS / GE MARS
- First and last year to simulate
- Year of database
  - *i.e.* what year the hourly load profiles are specified in
- Number of Cores to use
  - If running to convergence each year will only use 1 core
  - If running a fixed number of replications they will be parallelized
- Simulation engine version
- Number of replications

Program Options Tables

GEN-CASE-00 – General Case Information

GEN-TIME-00 – Study Time Period and Annual Output

CNV-CRIT-00 – Convergence Criteria

GEN-OPTN-00 – General Program Options

MNT-AOPT-00 – Annual Maintenance Output Options

MNT-OPTN-00 – Maintenance Options

INT-ONLY-00 – Infrequently Used Debugging Options

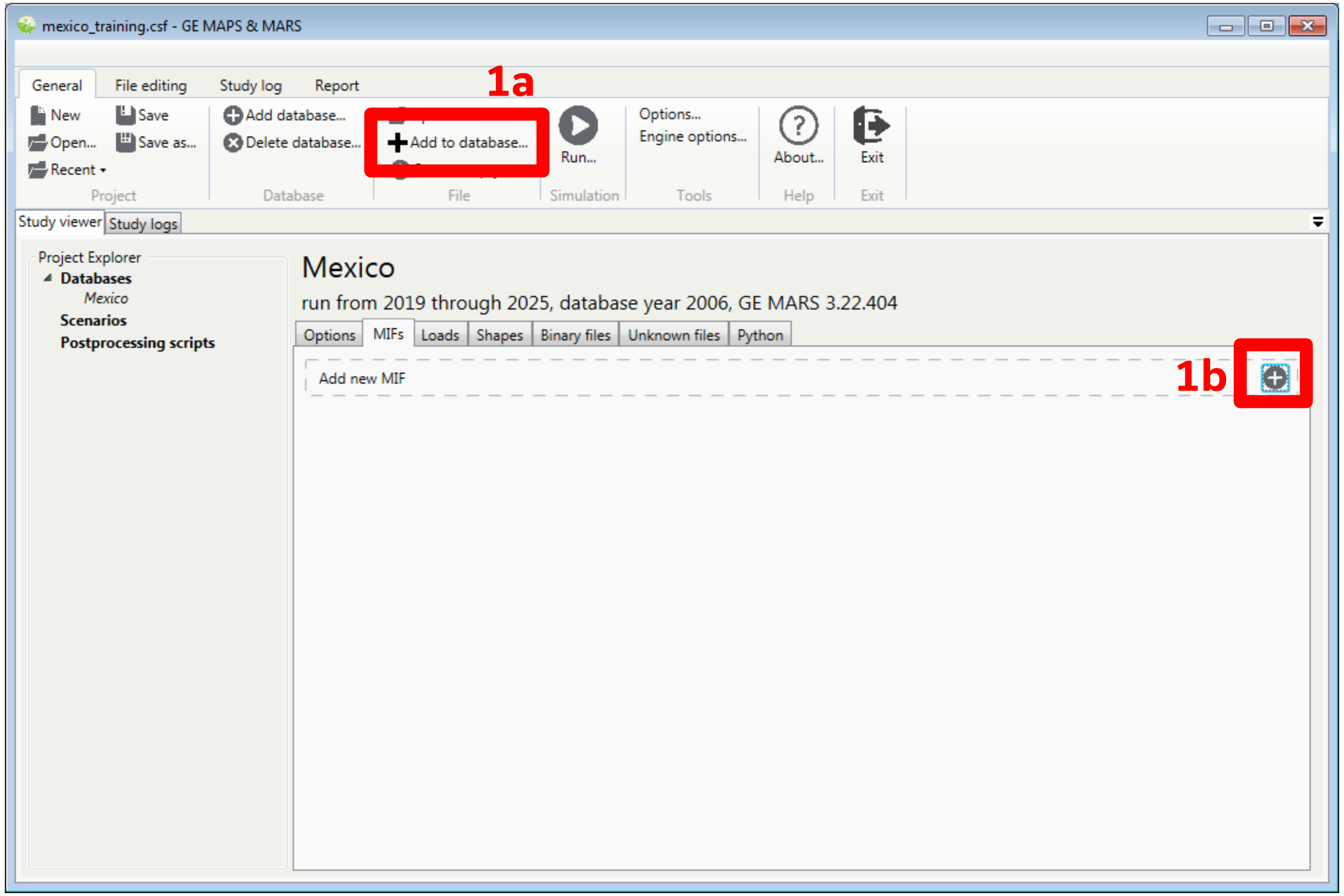
GEN-HDF5-00 – H5 Output File Options

Add program options to the database

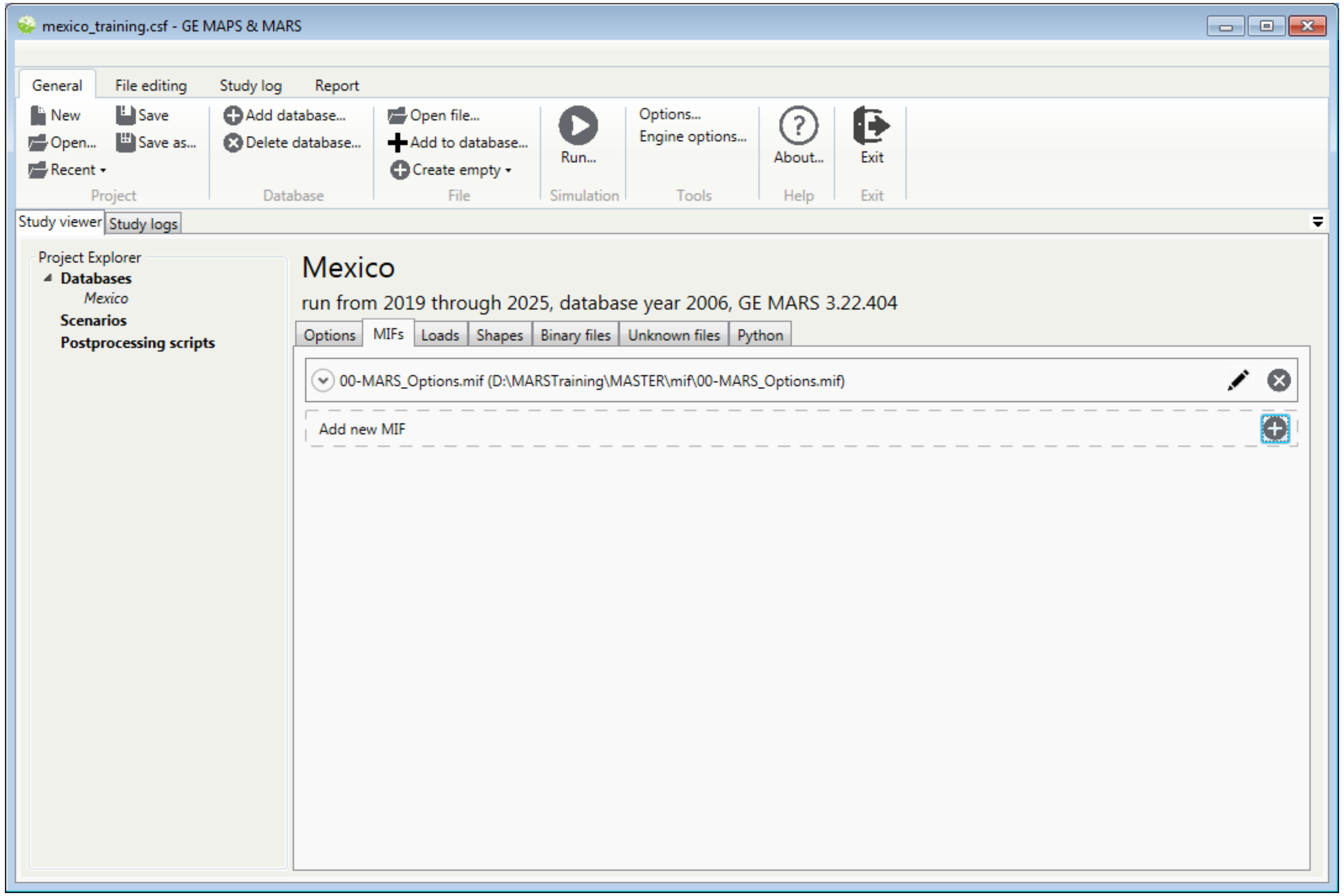
1) In the MAPS & MARS UI select
   a) “Add to database…” from the General ribbon, or
   b) “Add new MIF” on the “MIF” tab of the Study viewer
2) Select the MARS options file in the MIF subfolder of your user directory

OR

Drag the file from the folder and drop it in the study viewer



Add program options to the database



Pools, Areas, Area Groups

Pool:

- A collection of areas typically used to represent ISOs / RTOs or Balancing Authorities
- Reserve sharing can be done first on a pool level

Area:

- Generators are assigned to areas
- Areas have demand forecasts

Area Group:

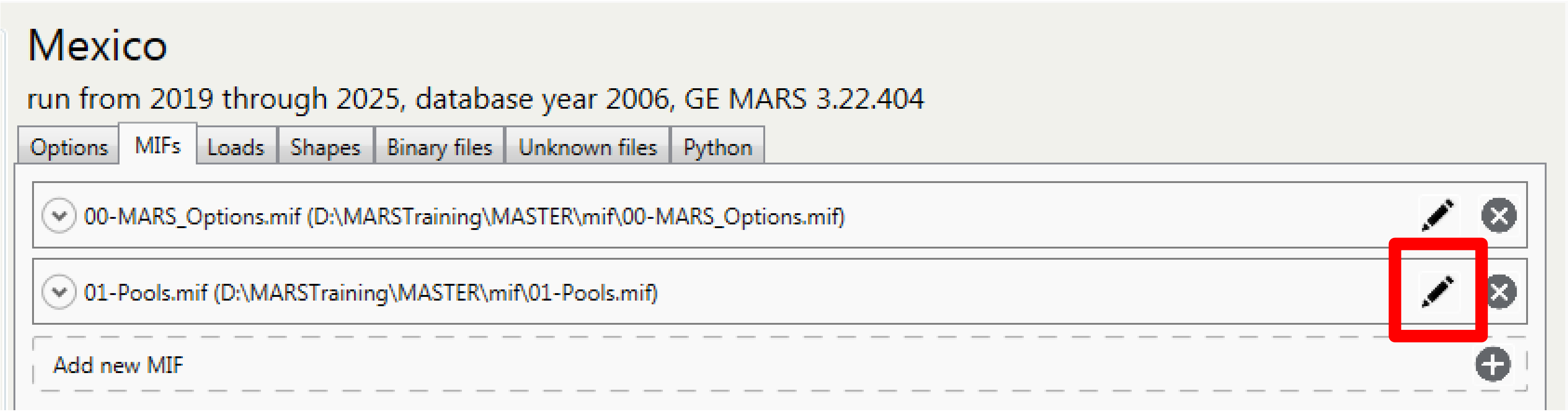
- An arbitrary grouping of Areas for which reliability metrics can be calculated

Creating a new file

1) In the MAPS & MARS UI select
   a) "Add to database…" from the General ribbon, or
   b) "Add new <file type>" on the appropriate tab of the Study viewer
   c) "Create empty" from the general ribbon or File Editing ribbon to create a file that is not associated with a database. By default this will create a new MIF File, but the dropdown next to "Create empty…" can be used to control the file type created
2) Navigate to the folder where you want the new file to be created
3) Enter the name of the file and click Open

Pool Definition

1) Create a new MIF in the database named “01-Pools.mif” and save in your folder
2) Click the edit icon on that file in the Study viewer

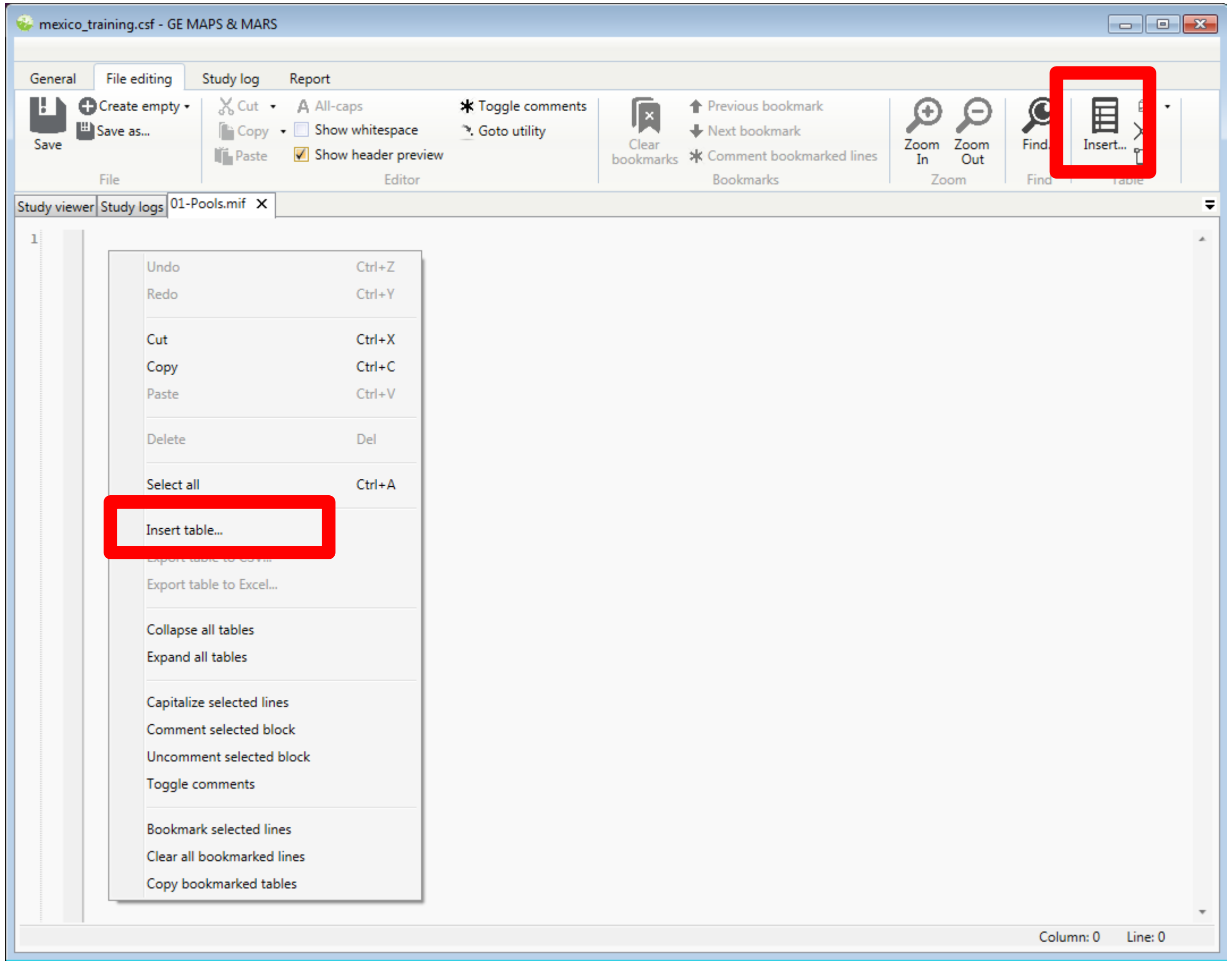


Pool Definition

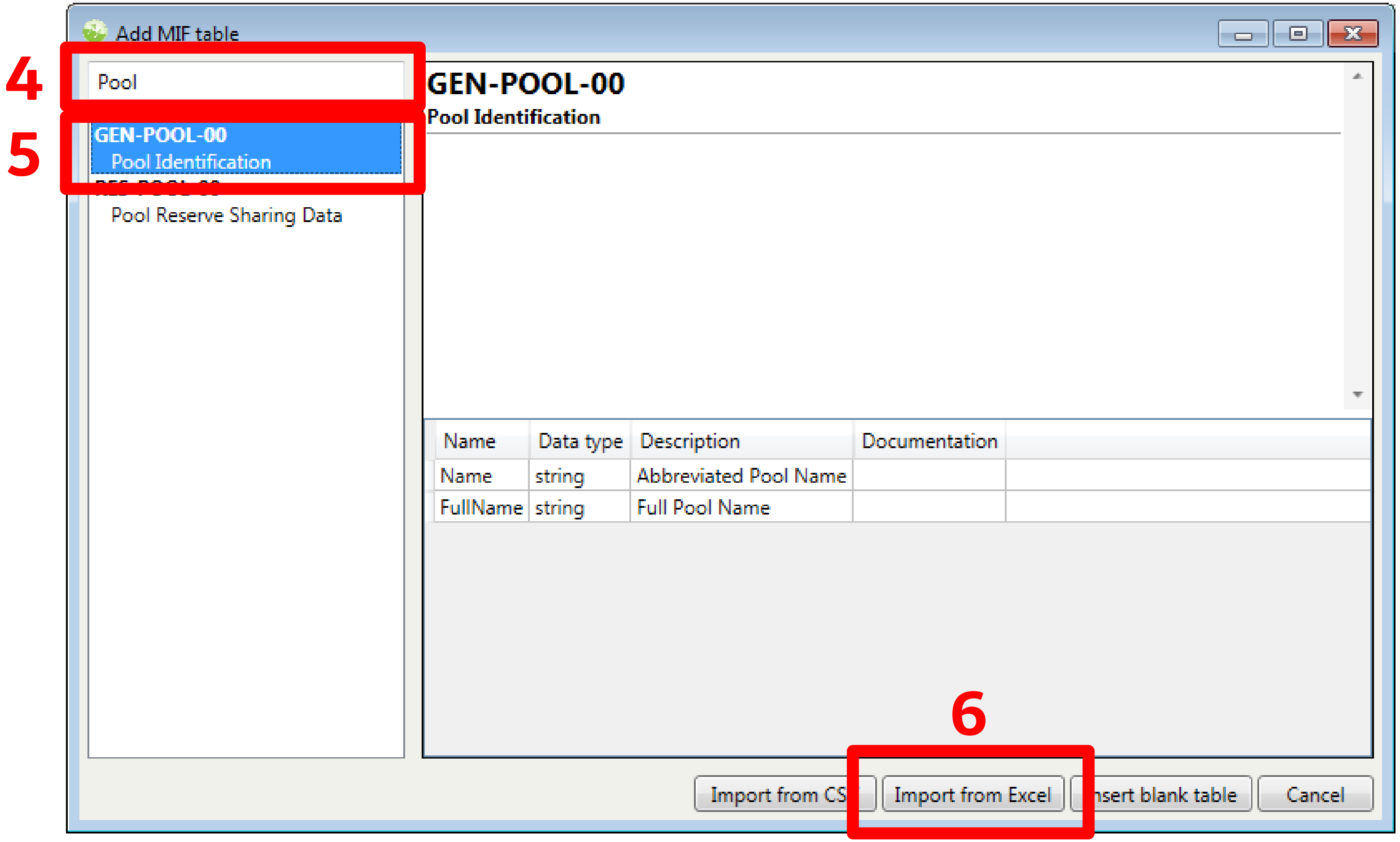
3) Select insert table:

   a) By right clicking anywhere in the editor and selecting "Insert table..." from the menu

   b) Selecting "Insert..." from the File editing ribbon



Pool Definition



4) In the "Add MIF Table" Dialog search for "Pool"

5) Select GEN-POOL-00

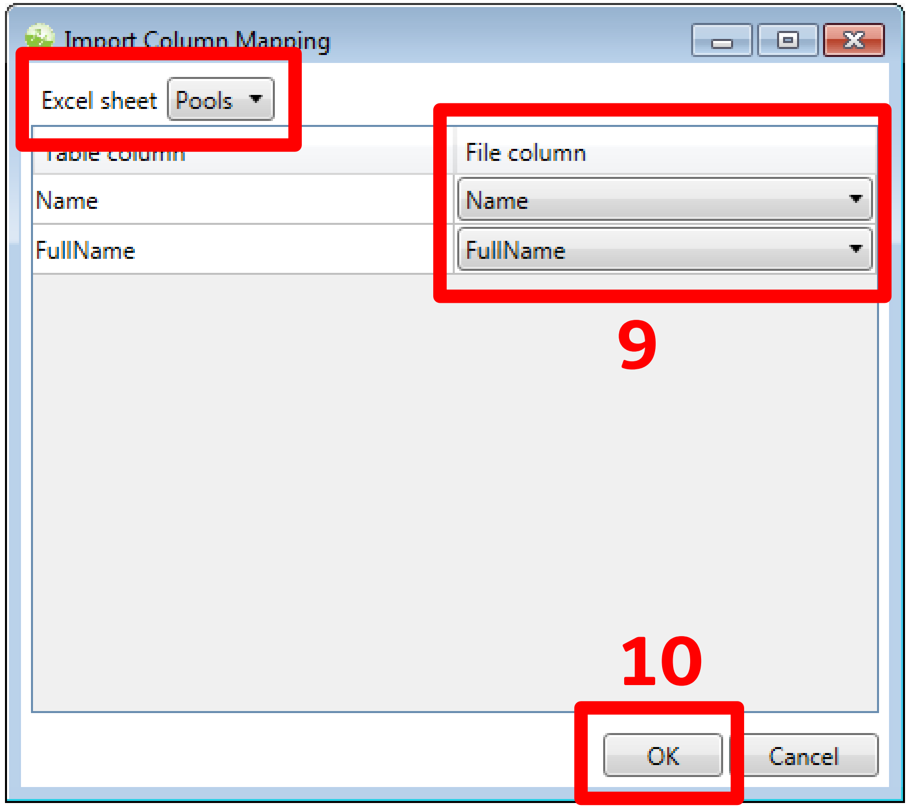
6) Click "Import from Excel"

7) Navigate to the exercises subfolder of your user director and select

"01-Pools_and_Areas.xlsx"

(NOTE: the file must be closed)

Pool Definition

8


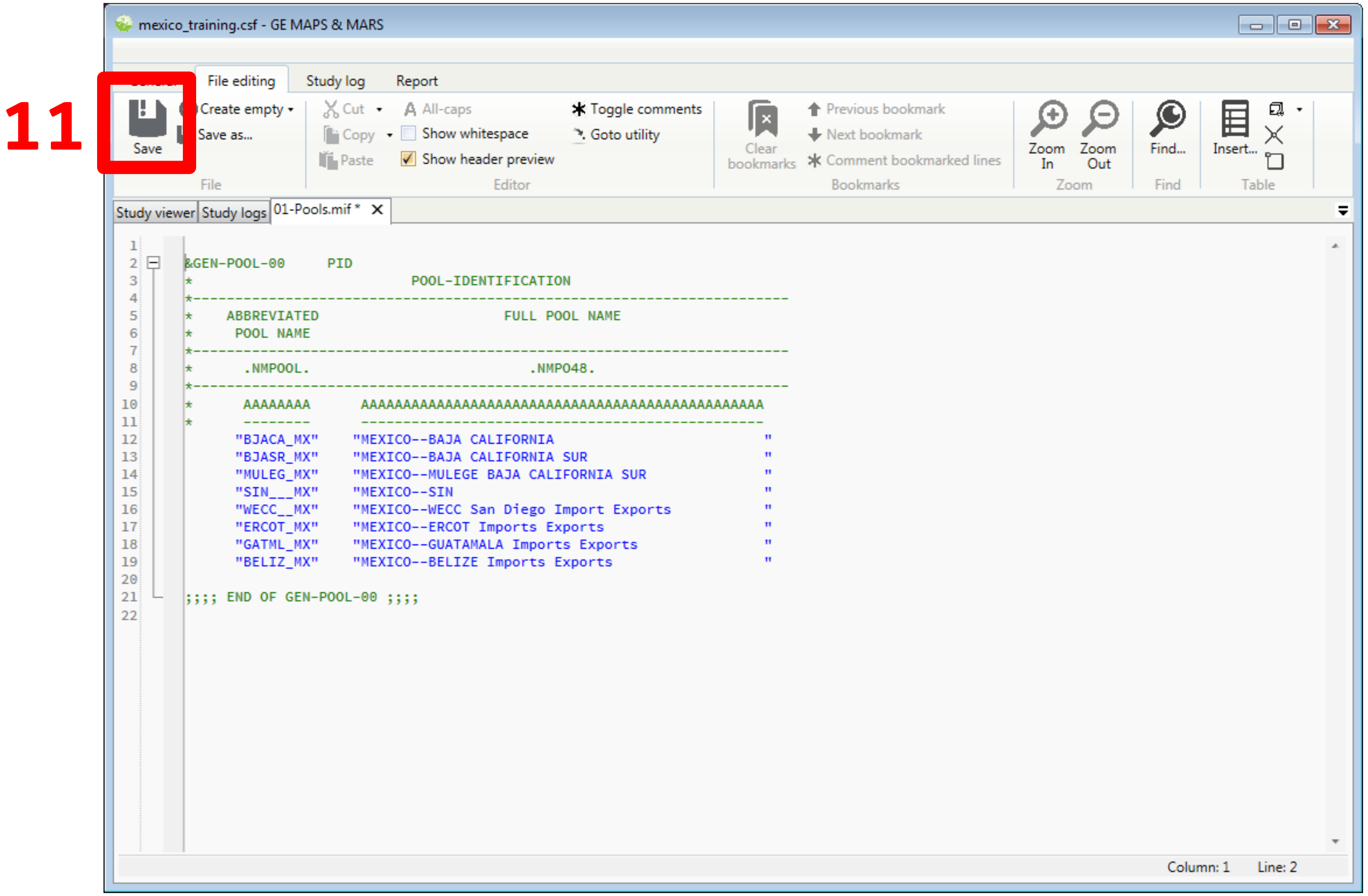
8) In the insert column mapping dialog, make sure the sheet "Pools" is selected

9) Make sure the columns mapped are the ones you want to insert

10) Click OK

Pool Definition

11) Save the File

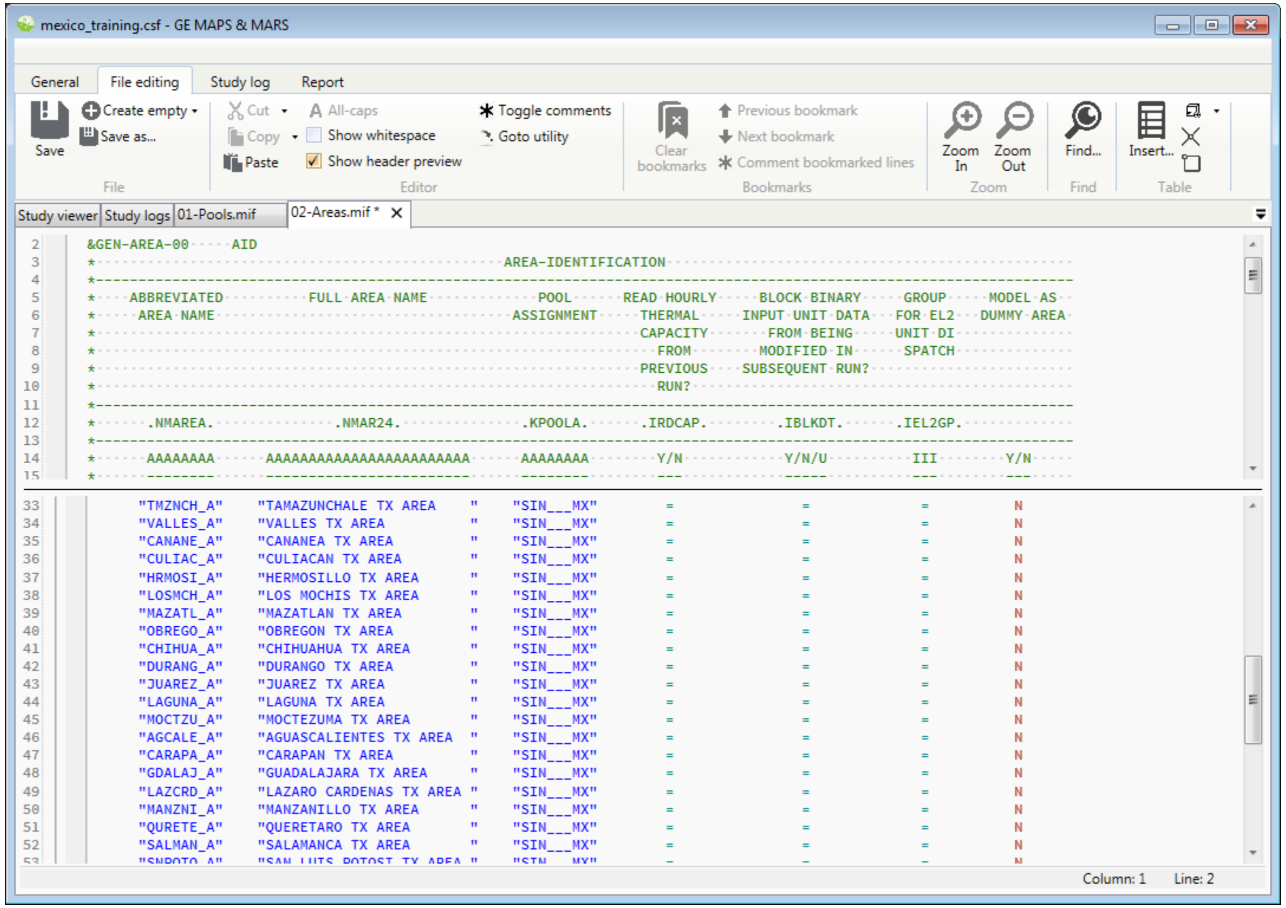


Area Definition

Follow the same steps as above to

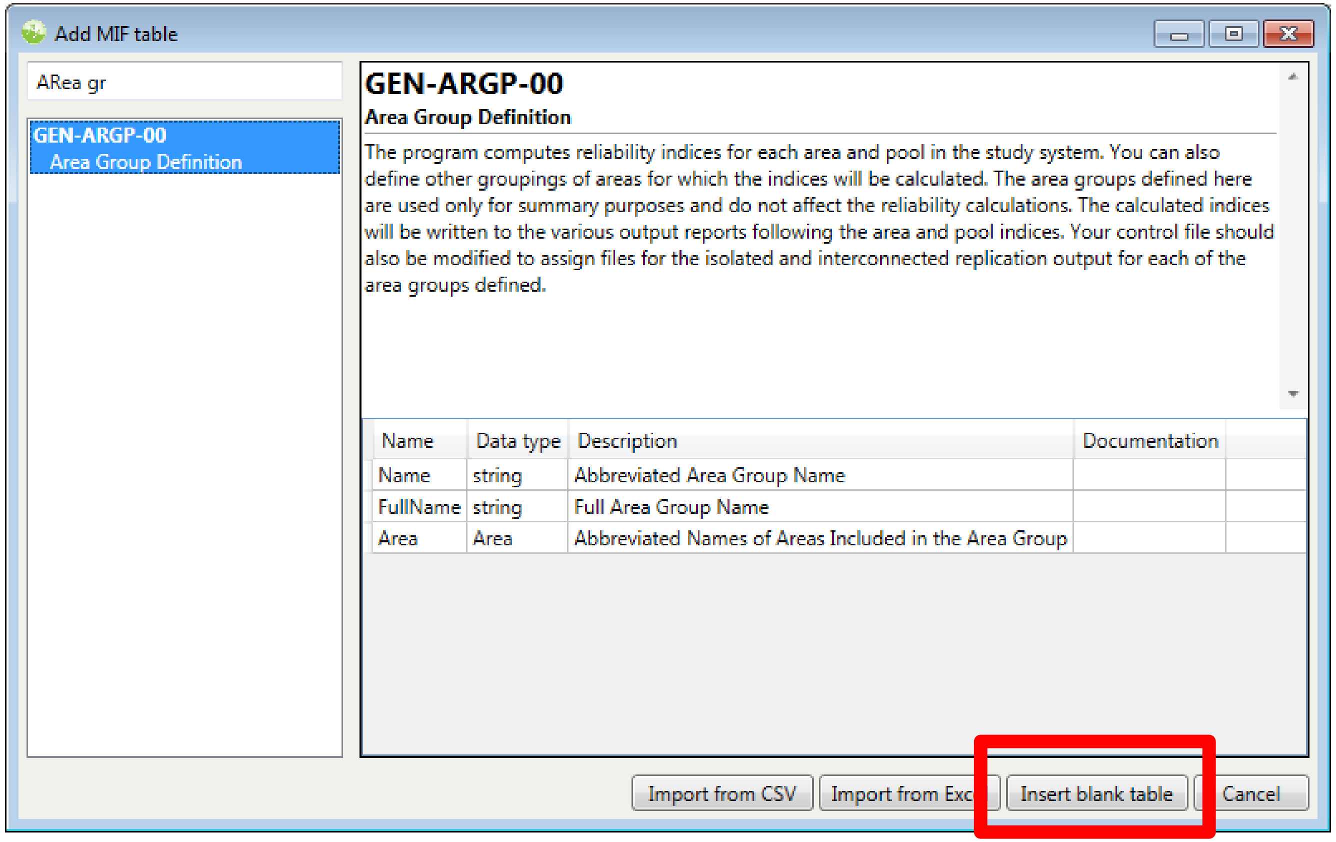
1) Create a new file in your database named “02-Areas.mif”
2) Insert a GEN-AREA-00 table from the “Areas” tab
3) Save the file

Area Definition



Add an Area Group

1) In the 02-Areas.mif file insert a blank GEN-ARGP-00 table below



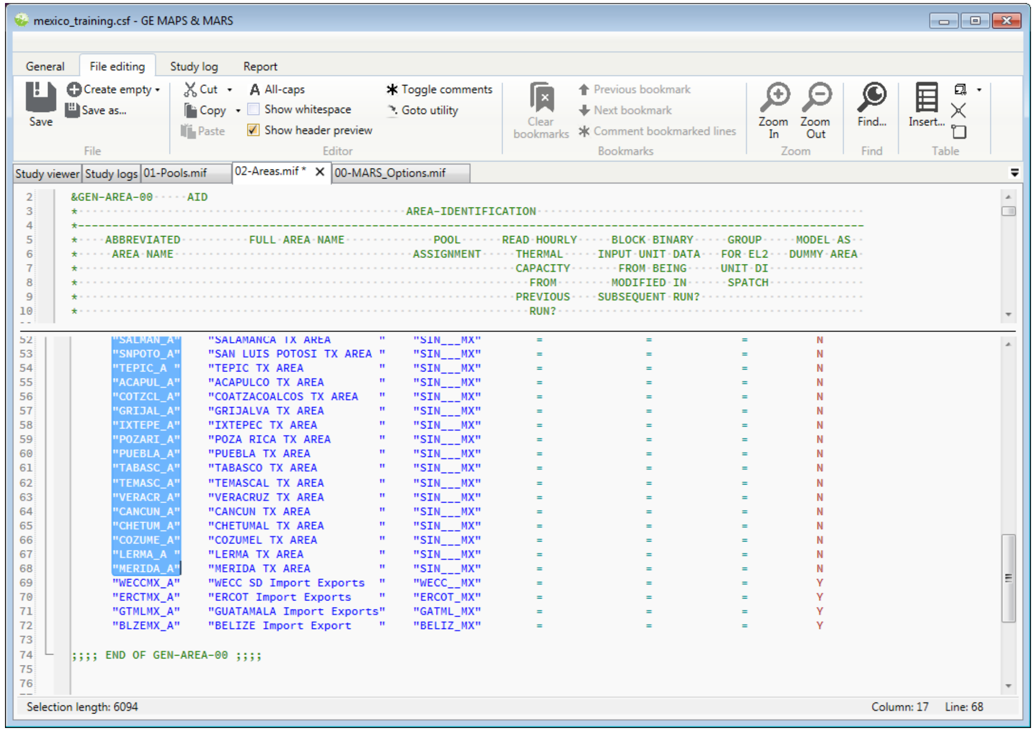
Add an Area Group

2) Name the Area Group “ALL_MEX “

```
&GEN-ARGP-00     AGP    CONTINUATION
*                                          AREA-GROUP-DEFINITION
*-----------------------------------------------------------------------------------------------------------
*    ABBREVIATED       FULL AREA GROUP NAME      ABBREVIATED NAMES OF AREAS INCLUDED IN THE AREA GROUP
*     AREA GROUP
*        NAME
*-----------------------------------------------------------------------------------------------------------
*      .NMARGP.             .NMAG24.                                   .IARGRP.
*-----------------------------------------------------------------------------------------------------------
*      AAAAAAAA     AAAAAAAAAAAAAAAAAAAAAAAA      AAAAAAAA      AAAAAAAA      AAAAAAAA      AAAAAAAA
*      --------     ------------------------      --------      --------      --------      --------
      "ALL_MEX "    "All Mexico Areas        "

;;;; END OF GEN-ARGP-00 ;;;;
```

Add an Area Group

3) Press and hold Alt (Block Selection) and select all areas from the GEN-AREA-00 Table, Copy the selection



Add an Area Group

4) Paste the selection into the GEN-ARGP-00 Table

5) Press and hold Alt and create a multiline cursor before all area names

6) Type "+" and enough spaces to align the area names with the first column of area names

```
"AGCALE_A"
"CARAPA_A"
"GDALAJ_A"
"LAZCRD_A"
"MANZNI_A"
"QURETE_A"
"SALMAN_A"
"SNPOTO_A"
"TEPIC_A "
"ACAPUL_A"
"COTZCL_A"
"GRIJAL_A"
"IXTEPE_A"
"POZARI_A"
"PUEBLA_A"
"TABASC_A"
"TEMASC_A"
"VERACR_A"
"CANCUN_A"
"CHETUM_A"
"COZUME_A"
"LERMA_A "
"MERIDA_A"
;;;; END OF GEN-ARGP-00 ;;;;
```

```
&GEN-ARGP-00    AGP    CONTINUATION
*                                      AREA-GROUP-DEFINITION
*------------------------------------------------------------------
*    ABBREVIATED       FULL AREA GROUP NAME      ABBREVIATED NAMES
*     AREA GROUP
*        NAME
*------------------------------------------------------------------
*      .NMARGP.              .NMAG24.
*------------------------------------------------------------------
       ........      ........................       ..
+                                               "AGCALE_A"
+                                               "CARAPA_A"
+                                               "GDALAJ_A"
+                                               "LAZCRD_A"
+                                               "MANZNI_A"
+                                               "QURETE_A"
+                                               "SALMAN_A"
+                                               "SNPOTO_A"
+                                               "TEPIC_A "
+                                               "ACAPUL_A"
+                                               "COTZCL_A"
+                                               "GRIJAL_A"
+                                               "IXTEPE_A"
+                                               "POZARI_A"
+                                               "PUEBLA_A"
+                                               "TABASC_A"
+                                               "TEMASC_A"
+                                               "VERACR_A"
+                                               "CANCUN_A"
+                                               "CHETUM_A"
+                                               "COZUME_A"
+                                               "LERMA_A "
+                                               "MERIDA_A"
;;;; END OF GEN-ARGP-00 ;;;;
```

Add an Area Group

7. Align the first area name on the first row
8. Save the File

```
&GEN-ARGP-00     AGP    CONTINUATION
*                                          AREA-GROUP-DEFINITION
*--------------------------------------------------------------------------------------------------------
*    ABBREVIATED        FULL AREA GROUP NAME      ABBREVIATED NAMES OF AREAS INCLUDED IN THE AREA GROUP
*     AREA GROUP
*        NAME
*--------------------------------------------------------------------------------------------------------
*      .NMARGP.              .NMAG24.                                  .IARGRP.
*--------------------------------------------------------------------------------------------------------
*      AAAAAAAA      AAAAAAAAAAAAAAAAAAAAAAAA      AAAAAAAA      AAAAAAAA      AAAAAAAA      AAAAAAAA
*      --------      ------------------------      --------      --------      --------      --------
      "ALL_MEX "    "All Mexico Areas        "    "ENSENA_A"
+                                                 "MEXICA_A"
+                                                 "RIOCLR_A"
+                                                 "TIJUAN_A"
+                                                 "CNSTCI_A"
+                                                 "LAPAZ_A "
+                                                 "LOSCAB_A"
+                                                 "MULEGE_A"
+                                                 "CENTRA_A"
+                                                 "GUEMEZ_A"
+                                                 "HUASTE_A"
```

GE

Demand Modeling

Load Data

Hourly load data input for each area for first year is mandatory

- Optionally input for subsequent years
- If not provided, use load from previous year

Areas can be specified as “Dummy Areas” in which case hourly load profiles are not required

Load Data

An internal calendar determines the day of the week for the beginning of the study year

- If the first day of the week does not match, load is shifted accordingly
- The 366th day is added for leap years (unless provided)
- Load shapes can be modified to match specified monthly & annual peaks and energies

Peak and Energy Adjustment

Automatically modify input hourly load data specified by user

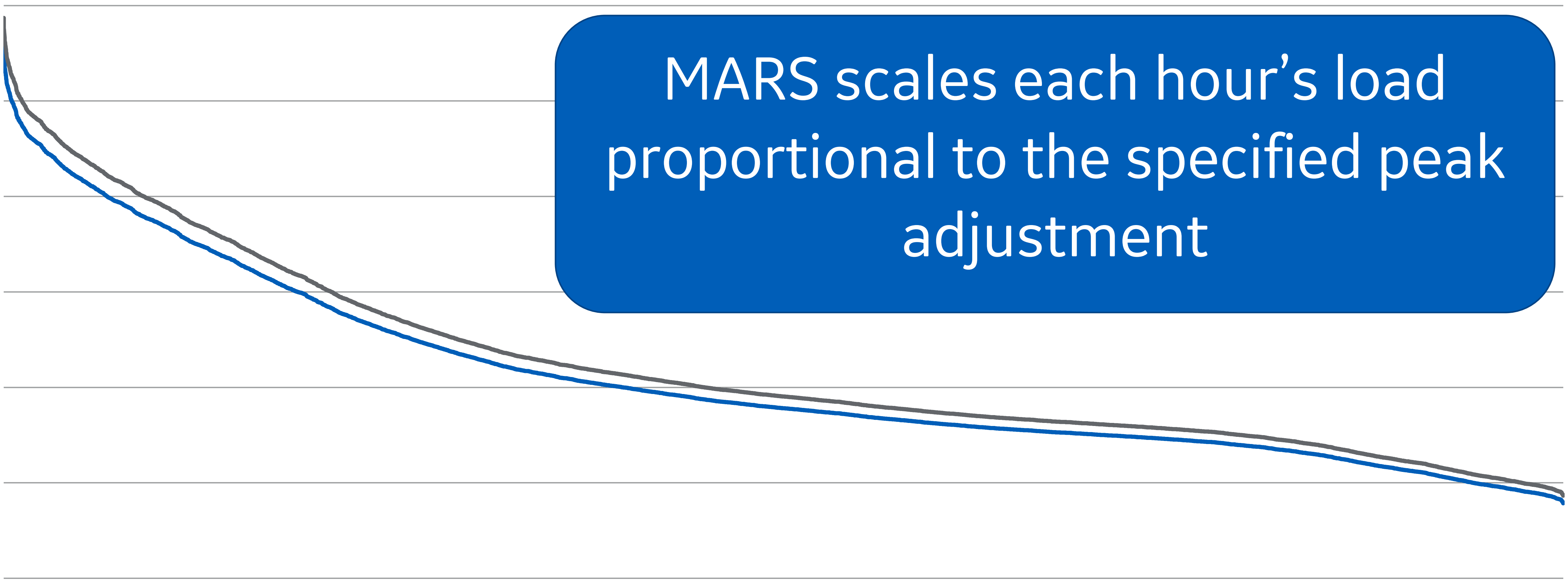
Adjusting peak load only

- All the hourly loads will be adjusted proportionately
- Load factor will be unchanged

Adjusting energy

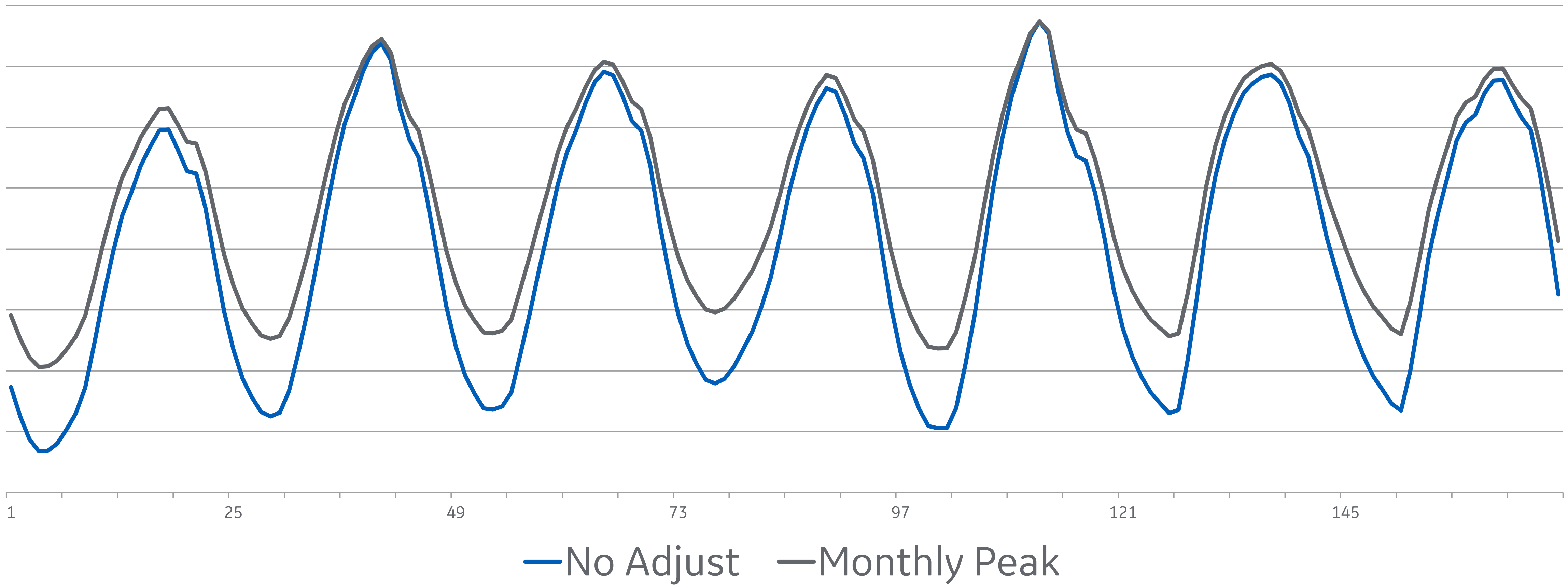
- Maintain monthly peak and adjust loads for specified energy
- Maintain monthly peak and valley
- Maintain daily peak and adjust daily loads for daily energy calculated in proportion to the original daily energies

Peak Adjustment

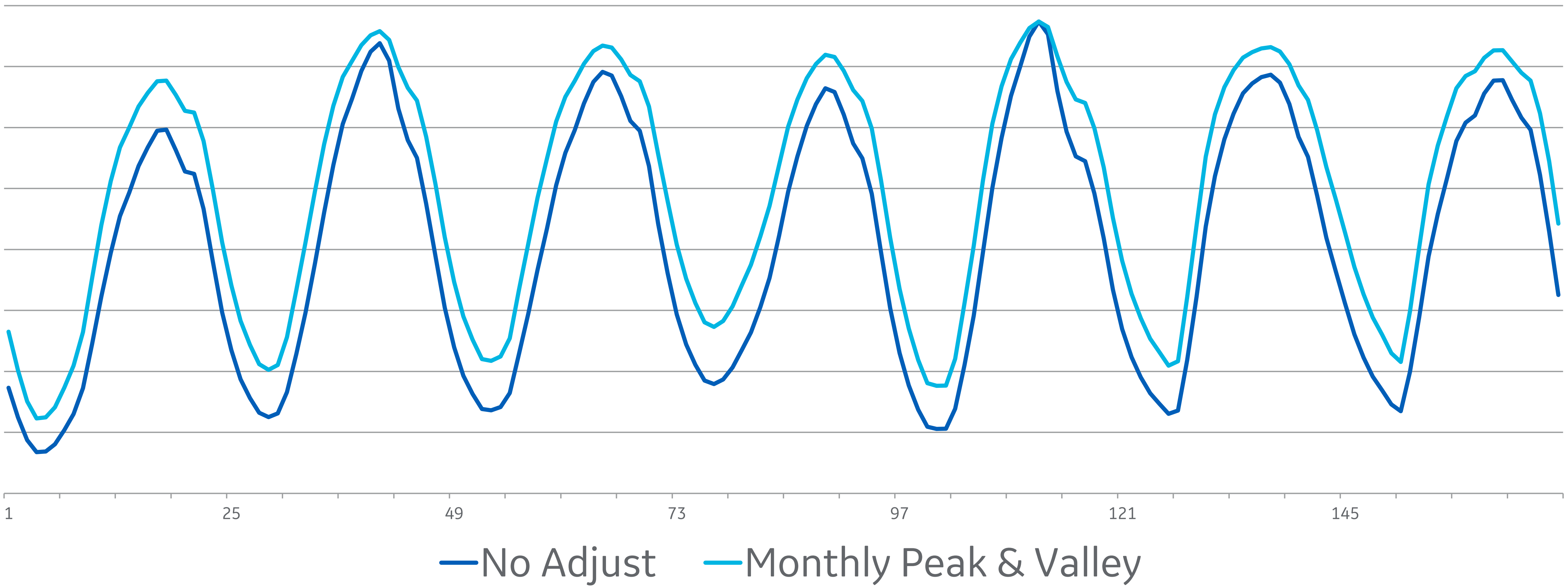


Energy Adjustment

Hold Monthly Peak

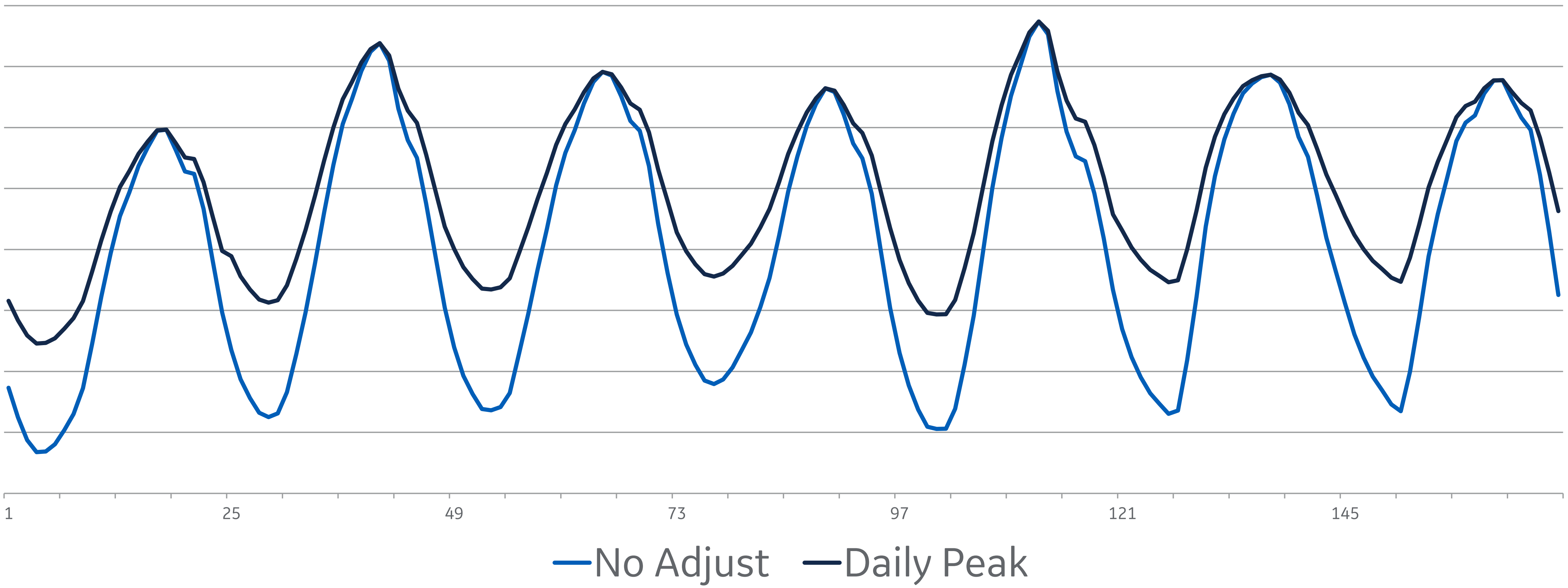


Energy Adjustment
Hold Monthly Peak and Valley

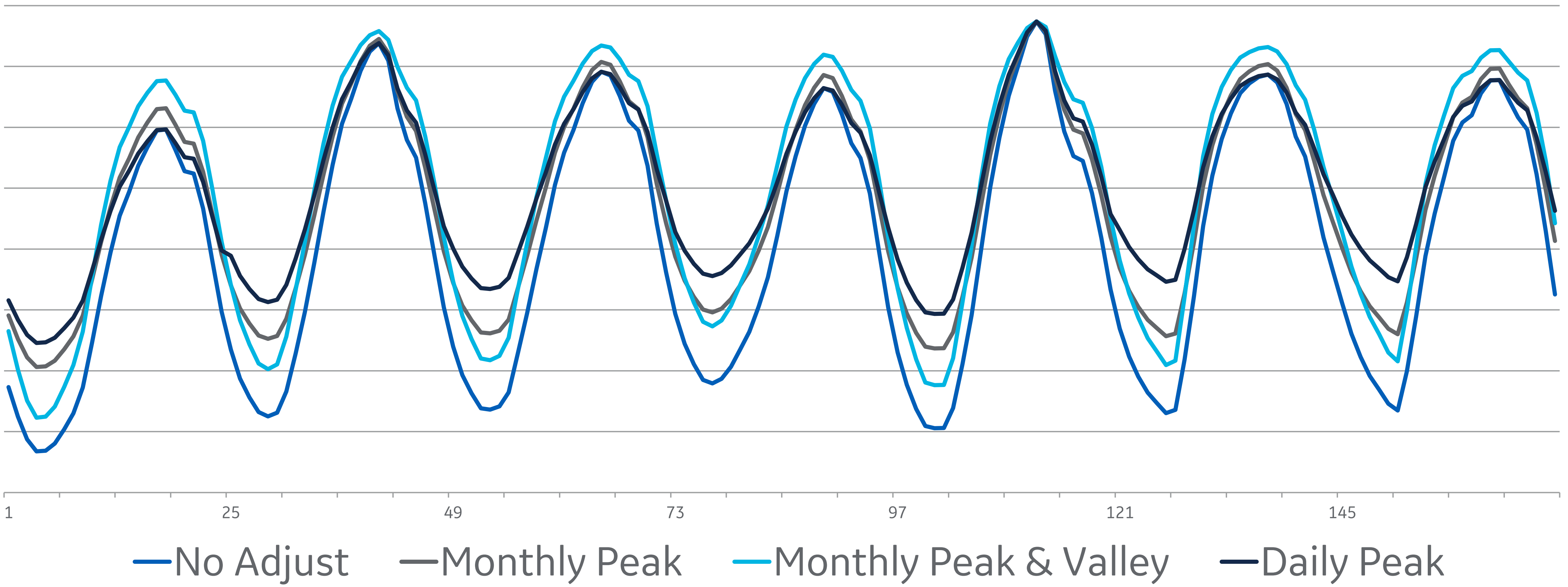


Energy Adjustment

Hold Daily Peak

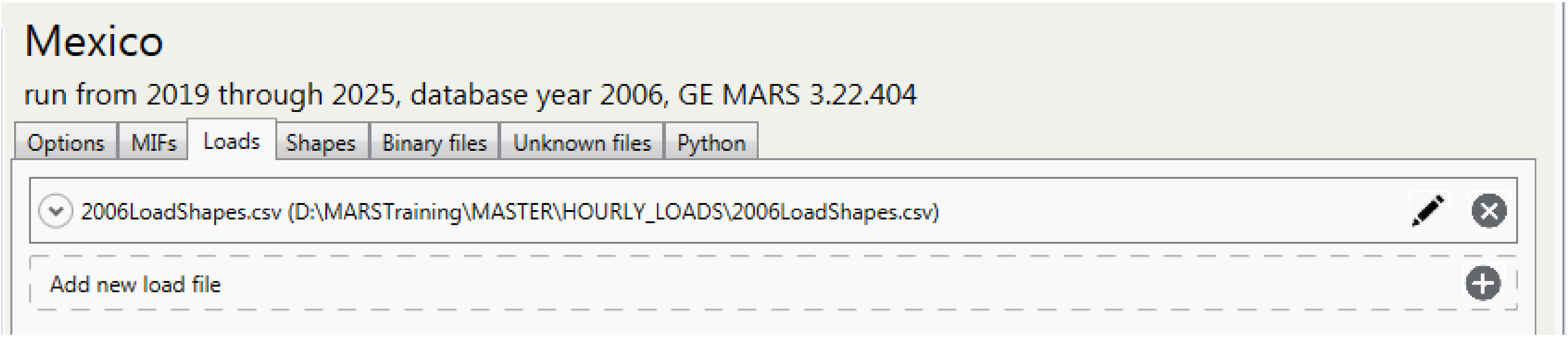


Energy Adjustment
All Options



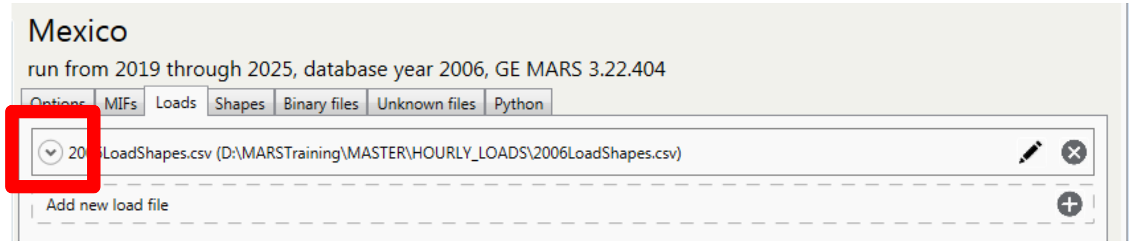
Add a Load Shape CSV to the Database

1) Open the 02-Load_Forecast file from the exercises subfolder of your user directory in Excel and go to the "2006 Hourly Loads" tab
2) Select "Save As" and save this tab as a Comma Separated Values (*.csv) file named "*2006LoadShapes.csv*" located in the folder you created
3) In the GE MAPS & MARS User interface, add the load file

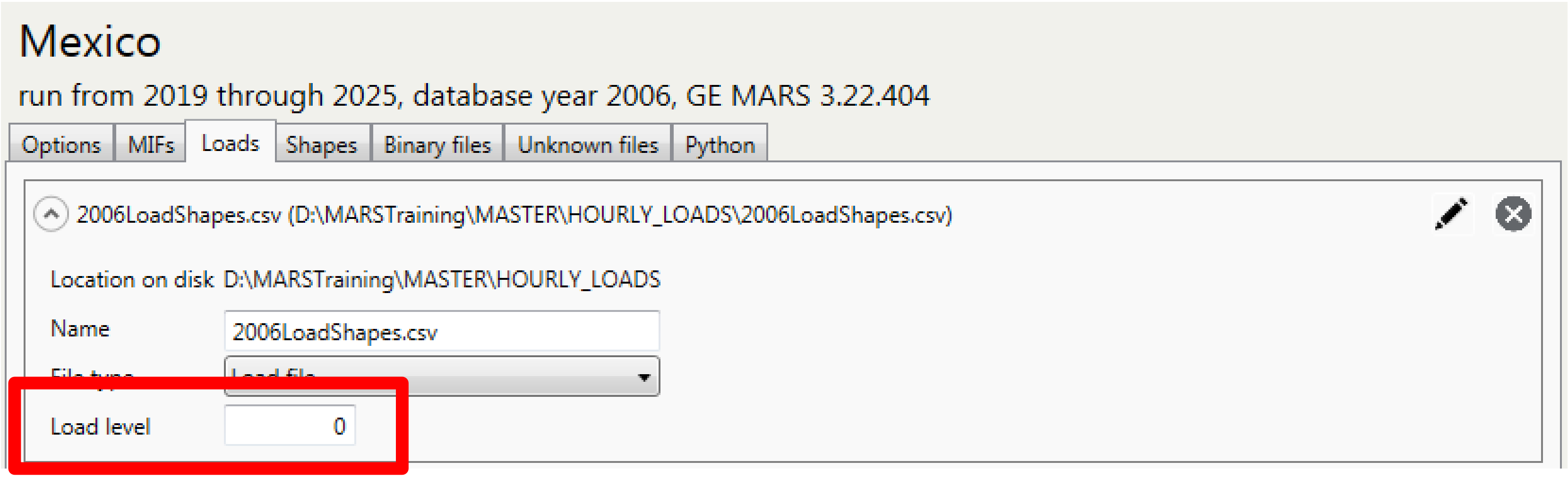


Add a Load Shape CSV to the Database

4) Expand the load shape configuration



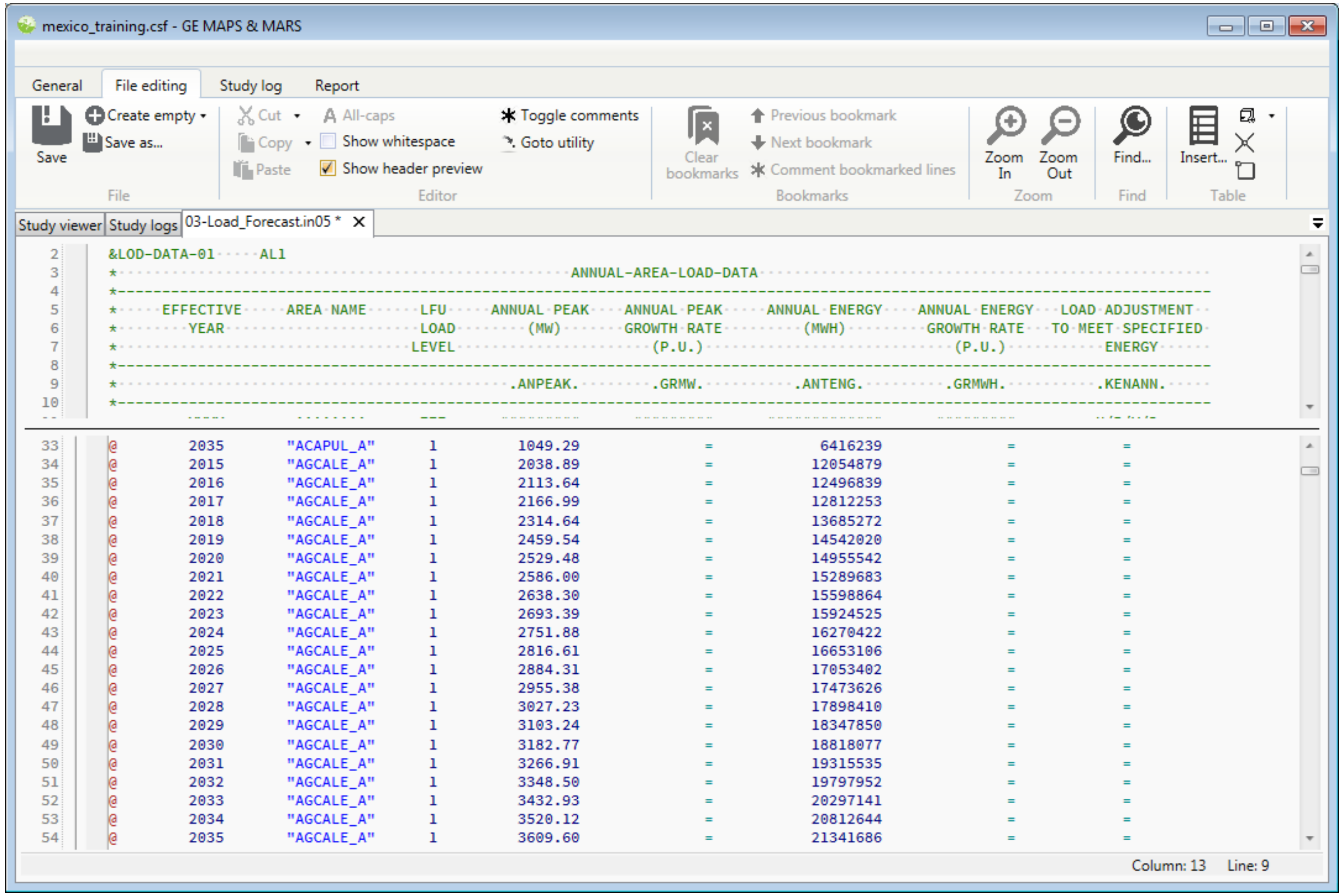
5) Set the load level to 0



Add Peak and Energy Adjustments to the Database

1) Create a new file in your database named ”03-Load_Forecast.mif”
2) Insert a LOD-DATA-01 table to the file from the “Load Forecast” tab
3) Save the file

Add Peak and Energy Adjustments to the Database



GE

Thermal Units

Thermal Units

Thermal Unit Parameters can be input for the following MARS Unit Classes:

1) Thermal
2) Cogen Type 1
3) Cogen Type 2
4) Energy Limited Type 1 Units

Thermal Units
Default Parameters

Default parameters can be set by Unit Summary Type for:

1) Forced Outage Rate
2) Number of Transitions
3) Planned Outage Rate

Any unit modelled using a defined Unit Summary Type will be modeled as a two state (On and Off) unit with these default parameters

Overrides can be input for any unit to model unit specific details where known

The MIF preprocessor must be used to use this feature

Specified in table DEF-MRTH-00

Thermal Units
General Data

Unique eight (8) character identifier to be used in other tables

Area location

Installation and retirement dates

Unit summary type

Specified in table UNT-DATA-00

Thermal Units
Unit Rating and Capacity States

Maximum unit rating in MW

- Specified in table **UNT-MXCP-00**
- Must be specified for each Thermal Unit

Capacity States

- Up to 11 capacity states for each unit
- Percent of maximum capacity of each state
- Specified in table **UNT-CAPS-00**
- If using default thermal parameters, two states will be specified: 0% and 100% of maximum rating. In this case UNT-CAPS-00 does not need to be added to the MIF

Thermal Units

Forced Outage Rates and Transition Rates

Random outage characteristics may be specified as:

Forced Outage Rates

- Partial forced outage rates for each capacity state
- Specified in table **UNT-FORS-00**
- If modelling forced outage rates, the number of transitions must be specified in **NUM-TRNS-00**

Unit Transition Rates

- Specified in table **UNT-TRNS-00**

If using default thermal parameters random outage characteristics do not need to be specified for each unit

Thermal Units
Transition Rates

A square matrix, used to represent how often a unit/interface switches between states

TR(from A, to B) =

Probability of A → B, assuming that it is in state A

How often is the unit at each state?

State	MW	Hours
1	200	5,000
2	100	2,000
3	0	1,000

How many times during the year does the unit change between states?

	To State		
From State	1	2	3
1	0	10	5
2	6	0	12
3	9	8	0

$$\mathrm{TR(A,B)} = \frac{Count\ A \rightarrow B}{Hours\ at\ A}$$

State Transition Rates

	To State		
From State	1	2	3
1	0.000	0.002	0.001
2	0.003	0.000	0.006
3	0.009	0.008	0.000

Thermal Units

Ambient Derates

MARS can derate unit capacities based on area loads (proxy for ambient temperatures) – input area load to be monitored, and up to 5 per unit capacity multipliers to determine the units rating when the specified area load is above the corresponding value

Specified in **UNT-DERT-00**

Thermal Units
Cogeneration

Modeled as thermal units with associated hourly load demand

- Specified as a typical week per month (Mon – Sun); can change monthly
- Difference between the unit’s available capacity and its load requirements is the amount of capacity that the unit can contribute to the system
- Two types of cogeneration units can be modeled in MARS

Thermal Units
Cogeneration

Type 1

- System will provide back-up if unit is on outage
- The cogen load is added to the area's hourly loads and the unit is modeled as a thermal unit

Type 2

- System does not provide back-up
- If available capacity is greater than its load, the remaining will serve the area demand; if the available capacity is less than its load, a portion of its load will not be served and net area contribution will be zero

Thermal Units

Energy Limited Type 1

Maximum capacity available at a given time may be less than that determined from its current capacity state

Can be used to represent:

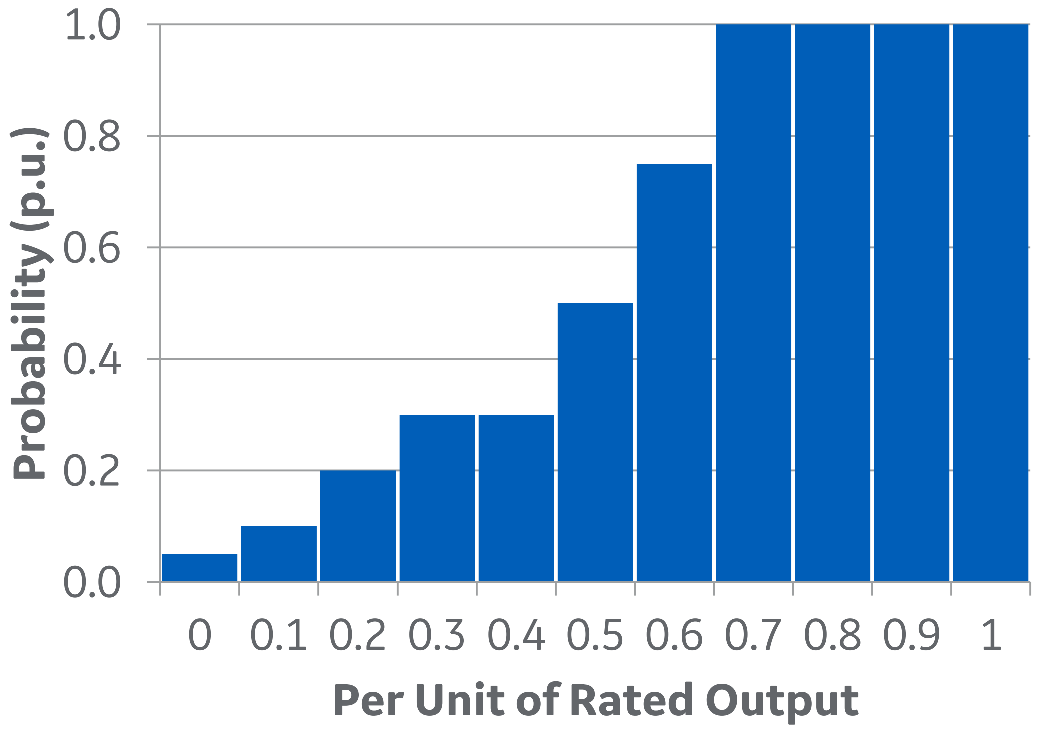
- Thermal units with restricted availability of fuel
- Hydro units with limited water availability
- Wind unit random availability

Thermal Units
Energy Limited Type 1

Random Energy Limits

- Defined by a cumulative probability density function – Specified in **ELU-DIST-00**
- The probability of the unit being at or below a given capacity level
- Frequency of capacity limit can be calculated either daily or monthly
- Daily – for wind or solar with often changing available energy
- Monthly – for fuel or water limitations that may change over a longer time period

Probability Density Function

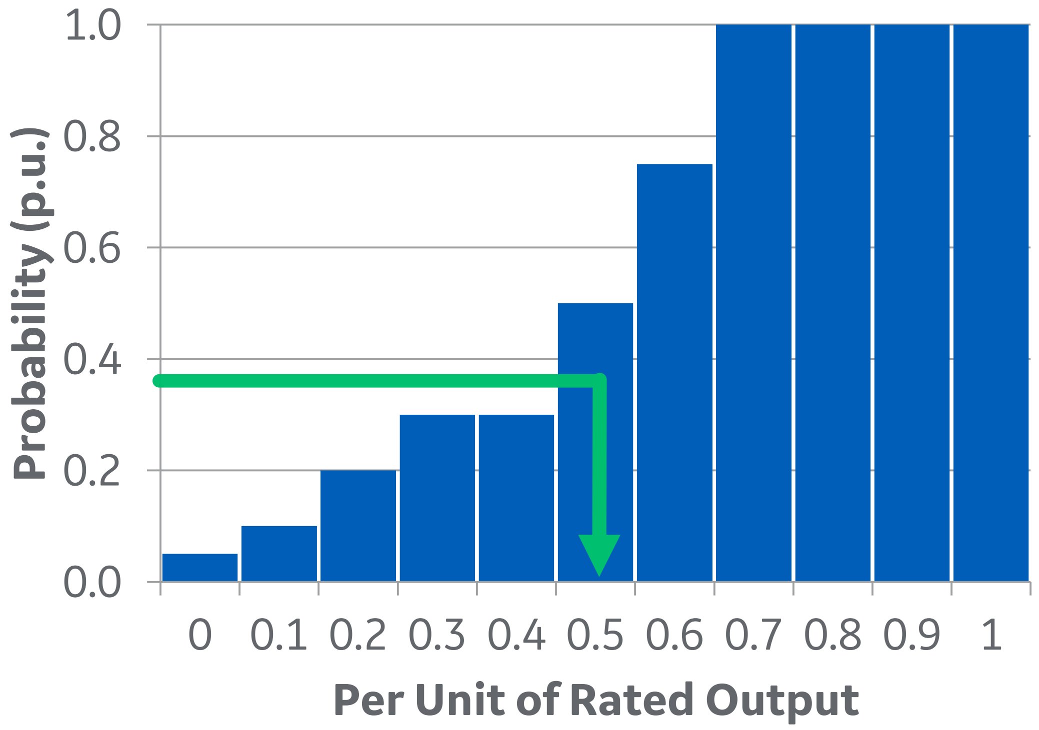


Thermal Units
Energy Limited Type 1

Random Energy Limits

- At the beginning of each day or month, MARS determines the maximum possible capacity available from the unit, recognizing its energy limits
- Randomly generating a probability value and find the capacity associated with that probability

Probability Density Function



Maintenance Scheduling

Maintenance can be input by users (fixed) or automatically scheduled by MARS

- Using a constant reserve approach on:
  - each area,
  - each pool, or
  - on the system
- In order of:
  - decreasing capacity
  - decreasing product of capacity times duration of maintenance

Options specified in **MNT-OPTN-00**

Maintenance Scheduling

Fixed Maintenance

- Up to 5 fixed maintenance periods are allowed
  - Thermal fixed maintenance specified in **MNT-FIXD-00**
  - Non-Thermal fixed maintenance specified in **MNT-FDMD-00**
- Scheduled maintenance is applied after fixed maintenance periods

Maintenance Scheduling
Thermal Units

- Unit returns to full available state after planned outages
- If unit is forced out when a maintenance begins, it will be postponed until the unit is back in service
- If the delay causes this maintenance to overlap with the next maintenance, the next maintenance will begin right away

Specified in **MNT-UNOP-00**

Multi-year cycles may be specified in **MNT-PLOR-00** and **MNT-WEEK-00**

If using default thermal parameters these do not need to be specified

Maintenance Scheduling
Non-Thermal Units

- Can be input on a plant basis
- Specify number of identical units; input all data by plant
- MARS will schedule automatic maintenance separately for each unit
- Fixed daily maintenance can be input by individual unit

Specified in **MNT-UNOP-00**

Multi-year cycles may be specified in **MNT-PLOR-00** and **MNT-WEEK-00**

Maintenance Scheduling

MARS does not schedule automatic maintenance on units

- that are installed or retired during the year, or
- for which fixed daily maintenance was specified, or
- if the unit's capacity is zero

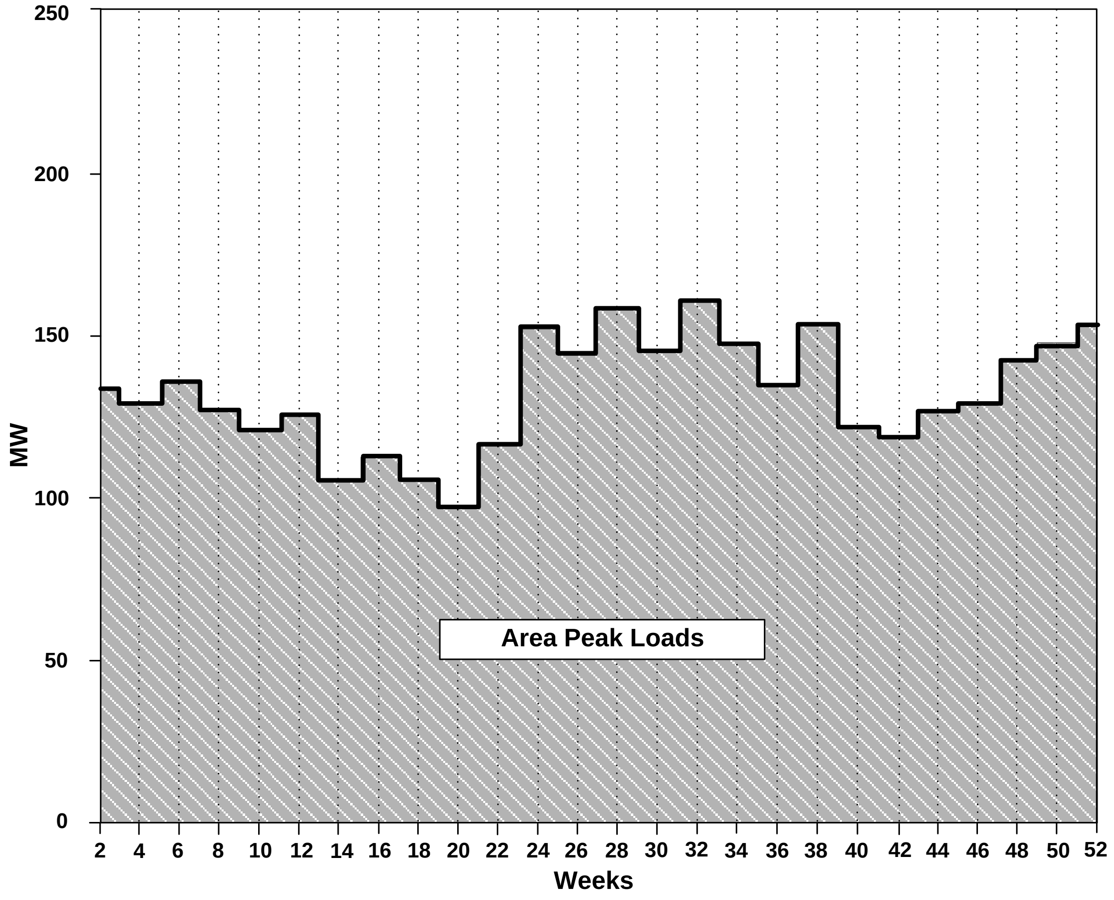
MARS also does not schedule automatic maintenance for

- Units representing contracts – does not include the capacity of these units in the automatic maintenance calculations
- Fixed maintenance can include these units

MARS schedules maintenance based on

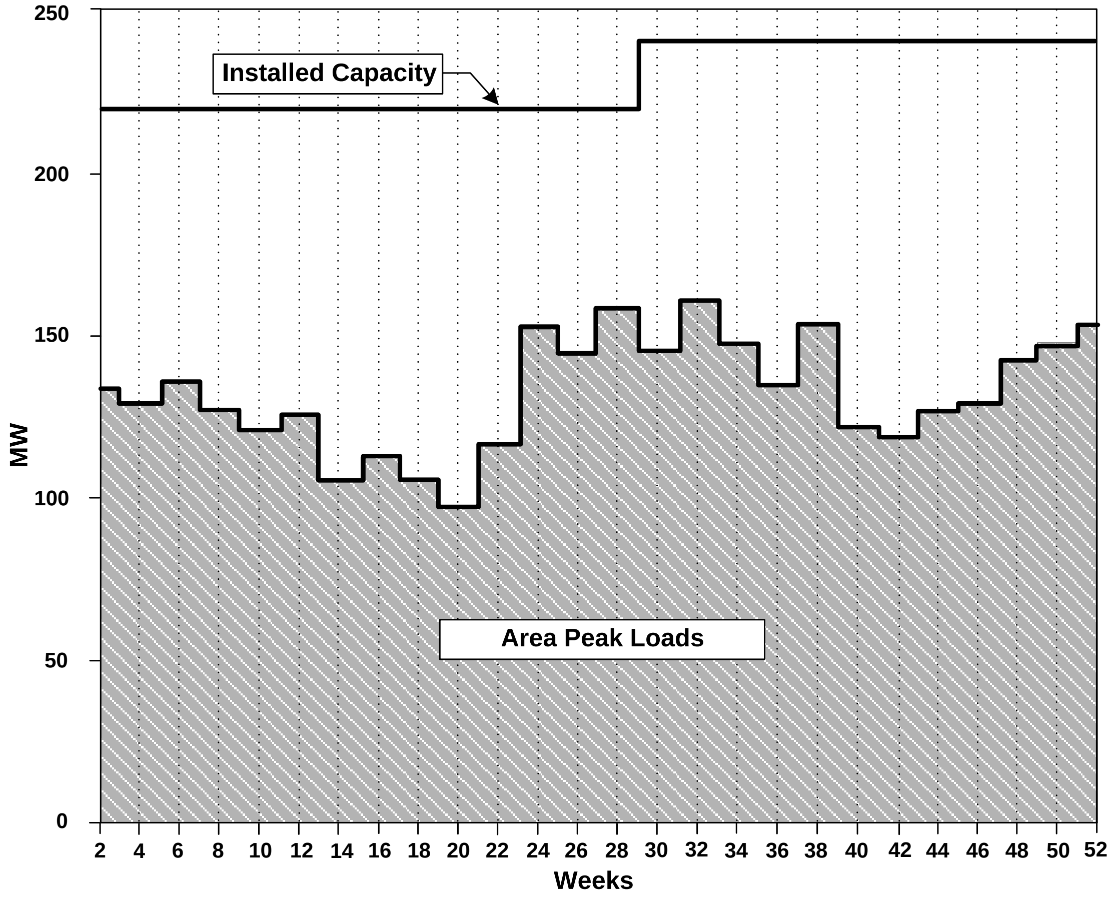
- Capacity of the units at the start of the year
- For ES/DSM units, MARS uses user input ratings (**MNT-MDCP-00**) for maintenance

Maintenance Scheduling
Constant Reserve

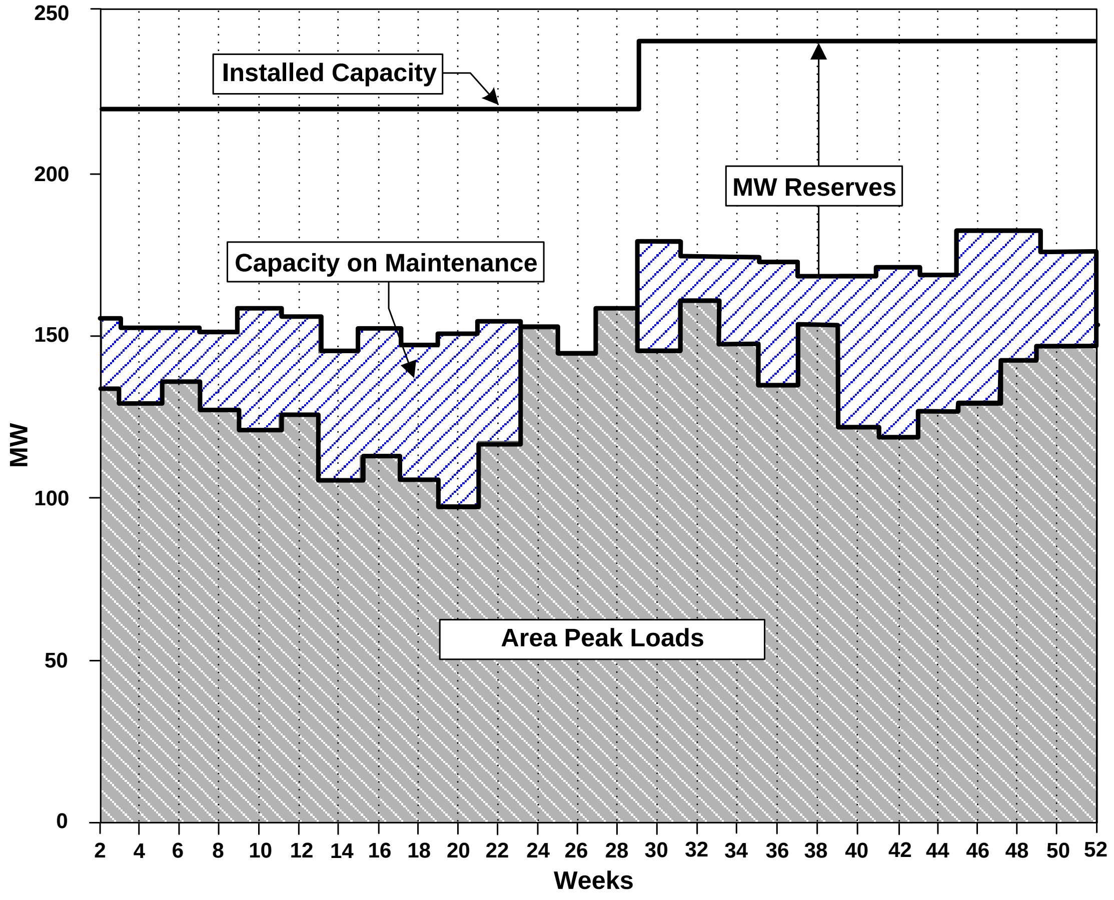


Maintenance Scheduling

Constant Reserve



Maintenance Scheduling
Constant Reserve

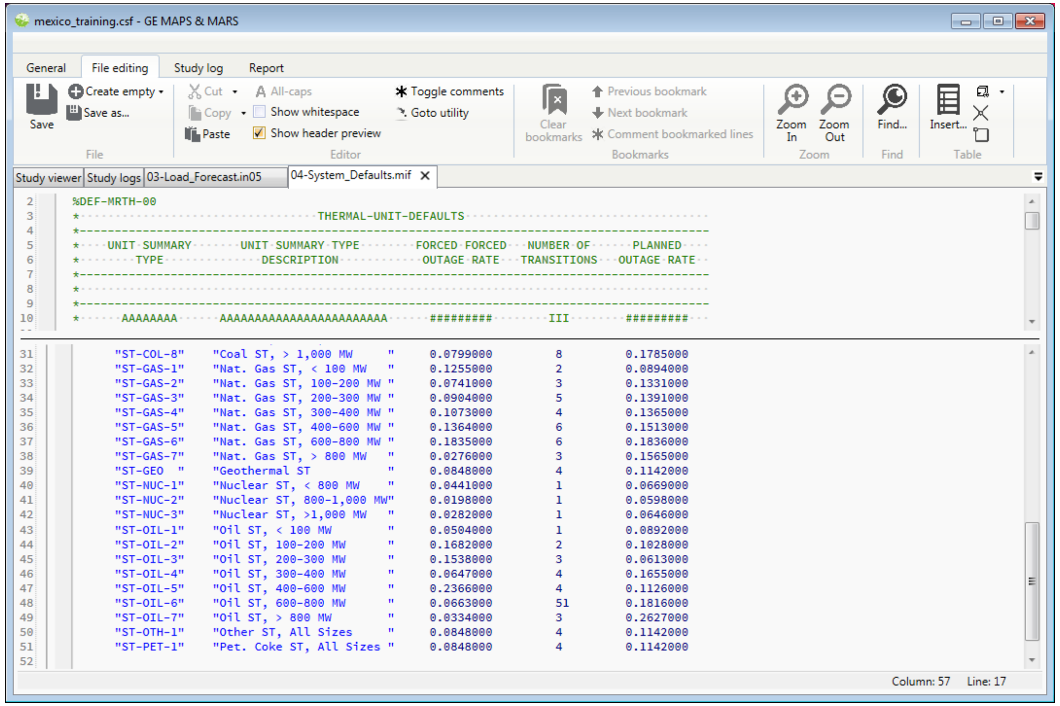


Set Up the Thermal Unit Defaults Table

1) Create a new file in the Database named 04-System_Defaults.mif

2) Insert a DEF-MRTH-00 Table from the “Thermal Defaults” tab of the 03-Thermal_Units.xlsx file in the exercises subfolder of your user directory

3) Save the file



Add Thermal Units to the database

1) Create a new file in the Database named 05-Thermal_Units.mif
2) Insert a UNT-DATA-00 Table from the “Thermal Units” tab (Leave the number of units blank)

Specify Thermal Unit Capacity

3) Insert three UNT-MXCP Tables from the “Thermal Units” tab
   a) No override date using the Winter Capacity column from the Excel sheet as the Capacity Column for the table – this will serve as the initialization data to be used if dates are not specified
   b) SummerOverrideDate as the date column, Summer Capacity as the Capacity
   c) WinterOverrideDate as Date column, WinterCapacity as the Capacity
4) Save the file

Specify Thermal Unit Capacity

```
&UNT-MXCP-00    UMC
*       THERMAL-UNIT-MAXIMUM-CAPACITY
*-----------------------------------------------
*    EFFECTIVE    UNIT NAME    MAXIMUM RATING
*       DATE                        (MW)
*-----------------------------------------------
*                                  .CAP.
*-----------------------------------------------
*     MMMYYYY     AAAAAAAA      ##########
```

```
                  "NUEVOGT3"       67.16
                  "NUEVOGT4"       67.16
                  "NUEVOGT5"       67.16
                  "NUEVOGT1"       13.03
                  "NUEVOGT2"       13.03
                  "PRTACC21"      197.39
                  "PRTACC22"      197.39
                  "DYNSLCC1"       17.37
                  "ALTMCC21"      119.42
                  "ALTMCC22"      119.42
                  "ALTMCC31"      249.94
                  "ALTMCC32"      249.94
                  "ALTMCC41"      249.94
                  "ALTMCC42"      249.94
                  "ALTAMST1"      144.75
                  "ALTAMST2"      144.75
                  "ALTAMST3"      144.75
                  "ALTAMST4"      241.25
                  "ALTMCC51"      270.44
                  "ALTMCC52"      270.44
                  "ALTMCC53"      270.44
                  "ALTMCC54"      270.44
                  "HORNOCC1"       63.69
```

```
&UNT-MXCP-00    UMC
*       THERMAL-UNIT-MAXIMUM-CAPACITY
*-----------------------------------------------
*    EFFECTIVE    UNIT NAME    MAXIMUM RATING
*       DATE                        (MW)
*-----------------------------------------------
*                                  .CAP.
*-----------------------------------------------
*     MMMYYYY     AAAAAAAA      ##########
```

```
@     MAY2019**   "ALTMCC21"      114.64
@     MAY2019**   "ALTMCC22"      114.64
@     MAY2019**   "ALTMCC31"      239.94
@     MAY2019**   "ALTMCC32"      239.94
@     MAY2019**   "ALTMCC41"      239.94
@     MAY2019**   "ALTMCC42"      239.94
@     MAY2019**   "ALTAMST1"      138.96
@     MAY2019**   "ALTAMST2"      138.96
@     MAY2019**   "ALTAMST3"      138.96
@     MAY2019**   "ALTAMST4"      231.60
@     MAY2019**   "ALTMCC51"      259.62
@     MAY2019**   "ALTMCC52"      259.62
@     MAY2019**   "ALTMCC53"      259.62
@     MAY2019**   "ALTMCC54"      259.62
@     MAY2019**   "HORNOCC1"       61.14
@     MAY2019**   "BAJA_CC1"      251.98
@     MAY2019**   "BAJA_CC3"      272.36
@     MAY2019**   "BJSURIC1"       34.28
@     MAY2019**   "BJSURIC2"       38.91
@     MAY2019**   "BJSURIC3"       39.84
@     MAY2019**   "BJSURIC4"       39.84
@     MAY2019**   "BJSURIC5"       43.36
@     MAY2019**   "BJSURCT1"       18.53
```

```
&UNT-MXCP-00    UMC
*       THERMAL-UNIT-MAXIMUM-CAPACITY
*-----------------------------------------------
*    EFFECTIVE    UNIT NAME    MAXIMUM RATING
*       DATE                        (MW)
*-----------------------------------------------
*                                  .CAP.
*-----------------------------------------------
*     MMMYYYY     AAAAAAAA      ##########
```

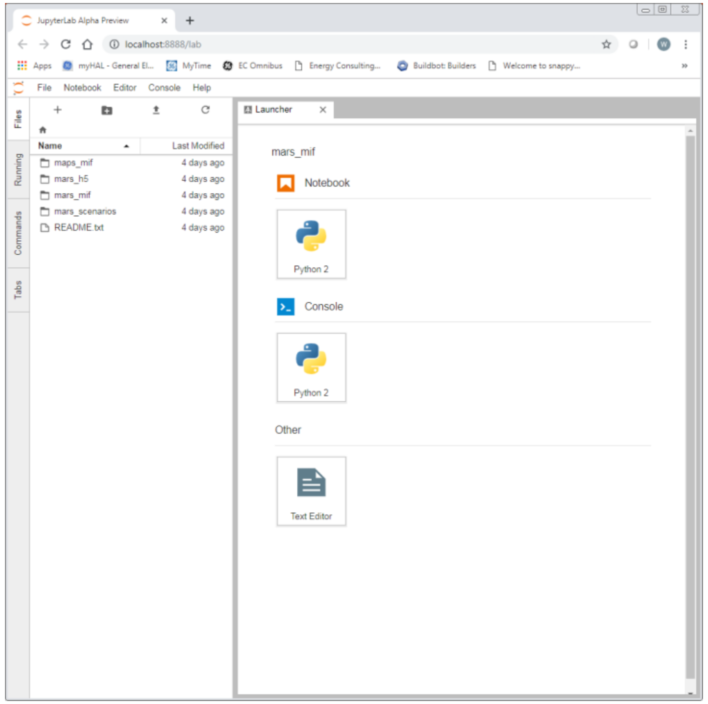
```
@     OCT2019**   "ESTANCC2"      100.74
@     OCT2019**   "NUEVOGT3"       67.16
@     OCT2019**   "NUEVOGT4"       67.16
@     OCT2019**   "NUEVOGT5"       67.16
@     OCT2019**   "NUEVOGT1"       13.03
@     OCT2019**   "NUEVOGT2"       13.03
@     OCT2019**   "PRTACC21"      197.39
@     OCT2019**   "PRTACC22"      197.39
@     OCT2019**   "DYNSLCC1"       17.37
@     OCT2019**   "ALTMCC21"      119.42
@     OCT2019**   "ALTMCC22"      119.42
@     OCT2019**   "ALTMCC31"      249.94
@     OCT2019**   "ALTMCC32"      249.94
@     OCT2019**   "ALTMCC41"      249.94
@     OCT2019**   "ALTMCC42"      249.94
@     OCT2019**   "ALTAMST1"      144.75
@     OCT2019**   "ALTAMST2"      144.75
@     OCT2019**   "ALTAMST3"      144.75
@     OCT2019**   "ALTAMST4"      241.25
@     OCT2019**   "ALTMCC51"      270.44
@     OCT2019**   "ALTMCC52"      270.44
@     OCT2019**   "ALTMCC53"      270.44
@     OCT2019**   "ALTMCC54"      270.44
```

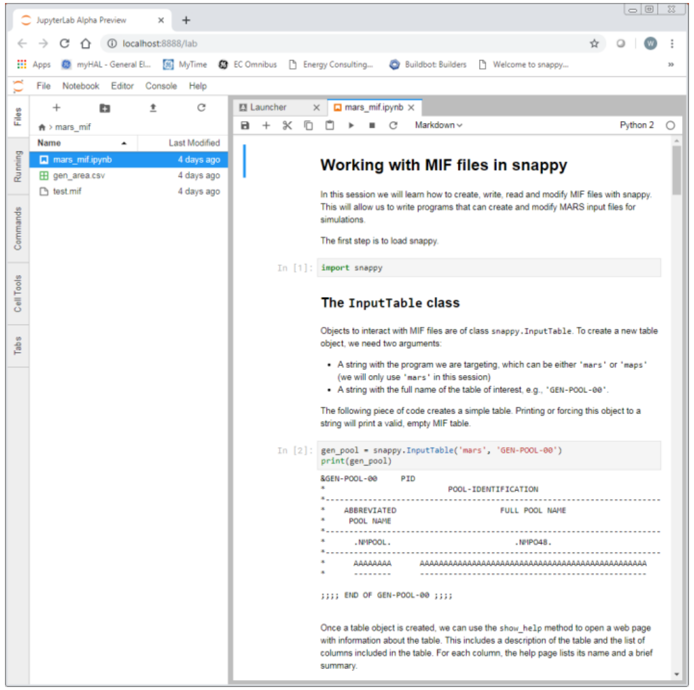
GE MARS Python Application Programming Interface (snappy)

Reading and Writing the MIF

Reading and Writing the MIF

1) Double click on the snappy Training icon on the desktop
2) Go to the mars_mif subfolder and double click on mars_mif.ipynb





GE

GE MARS Training

Wednesday April 17th, 2019

Start	End	Description
9:00	9:15	Running our first case
9:15	9:45	GE MARS Output Files, and Results Reporting
9:45	10:30	GE MARS Python API (snappy) – Output Reporting
10:30	10:45	Break
10:45	11:00	Hourly Modifier Unit Modelling - Lecture
11:00	11:30	Wind and Solar Unit Modelling – Hands-on Exercise
11:30	12:00	System Imports and Exports – Hands-on Exercise
12:00	1:00	Lunch

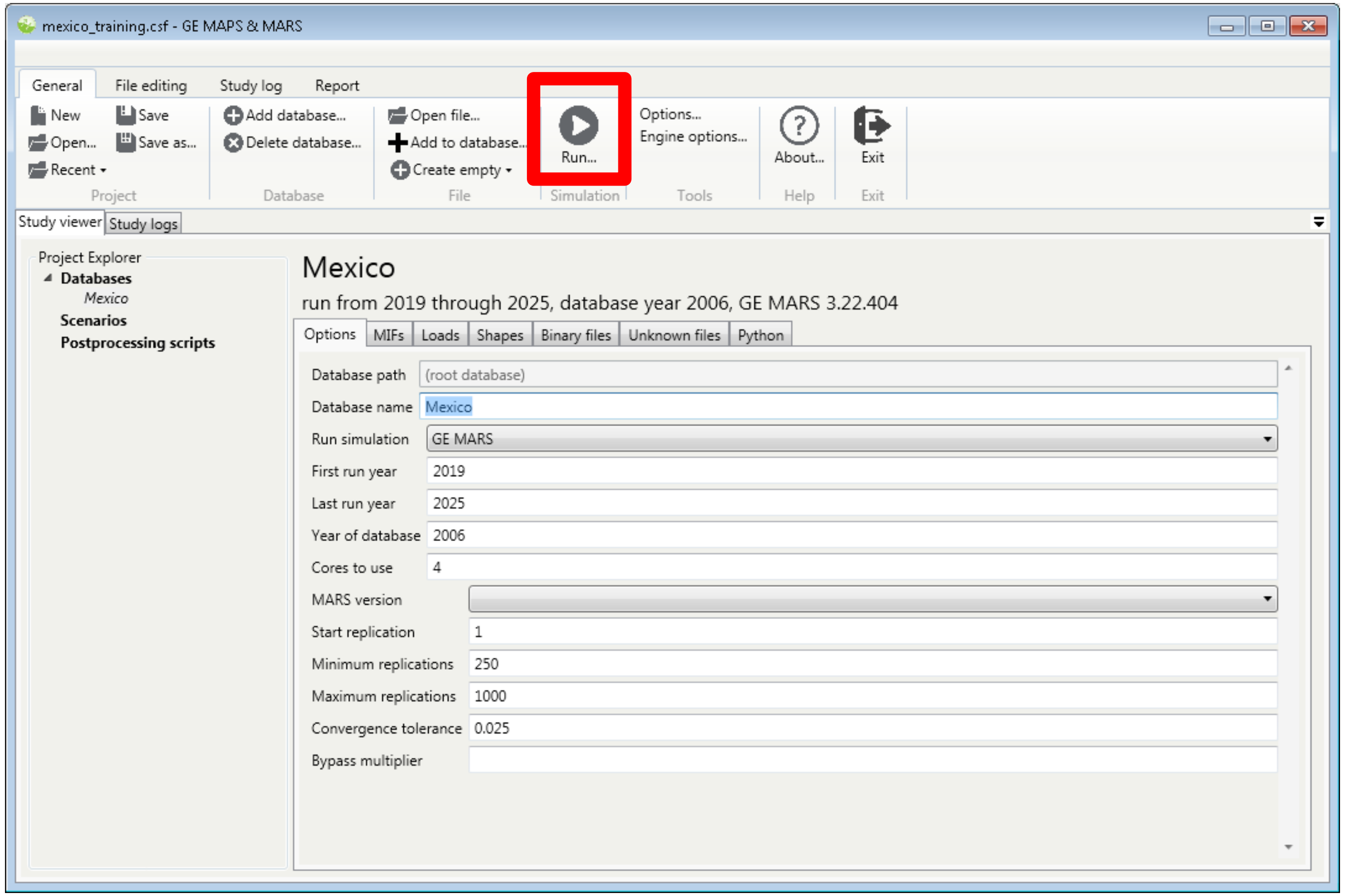
Wednesday April 17th, 2019

Start	End	Description
1:00	1:30	Energy Limited Unit Modelling – Lecture
1:30	2:15	Energy Limited Unit Modelling – Hands-on Exercise
2:15	2:30	Transmission Interconnections – Lecture
2:30	2:45	Break
2:45	3:30	Transmission Interconnections – Hands-on Exercise
3:30	3:45	Emergency Operating Procedures – Lecture
3:45	4:30	Emergency Operating Procedures – Hands-on Exercise
4:30	5:00	Contract Modelling

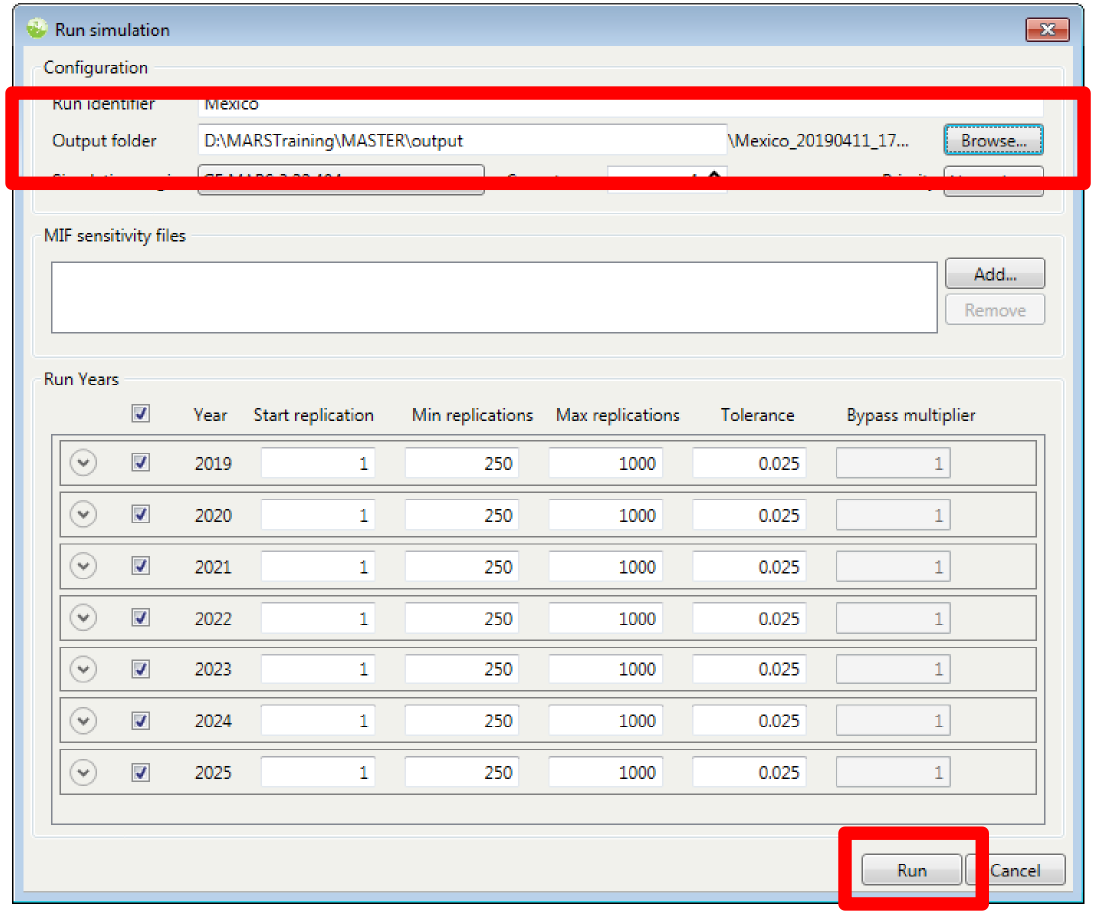
Running Our First Case

Running the Case

1) Select a database
2) Click Run



Running a Case



3) Set the output folder to the output folder in your user directory

4) Click Run

GE

GE MARS Outputs

GE MARS Output Files

Errors and Warnings (*.ot06)

Generated for each year for each MARS Task

Located in each .\<run_folder>\<year> subfolder

- Program Dimension Summary
- Program Progress Summary
  - Lists warnings and errors

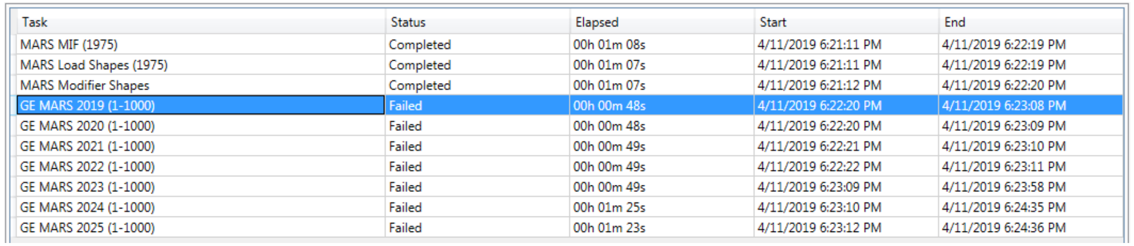
You should ALWAYS check your *.ot06

Can be opened in the MAPS & MARS UI by

a) selecting a MARS task in the study log, and

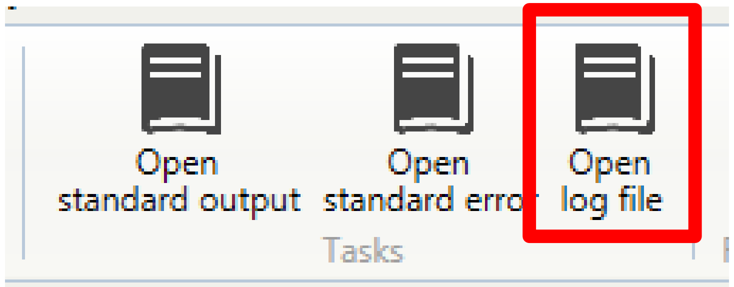
b) Clicking “Open log file” in the Study log ribbon

a)



Task	Status	Elapsed	Start	End
MARS MIF (1975)	Completed	00h 01m 08s	4/11/2019 6:21:11 PM	4/11/2019 6:22:19 PM
MARS Load Shapes (1975)	Completed	00h 01m 07s	4/11/2019 6:21:11 PM	4/11/2019 6:22:19 PM
MARS Modifier Shapes	Completed	00h 01m 07s	4/11/2019 6:21:12 PM	4/11/2019 6:22:20 PM
GE MARS 2019 (1-1000)	Failed	00h 00m 48s	4/11/2019 6:22:20 PM	4/11/2019 6:23:08 PM
GE MARS 2020 (1-1000)	Failed	00h 00m 48s	4/11/2019 6:22:20 PM	4/11/2019 6:23:09 PM
GE MARS 2021 (1-1000)	Failed	00h 00m 49s	4/11/2019 6:22:21 PM	4/11/2019 6:23:10 PM
GE MARS 2022 (1-1000)	Failed	00h 00m 49s	4/11/2019 6:22:22 PM	4/11/2019 6:23:11 PM
GE MARS 2023 (1-1000)	Failed	00h 00m 49s	4/11/2019 6:23:09 PM	4/11/2019 6:23:58 PM
GE MARS 2024 (1-1000)	Failed	00h 01m 25s	4/11/2019 6:23:10 PM	4/11/2019 6:24:35 PM
GE MARS 2025 (1-1000)	Failed	00h 01m 23s	4/11/2019 6:23:12 PM	4/11/2019 6:24:36 PM

b)



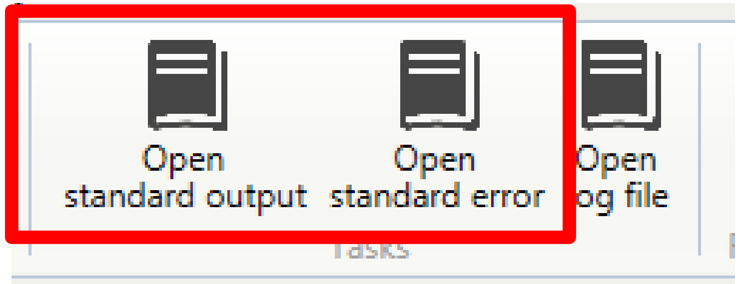
GE MARS Output Files
Standard Error and Standard Output

Generated for each task

Located in .\<run_folder>\tasks\<task_name> subfolder

If MARS fails for reasons which are not adequately caught in the program the errors will be written to standard output or standard error which can also be accessed through the MAPS & MARS User Interface

For tasks other than MARS Tasks, errors, warnings or other information may be printed here



GE MARS Output Files

Annual Maintenance and Capacity Summaries (*.ot07)

Generated for each year for each MARS Task

Located in each .\<run_folder>\<year> subfolder

Weekly Maintenance Summaries by Unit

Maintenance start and end dates and types listed for each unit

Weekly reserve summaries by area and pool

Thermal Capacity, capacity state, planned and forced outages

Non-Thermal Capacity, Energy, and Planned Maintenance

Interface ratings and capacity states

GE MARS Output Files

Annual Summaries (*.ot09)

Generated for each year for each MARS Task

Located in each .\<run_folder>\<year> subfolder

Program Options Summary

Calculated Reliability Indices, Isolated and Interconnected

Calculated Reliability Indices, Isolated and Interconnected by Margin State

Interface Flow Summaries

Contract Usage Summaries

Emergency Operating Procedure usage

As-needed Energy Limited unit usage

GE MARS Output Files

Weekly and Monthly Reliability Indices (*.ot08)

Generated for each year for each MARS Task

Located in each .\<run_folder>\<year> subfolder

Same summaries as listed in the *.ot09 but summarized weekly and/or monthly as specified in **GEN-TIME-00**

GE MARS Output Files

Weekly and Monthly Reliability Indices by Load Level (*.ot11)

Generated for each year for each MARS Task

Located in each .\<run_folder>\<year> subfolder

Same summaries as listed in the *.ot08 and *.ot09 but summarized weekly and/or monthly as specified in **GEN-TIME-00** and by load forecast uncertainty level

GE MARS Output Files

Replication Year Summaries (*.ot21 - *.ot***)

Generated for each year for each MARS Task for each pool, area group, and area, isolated and interconnected

Located in each .\<run_folder>\<year> subfolder

Daily and Hourly LOLE and LOEE by replication as well as the average and standard error of each metric

GE MARS Output Files

Hourly Summaries (*.ot10 - *.ot16)

Generated for each year for each MARS Task

Located in each .\<run_folder>\<year> subfolder

Optionally output as *.csv or binary as specified in **GEN-TIME-00**

*.ot10 contains hourly area margins for all areas, all load levels, all margin states, and all hours specified

*.ot16 contains hourly interface limits and flows for all interfaces, all load levels, the final margin state, and all hours specified

GE MARS Output Files
Run Log

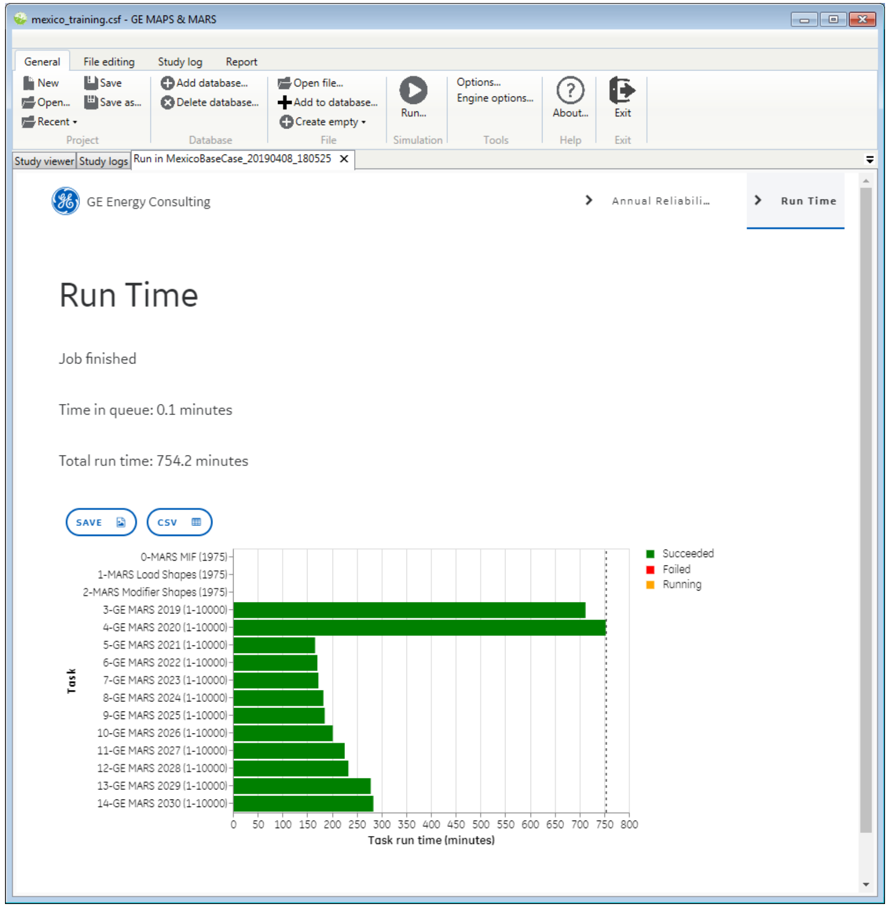
Generated for each run

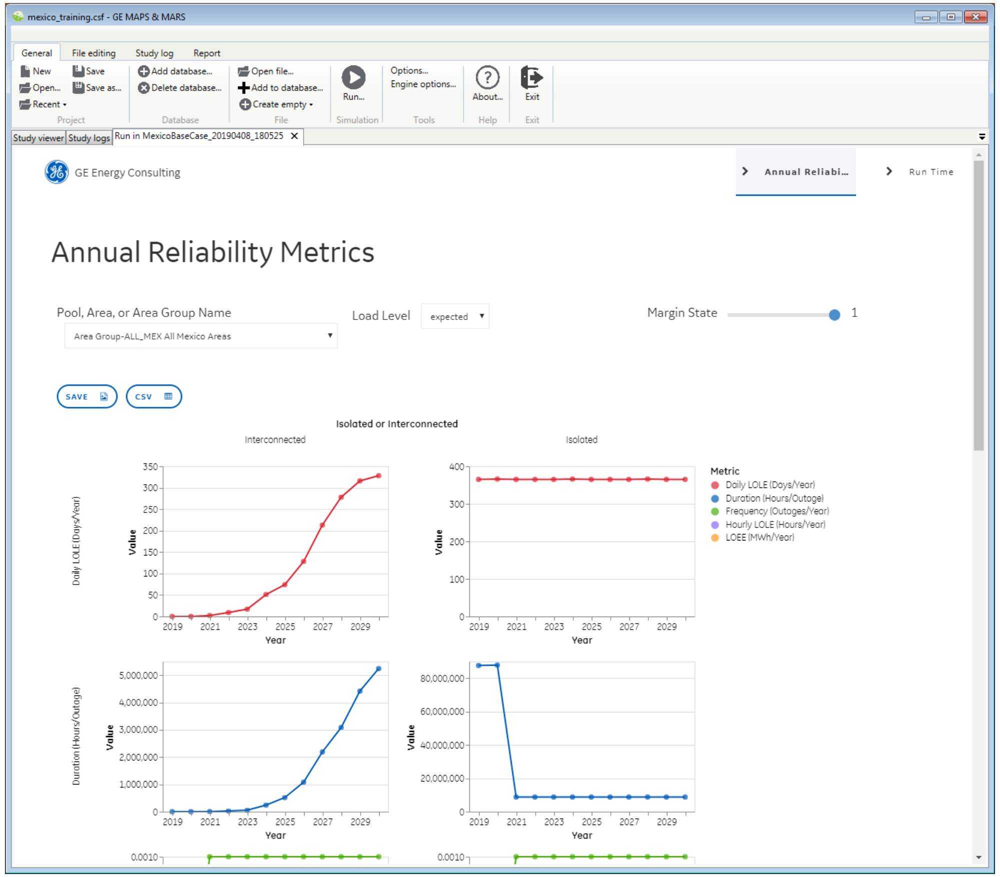
Located in the root of the run folder

Contains two tabs

1) Simulation run information
2) Annual Reliability Statistics by Pool, Area, Area Group, Load Level, and Margin State, isolated and interconnected both in tabular form and as an interactive chart

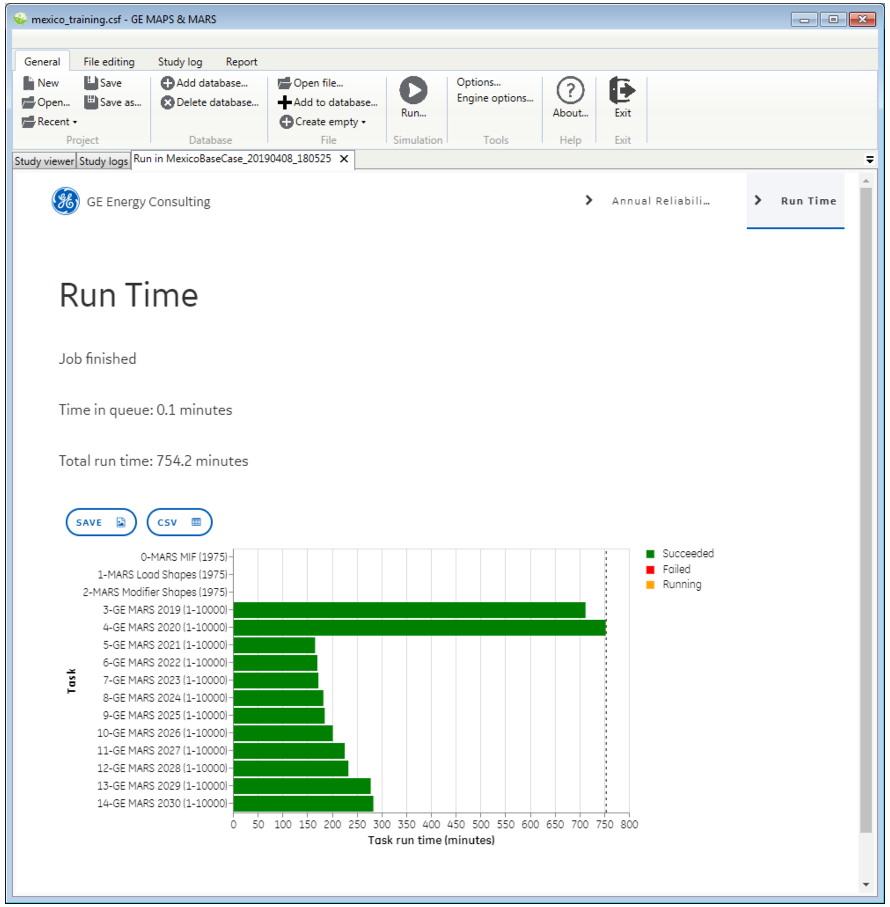
GE MARS Output Files
Run Log

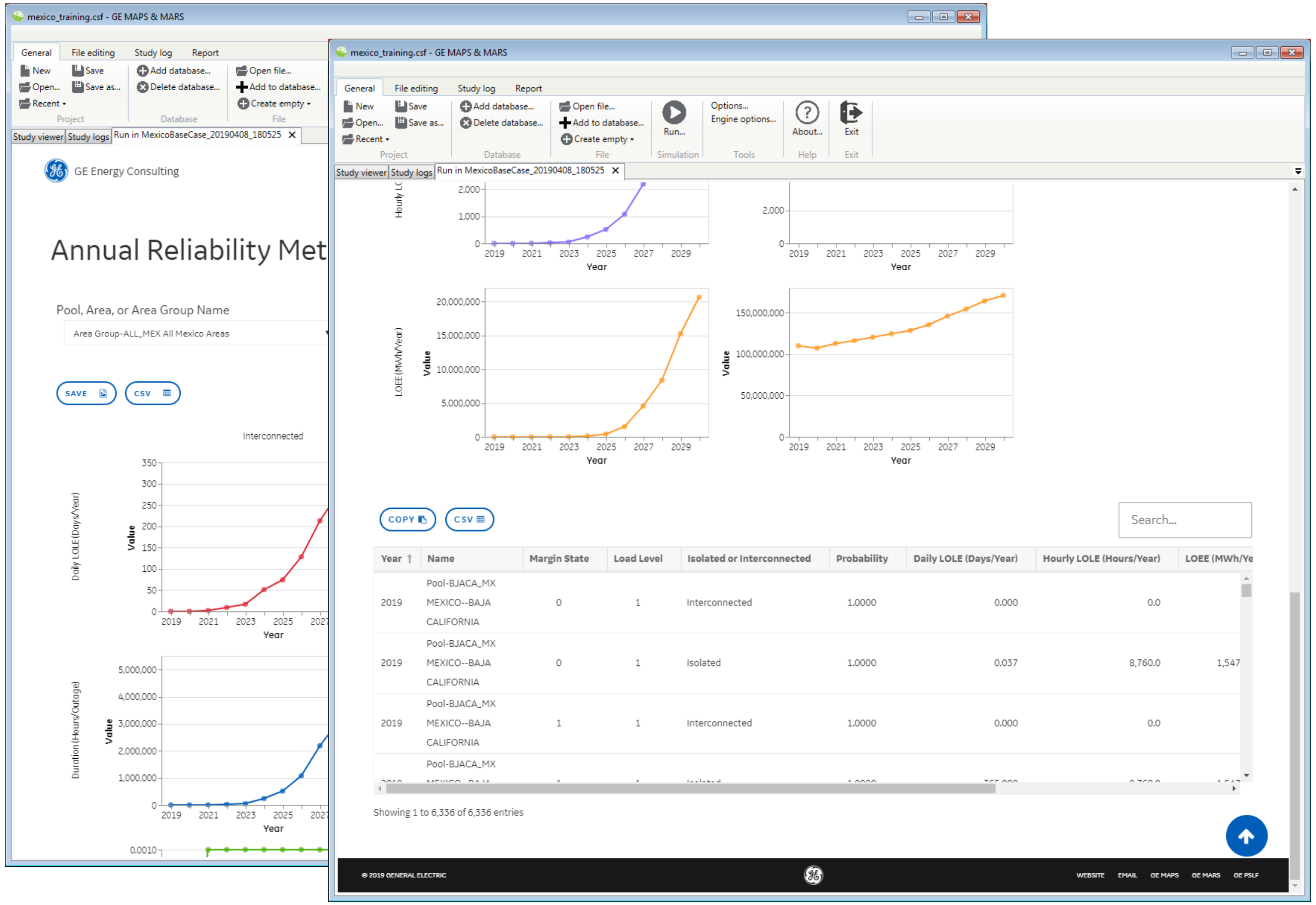




GE MARS Output Files

Run Log





GE MARS Outputs

*.h5 File - General Data

Controlled by GEN-HDF5-00

Outputs all reliability metrics hourly for all load levels and all margin states

- this data can be summarized using snappy to generate the same outputs as are in the *.ot08, *.ot09, *.ot11 and more

Outputs generator capacities, maintenance schedules, and EFORs

- This data can be summarized using snappy to generate the same outputs as are in the *.ot07 and more

Outputs all reliability metrics annually by load level, margin state, and replication

- This data can be summarized using snappy to generate the same outputs as are in the *.ot21 - *.ot*** and more

GE MARS Outputs
*.h5 File – Detailed Interface Flow Data

Can optionally output hourly flow data by interface, by replication, by load level, by margin state

Can be extracted with snappy to recreate the flow data in the *.ot16 (and more)

Hourly Limit data is currently under development

GE MARS Outputs

*.h5 File – Detailed Capacity and Margin Data

Can optionally output:

- hourly capacity states for all thermal units for all replications for all hours
- daily random hourly modifier draws for all hourly modifiers for all replications for all days
- daily random energy distribution draws for all energy limited type 1 units for all replications for all days
- Hourly deterministic EL2 unit schedules for all hours

Currently Under Development

- Hourly EL3 and as-needed EOP usage for all replications for all hours

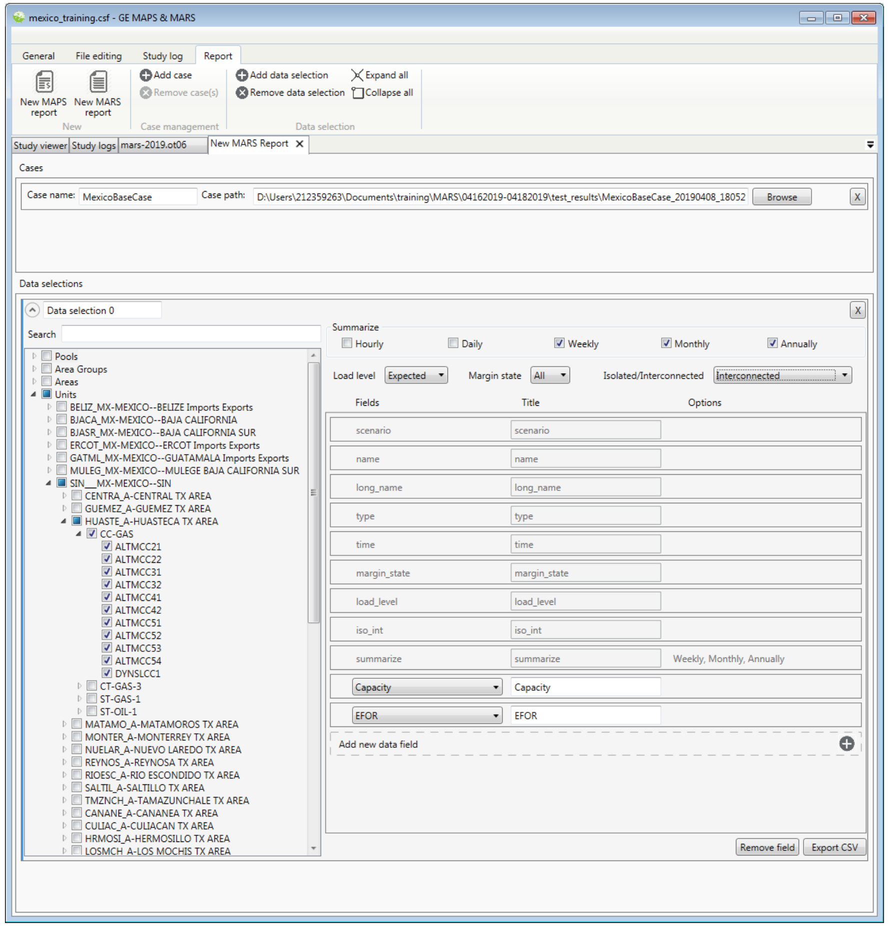
Combined with the datasets which are in progress, and the detailed flow data, can be extracted using snappy to recreate the *.ot10

Will allow the user to dig into which units are online in which hours and which replications to better understand specific loss of load events

GE MARS Outputs

*.h5file – MAPS & MARS User Interface Integration

When using the *.h5 file, results can be extracted interactively using the MAPS & MARS User Interface



GE

GE MARS Python Application Programming Interface (snappy)

MARS Output Reporting

GE MARS Output Reporting

1) Double click the snappy Training shortcut on the desktop
2) Open the mars_h5 subfolder and mars_h5.ipynb
3) Open the mars_scenarios subfolder and mars_scenarios.ipynb

GE

Hourly Modifiers

Hourly Modifiers

- Intermittent renewables (Wind and Solar)
- Energy Storage (if charge / recharge cycle is known)
- Fixed Imports from un modelled systems
- Contracts from one area to another
- Demand side resources

Hourly Modifiers

- Each unit specifies a net hourly load modification
  - for a typical week 168 hourly values from Monday through Sunday, specified in MOD-MDMW-00, or
  - an hourly profile for 8760 Hours
- Input load modification is subtracted from the hourly loads for the unit's area
  - positive values decrease the area loads
  - negative values increase the loads

Hourly Modifiers
General Data

Unique eight (8) character identifier to be used in other tables

Area location

Installation and retirement dates

Number of units in the plant for maintenance scheduling (optional)

Unit summary type

Specified in table UNT-DATA-00

Hourly Modifiers
Shape Data

- Negative values can be used to model the recharging cycle of an energy-storage unit, while positive values would represent the discharge or generating cycle
- Hourly value of each shape can be input through the shape file (*.eei, *.h5, or *.csv)
- Net hourly load modification can be calculated by the program from a combination of different hourly shapes
- User specifies which shapes (**MOD-SHAP-00, -01, -02, -03**) to use and their associated penetration levels (**MOD-PENE-00**) to form a composite hourly unit profile

Hourly Modifiers
Random Output

Random Shape Modeling

MARS can introduce a degree of randomness in the simulation of resources that are modeled with hourly shapes

The random selection can be limited to a specific day and the shape within days is maintained

Options

1) Select randomly a day from same study month for each simulation day
2) Select randomly a day from a specified window for a given shape for each simulation day
3) Select a random shape at the beginning of each replication from a given multiple shape sets

Non-Thermal Units

Unit Types

User must specify which “summary types” used in UNT-DATA-00 are Thermal and which are Non-Thermal

Thermal summary types are handled automatically by the MIF Preprocessor DEF-MRTH-00 table

Specified in **GEN-UNTY-00**

Modifier Priority List

Modifier Types

Specify order in which non-thermal units are scheduled

- Type 2 energy-limited
- Energy-storage
- Demand-side management

Specified by unit in **MOD-PRIO-00** or if using the MIF Preprocessor, by summary type in **TYP-PRIO-00**

Impacts

- Loads are modified in the order of the priority list
- Only ELU2 units will be impacted – only type scheduled by the program
- The dispatch of other types are user specified

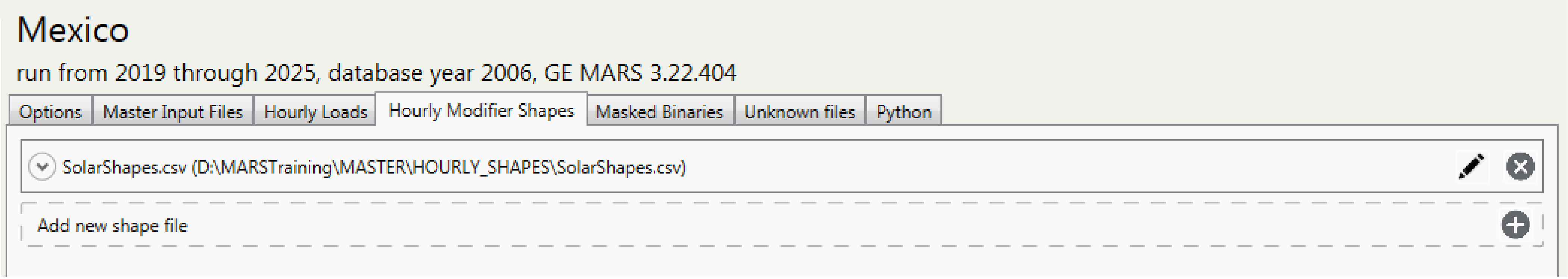
Add Unit Types and Scheduling Priority

1) Open file 04-System_Defaults.mif
2) Insert a blank GEN-UNTY-00 Table
3) Populate with “WIND   “, “SOLAR   “, and “IMPORT   “, and specify each as Non-Thermal
4) Insert a blank TYP-PRIO-00 Table
5) Populate with “WIND   “, “SOLAR   “, and “IMPORT   “
6) Save the file

```
&GEN-UNTY-00      STU
*        UNIT-SUMMARY-TYPE
*--------------------------------
*    UNIT TYPE NAME    GENERAL
*                      UNIT TYPE
*--------------------------------
*       .NMUNTY.       .IUNTMD.
*--------------------------------
*       AAAAAAAA         T/N
*       --------         ---
       "WIND    "         N
       "SOLAR   "         N
       "IMPORT  "         N

;;;; END OF GEN-UNTY-00 ;;;;


%TYP-PRIO-00    CONTINUATION
*         PRIORITY-ORDER-FOR-SCHEDULING-NON-THERMAL-SUMMARY-TYPES
*------------------------------------------------------------------------
*     EFFECTIVE         PRIORITY ORDER FOR SCHEDULING LOAD MODIFIERS
*        YEAR
*------------------------------------------------------------------------
*
*------------------------------------------------------------------------
*        YYYY        AAAAAAAA      AAAAAAAA      AAAAAAAA      AAAAAAAA
*        ----        --------      --------      --------      --------
                    "WIND    "    "SOLAR   "    "IMPORT  "

:::: END OF TYP-PRIO-00 ::::
```

Add Solar Unit Hourly Profiles

1) Create an “HOURLY_SHAPES” subfolder in your working folder
2) Open the mexico.xlsx file in Excel and go to the “Hourly Solar Shapes” tab
3) Select “Save As” and save this tab as a Comma Separated Values (*.csv) file named “*SolarShapes.csv*” located in the folder you created
4) In the GE MAPS & MARS User interface, add the shape file

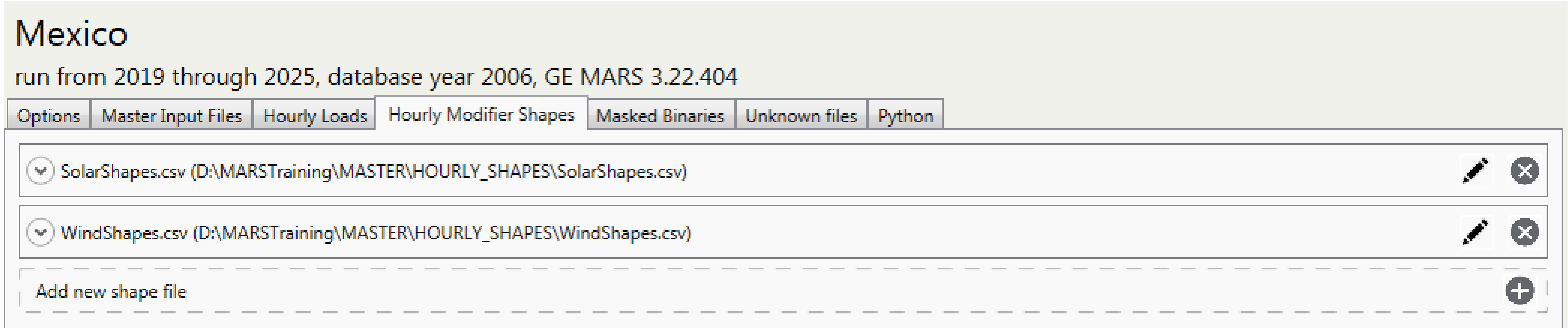


Add Solar Units

1) Create a new MIF in the database named “06-Solar_Units.mif”
2) Insert a UNT-DATA-00 table from the “Solar Units” tab of the mexico.xlsx file
3) Insert a MNT-MDCP-00 table from the “Solar Units” tab of the mexico.xlsx file
4) Insert a MOD-SHAP-02 table from the “Solar Units” tab of the mexico.xlsx file
5) Set the max number of days for shift to 3
6) Insert a MOD-PENE-00 table from the “Solar Units” tab of the mexico.xlsx file
7) Save the file

Add Wind Unit Hourly Profiles

1) Open the mexico.xlsx file in Excel and go to the “Hourly Wind Shapes” tab
2) Select “Save As” and save this tab as a Comma Separated Values (*.csv) file named “*WindShapes.csv*” located in the HOURLY_SHAPES folder you created
3) In the GE MAPS & MARS User interface, add the shape file



Add Wind Units

1) Create a new MIF in the database named “07-Wind_Units.mif”
2) Insert a UNT-DATA-00 table from the “Wind Units” tab of the mexico.xlsx file
3) Insert a MNT-MDCP-00 table from the “Wind Units” tab of the mexico.xlsx file
4) Insert a MOD-SHAP-03 table from the “Wind Units” tab of the mexico.xlsx file with the ShapeName1 column from the excel sheet as the Shape
5) Specify the Shape Set to be “REALTIME”
6) Insert a MOD-SHAP-03 table from the “Wind Units” tab of the mexico.xlsx file with the ShapeName2 column from the excel sheet as the Shape
7) Specify the Shape Set to be “DAYAHEAD”
8) Insert a MOD-PENE-00 table from the “Wind Units” tab of the mexico.xlsx file
9) Save the file

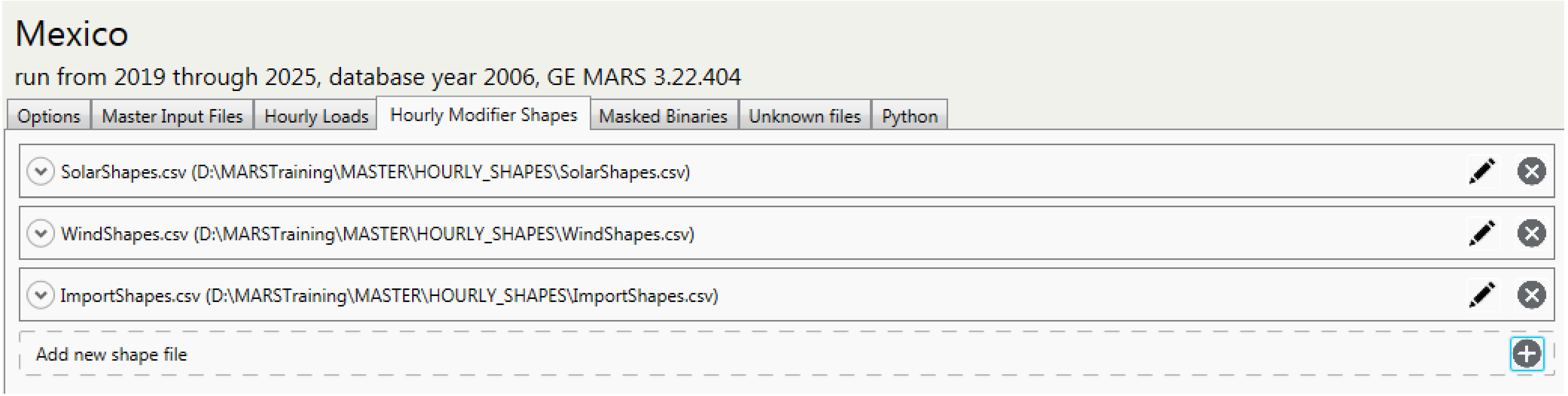
Add Shape Sets

1) Open 07-Wind_Units.mif
2) Insert a blank MOD-RAND-00 Table
3) Specify “REALTIME” and “DAYAHEAD” as 50% probability each for shape group 13
4) Save the file

```
&MOD-RAND-00     MPE    CONTINUATION
*     DEFINITION-OF-RANDOM-SETS-AND-PROBABILITIES
*-------------------------------------------------------
*     GROUP NUMBER    SET NAME FOR     P.U. OF RANDOM
*      FOR RANDOM     RANDOM DRAW           DRAW
*      SELECTION
*-------------------------------------------------------
*       .IMDGRP.
*-------------------------------------------------------
*          III          AAAAAAAA         ########
*          ---          --------         --------
           13          "REALTIME"            0.50
+                      "DAYAHEAD"            0.50

;;;; END OF MOD-RAND-00 ;;;;
```

Add Import / Export Unit Hourly Profiles

1) Open the mexico.xlsx file in Excel and go to the “Hourly Import Shapes” tab
2) Select “Save As” and save this tab as a Comma Separated Values (*.csv) file named “*ImportShapes.csv*” located in the HOURLY_SHAPES folder you created
3) In the GE MAPS & MARS User interface, add the shape file



Add Import / Export Units

1) Create a new MIF in the database named “08-Import_Units.mif”
2) Insert a UNT-DATA-00 table from the “Import Units” tab of the mexico.xlsx file
3) Insert a MNT-MDCP-00 table from the “Import Units” tab of the mexico.xlsx file
4) Insert a MOD-SHAP-00 table from the “Import Units” tab of the mexico.xlsx file, remove “SDLOAD “ from MOD-SHAP-00
5) Insert a MOD-PENE-00 table from the “Import Units” tab of the mexico.xlsx file, remove “SDLOAD ” form MOD-PENE-00
6) Save the file

Add Fixed Load for “SDLOAD “

1) Open “08-Import_Units.mif”
2) Insert a blank MOD-MDMW-00 table
3) Specify a typical week of 168 hours * -738 MW of export
4) Save the file

```
&MOD-MDMW-00     ESD     CONTINUATION    ASTERISK
*                                   ENERGY-STORAGE-DSM-MOD-MW
*------------------------------------------------------------------------------------------
*     EFFECTIVE    UNIT NAME        NET HOURLY LOAD MODIFICATION FOR TYPICAL WEEK (MW)
*        DATE
*------------------------------------------------------------------------------------------
*                                                       .ESUMOD/DSMMOD.
*------------------------------------------------------------------------------------------
*      MMMYYYY      AAAAAAAA      #########      #########      #########      #########
*      -------      --------      ---------      ---------      ---------      ---------
                   "SDLOAD  "      168*-738

;;;; END OF MOD-MDMW-00 ;;;;
```

GE

Energy Limited Unit Modelling

Energy Limited Units

General Data

Unique eight (8) character identifier to be used in other tables

Area location

Installation and retirement dates

Number of units in the plant for maintenance scheduling (optional)

Unit summary type

Specified in table UNT-DATA-00

Energy Limited Units

Type 2

Applications

- Model conventional hydro units for which the available water is assumed to be known with little or no uncertainty
- Can also be used to model certain types of contracts
- Scheduled as deterministic load modifiers

Specifications – Can be Changed Monthly

- Maximum and minimum ratings
- Monthly available energy

Specified in **MOD-ELMW-00**

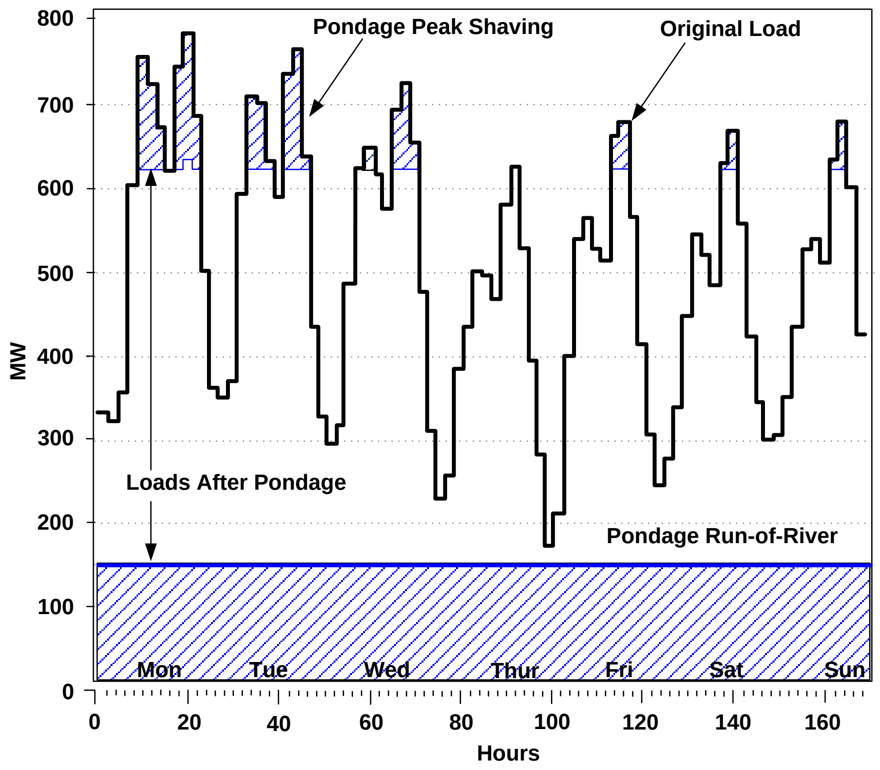
- Specify area or pool loads to schedule the unit – already modified for Cogen-1 & previously scheduled modifiers

Specified in **MOD-ELLD-00**

Energy Limited Units

Type 2

Peak Shaving



Deterministic Scheduling

- Each unit scheduled on a monthly basis
- Dispatch unit’s minimum rating for all the hours in the month
- Dispatch peaking portion of the energy to shave the load

Energy Limited Units

Type 3

As-Needed Scheduling

- Dispatched the peak shaving portion (difference between min/max ratings) as needed during the Monte Carlo simulation
- Dispatch only if thermal capacity is insufficient to serve the load
- If sufficient, energy will be saved for used in future hours
- Energy not used in a month can be carried forward to next month, up to its maximum storage, but not from year to next year
- Minimum rating, will be dispatched deterministically as with Type 2 Energy Limited Units

Three Options

1) units are used to cover shortfalls only in the area it is located
2) units are used first to cover shortfalls in the area it is located; if after emergency assistance has been done and an area is still deficient because of lack of thermal capacity, MARS will attempt to cover this shortfall with ELU2 units that are in another area
3) scheduled only on an interconnected basis. Used only if one of more areas are deficient after the emergency assistance has been calculated. Isolated indices are computed as if the peak-shaving portion of the ELU2 units are not available

Energy Limited Units

Type 3

In addition to monthly energy, limits can also be implemented on

Days per Year and/or Month

Hours per Year, Month, and/or Day

Energy Per Day

Specified in **MOD-ELMW-00**

Energy Limited Units

Type 2 and 3

- Units are dispatched by area, starting with the units with the greatest number of hours of full-load operation remaining, based on their capacity and remaining available energy
- If option 3, type 3 energy limited units in multiple areas can be dispatched as a single group; The type 3 energy limited units that are assigned to groups will be scheduled first, based on their group numbers and recognizing the transfer limits between the areas.
- Then all of the areas (including any remaining capacity in areas that are in groups) will be scheduled, and dispatched by areas, to cover any remaining shortages

Add Hydro Units Type

1) Open file 04-System_Defaults.mif
2) Add "HYDRO " to GEN-UNTY-00 and specify as Non-Thermal
3) Add "HYDRO " to TYP-PRIO-00
4) Save the file

```
&GEN-UNTY-00     STU
*       UNIT-SUMMARY-TYPE
*---------------------------------
*    UNIT TYPE NAME    GENERAL
*                      UNIT TYPE
*---------------------------------
*       .NMUNTY.       .IUNTMD.
*---------------------------------
*       AAAAAAAA         T/N
*       --------         ---
       "WIND    "          N
       "SOLAR   "          N
       "IMPORT  "          N
       "HYDRO   "          N

;;;; END OF GEN-UNTY-00 ;;;;


%TYP-PRIO-00    CONTINUATION
*         PRIORITY-ORDER-FOR-SCHEDULING-NON-THERMAL-SUMMARY-TYPES
*---------------------------------------------------------------------------
*     EFFECTIVE         PRIORITY ORDER FOR SCHEDULING LOAD MODIFIERS
*        YEAR
*---------------------------------------------------------------------------
*
*---------------------------------------------------------------------------
*        YYYY        AAAAAAAA      AAAAAAAA      AAAAAAAA      AAAAAAAA
*        ----        --------      --------      --------      --------
                    "WIND    "    "SOLAR   "    "IMPORT  "    "HYDRO   "

:::: END OF TYP-PRIO-00 ::::
```

Add Hydro Units

1) Create a new file in the Database named 09-Hydro_Units.mif
2) Insert a new UNT-DATA-00 Table from the “Hydro Units” tab of the mexico.xlsx file
3) Insert a new MOD ELLD-00 table from the “Hydro Units” tab of the mexico.xlsx file with the Pool column as the location
4) Set PU of Load to schedule against to 1.00 for all units
5) Insert a new MOD-ELMW-00 table from the “Hydro Energy” tab of the mexico.xlsx file
6) Save the file

Add Storage Type

1) Open file 04-System_Defaults.mif
2) Add “STORAGE “ to GEN-UNTY-00 and specify as Non-Thermal
3) Add “STORAGE “ to TYP-PRIO-00
4) Save the file

```
&GEN-UNTY-00     STU
*       UNIT-SUMMARY-TYPE
*---------------------------------
*    UNIT TYPE NAME     GENERAL
*                      UNIT TYPE
*---------------------------------
*       .NMUNTY.       .IUNTMD.
*---------------------------------
*       AAAAAAAA         T/N
*       --------         ---
       "WIND    "          N
       "SOLAR   "          N
       "IMPORT  "          N
       "HYDRO   "          N
       "STORAGE "          N

;;;; END OF GEN-UNTY-00 ;;;;
```

```
%TYP-PRIO-00    CONTINUATION
*         PRIORITY-ORDER-FOR-SCHEDULING-NON-THERMAL-SUMMARY-TYPES
*--------------------------------------------------------------------------
*     EFFECTIVE         PRIORITY ORDER FOR SCHEDULING LOAD MODIFIERS
*        YEAR
*--------------------------------------------------------------------------
*
*--------------------------------------------------------------------------
*        YYYY        AAAAAAAA      AAAAAAAA      AAAAAAAA      AAAAAAAA
*        ----        --------      --------      --------      --------
                    "WIND    "    "SOLAR   "    "IMPORT  "    "HYDRO   "
+                   "STORAGE "

:::: END OF TYP-PRIO-00 ::::
```

Add Storage Units

1) Create a new file in the Database named 09-Storage_Units.mif
2) Insert a new UNT-DATA-00 Table from the "Storage Units" tab of the mexico.xlsx file
3) Insert a new MOD-ELMW-00 table from the "Storage Units" tab of the mexico.xlsx file
4) Save the file

GE

Transmission Interconnections

Transmission Interfaces
General Data

Unique 8 character identifier

Descriptive 24 character name

Interfaces:

- To and from area
- Specified in INF-DATA-00

Interface Groups:

- Interface names and flow multipliers
- Specified in INF-GRPS-00

Transmission Interfaces
Limits

- Each interface and Interface group has a transfer limit in each direction
  - Positive and Negative Directions are implemented independently
  - Ratings can change monthly
- System configuration cannot change during the study, but the maximum transfer capability of the ties can change monthly

Specified in **INF-TRLM-00**

Transmission Interfaces
Limits

- Transfer limits can vary hourly based on defined condition sets
  - whether specified units are available or unavailable
  - Whether area loads are greater than or less than a specified value
  - Number of conditions that must be met for the condition set to be satisfied
  - Specified in **INF-DYLM-00**
- If an interface is being used for scheduling contracts but not for non-firm emergency assistance, the tie limits can be set to zero before doing the non-firm assistance calculations
- Interface limits can be zeroed until a specified Emergency Operating Procedure has been called

Transmission Interfaces

Outages

Add Transmission Interconnections

1) Add a file named 11-Transmission.mif to the database
2) Add an INF-DATA-00 Table from the “Transmission Interfaces” tab of the mexico.xlsx file
3) Add an INF-TRLM-00 Table from the “Transmission Limits” tab of the Mexico.xlsx file
4) Save the file

GE

Emergency Operating Procedures

Emergency Operating Procedures

EOPs are steps taken by utilities as the reserve conditions on the system approach critical levels

- Consist of load control and generation supplements which can be implemented before load has to be curtailed
- Load control measures could include disconnecting interruptible loads, public appeals to reduce demand, and voltage reductions
- Generation supplement includes overloading units, emergency purchases, and reducing operating reserves

Emergency Operating Procedures

The frequency with which various emergency operating procedures are initiated provides a physically meaningful measure of the reliability of the system

MARS evaluates the reliability metrics at specified margin states

- Computes the expected number of days per year
- First margin typically represents the desired operating reserves since the emergency measures would be implemented as soon as the available reserves dropped below this level

Emergency Operating Procedures

User can define up to 20 margin states for each area

- Operating reserve requirement
- Actual benefit available from each of the EOPs
- Each benefit can be input as the sum of a fixed MW, a p.u. of the area hourly load, and a p.u. of the area available capacity
- Can limit the number of days that an EOP will be implemented each month
- Can limit the number of hours that an EOP can be used each year, month, and/or day
- Can limit the energy that an EOP can use in a day
- Can specify whether the EOP will be implemented for the benefit of the area only, for the benefit of other areas within the same pool, or for the benefit of any areas in the system

Emergency Operating Procedures

Interpreting Results by “Margin State”

- The result after margin state one would indicate the frequency of running units at their emergency ratings
- The result after the 5th margin state would indicate the number of days during the year in which appeals would be made to the customers to have them reduce demand
- The results after margin state 6 would indicate a loss of load

Example

Margin State	EOP	MW Benefit
1	Operating Reserve	-1,200
2	Emergency Ratings	800
3	Interruptible Loads	1,000
4	30-min Reserve	300
5	Voltage Reductions	400
6	Customer Appeals	700

Emergency Operating Procedures

- MARS assumes that all of the areas move through the EOPs together
- All areas initiate the first step at the same time, then move to the second step together and so on
- Stagger EOP implementation - deficient areas must implement a specific number of EOPs before the other areas that are not deficient begin their EOPs
- If any of the initial steps are negative, all areas must be negative
- Once an area has a positive step, all remaining steps must be positive

Emergency Operating Procedures

Isolated

EOPs used by each area as needed to meet load after dispatch of type 2 and 3 energy limited units

Interconnected

EOPs used as last resort after

- Dispatch of type 2 and 3 energy limited units
- Assistance from other areas
- Contract curtailments

Add Emergency Operating Procedures

1) Create a new file in the database named 12-Emergency_Operating_Procedures.mif
2) Insert an EOP-DATA-02 Table from the “Emergency Procedures” tab of the mexico.xlsx file
3) Save the file

GE

Contract Modelling

Capacity Contracts

- Can be modeled as Type 2 Energy Limited Units, or as Hourly Modifiers
- User Specifies:
  - Sending and receiving areas
  - Hourly contract profile
  - Interchange path for delivery

Contracts

Firm Contracts

Scheduled regardless of sending area sufficiency, curtailed only due to interface limits

Will be included in Isolated area metrics

Curtailable Contracts

Scheduled only if sending area has sufficient capacity or can receive them as emergency assistance from other areas

If a sending area's margin is negative after curtailable contract is scheduled, the contract will be curtailed in proportion to the area's total shortfall

Contract Paths

- Specify area interfaces to deliver contract from sending to receiving areas
- MARS will not check if specified paths actually connect both areas
- When the contract is scheduled, related interfaces and group limits will be adjusted accordingly
- Limits can be changed in one or both directions
- If interface limit is exceeded, the contract will be adjusted subject to interface limits, undelivered MW will be accumulated for output summary

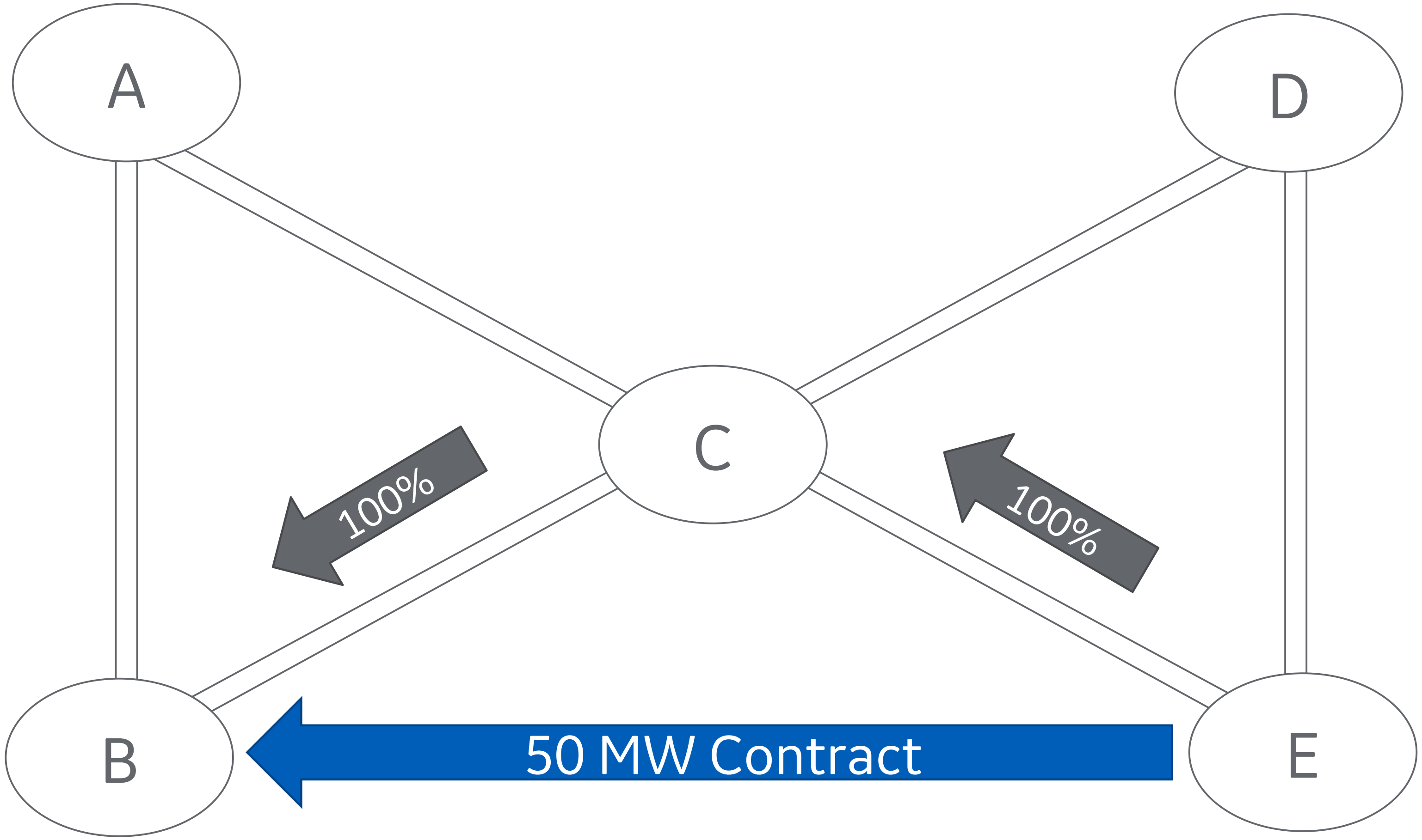
Contract Path Modelling

Contracts can be modeled across a set of interfaces

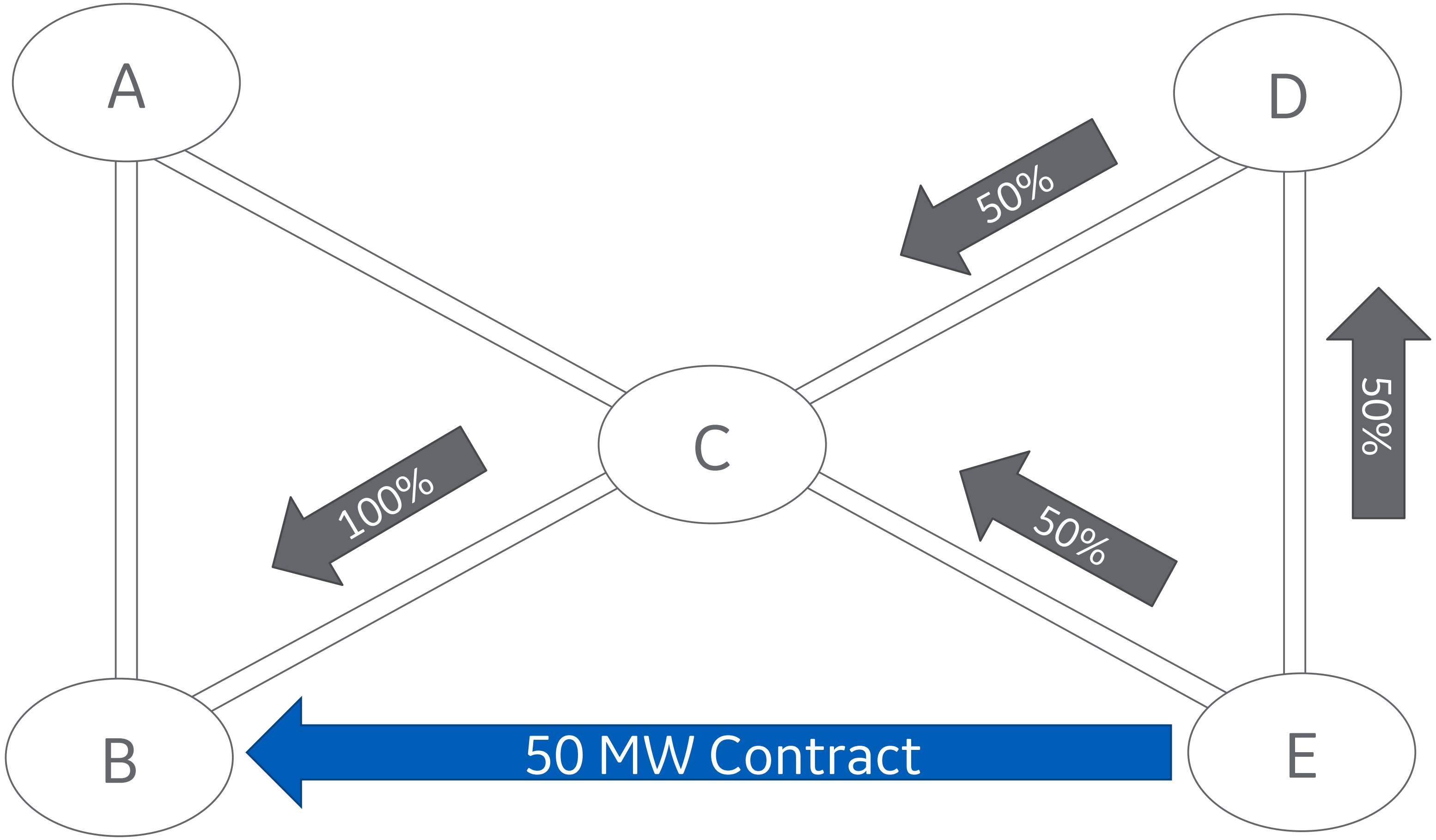
Path can bifurcate, be non-continuous, or not even connect the sending and receiving areas

Allows for flexibility of modeling

Contract Paths



Contract Paths



GE

GE MARS Training

Thursday April 18th, 2019

Start	End	Description
9:00	9:30	Load Forecast Uncertainty - Lecture
9:45	10:00	Load Forecast Uncertainty – Hands-on Exercise
10:00	10:30	Break
10:30	10:45	Capacity Value and Effective Load Carrying Capability - Lecture
10:45	11:15	Capacity Value and Effective Load Carrying Capability – Hands On Exercise
11:15	12:00	Scenario Analysis
12:00	1:00	Lunch
1:00		Q&A / Customer Feedback

Load Forecast Uncertainty

Load Forecast Uncertainty

- Weather conditions & economic factors
- Up to 10 steps of peak loads and associated probabilities
- Can be overridden monthly
- LFU load shapes not mandatory for all areas
- If used for an area, a shape must be input for each of the LFU load levels; can be different shape
- Can also input a base profile or expected load shape
- If base shape is not input, MARS will create it

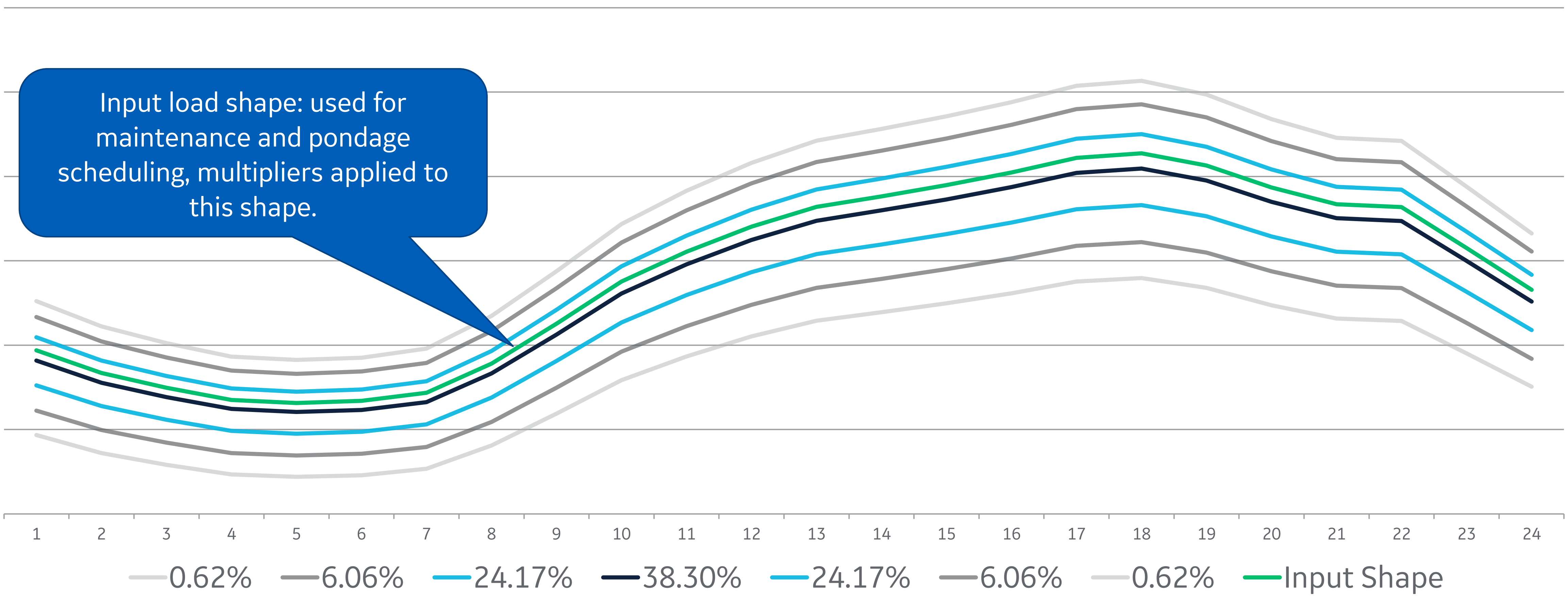
Load Forecast Uncertainty

Common practice to model: 7 step normal distribution with mean and standard deviation

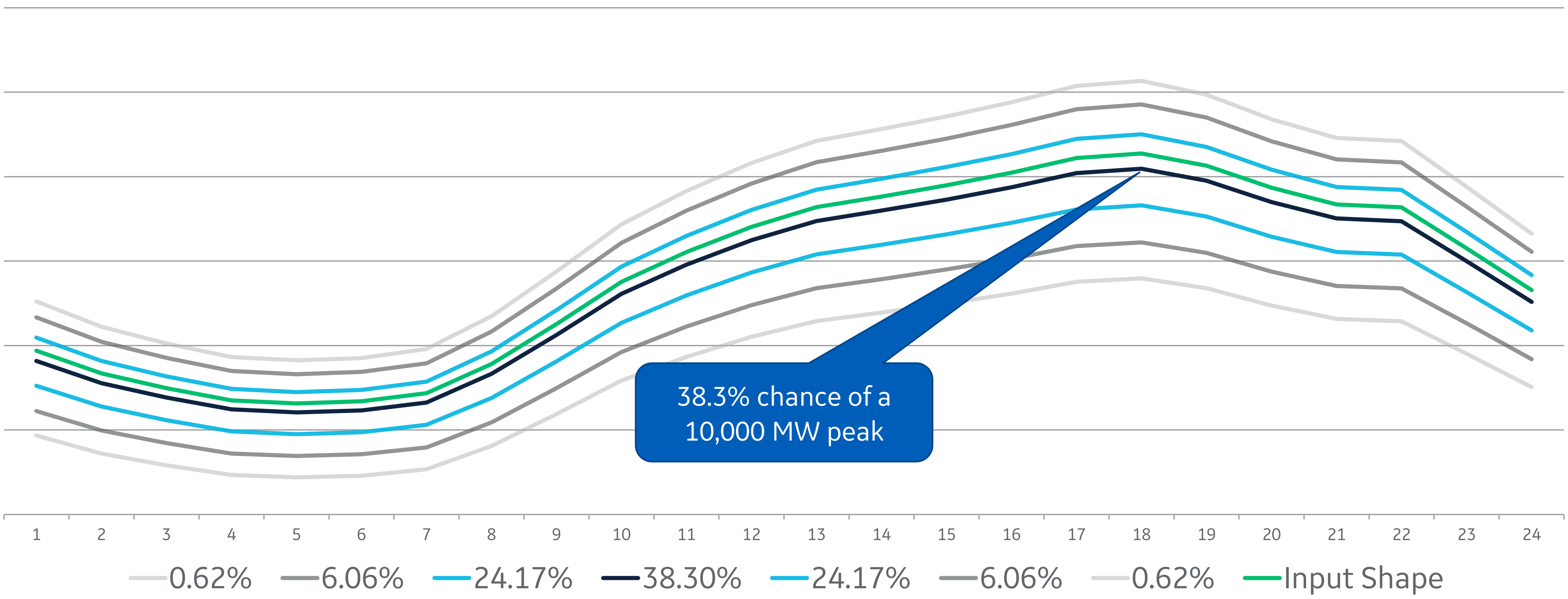
MARS computes the reliability indices at each of the load levels

- Using each LFU’s load shape and peak load multiplier
- Calculate weighted average values based on the associated probabilities
- Convergence is tested based on the weighted-average value of the specified index

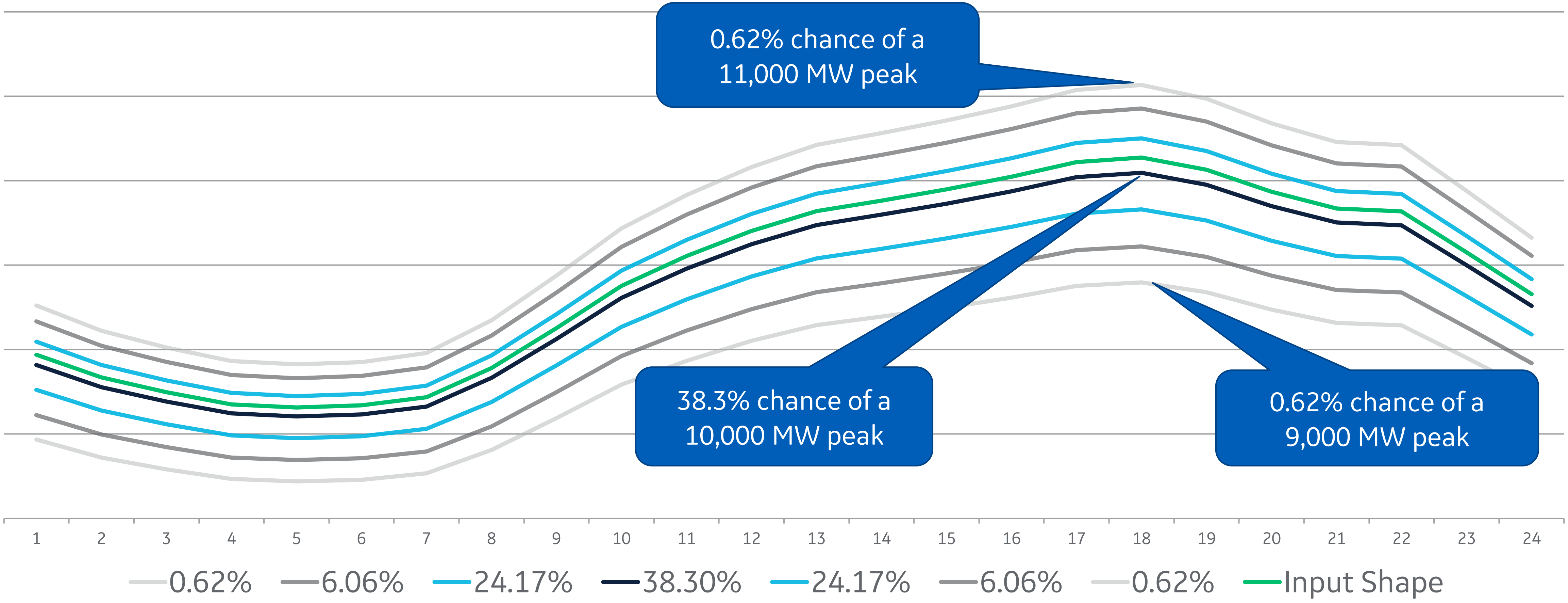
Load Forecast Uncertainty



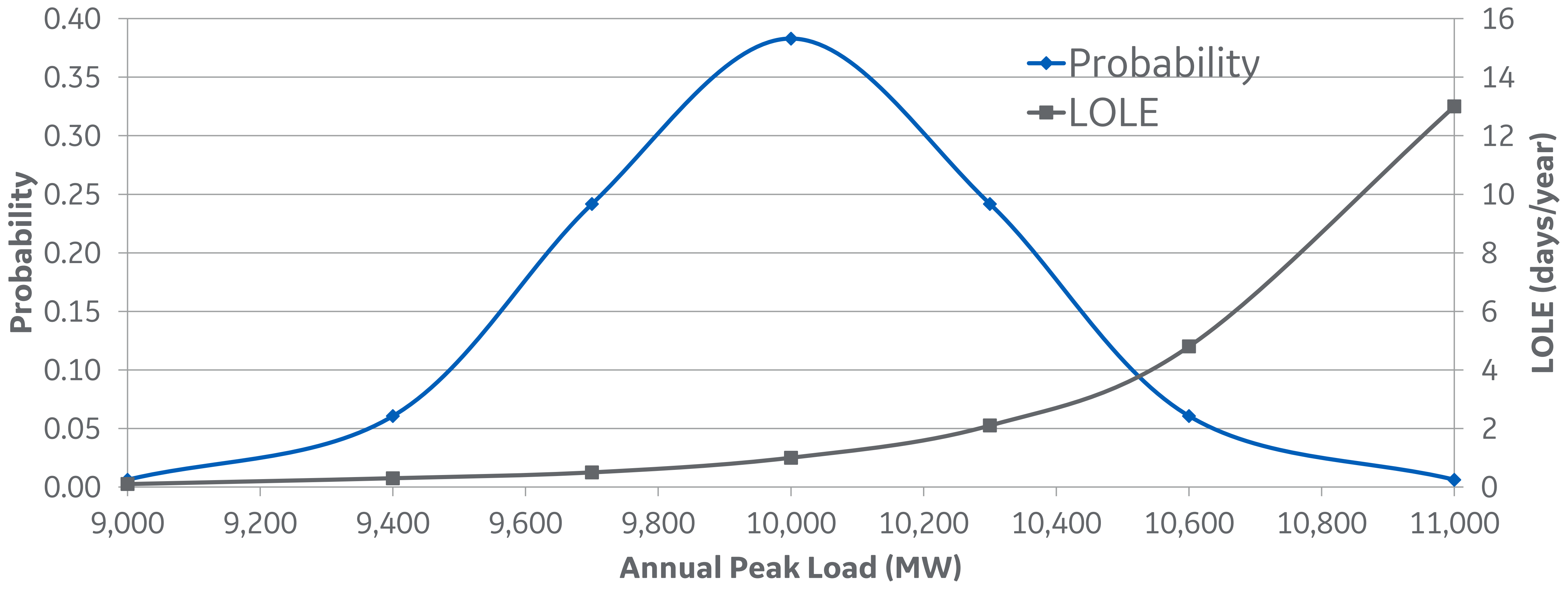
Load Forecast Uncertainty



Load Forecast Uncertainty

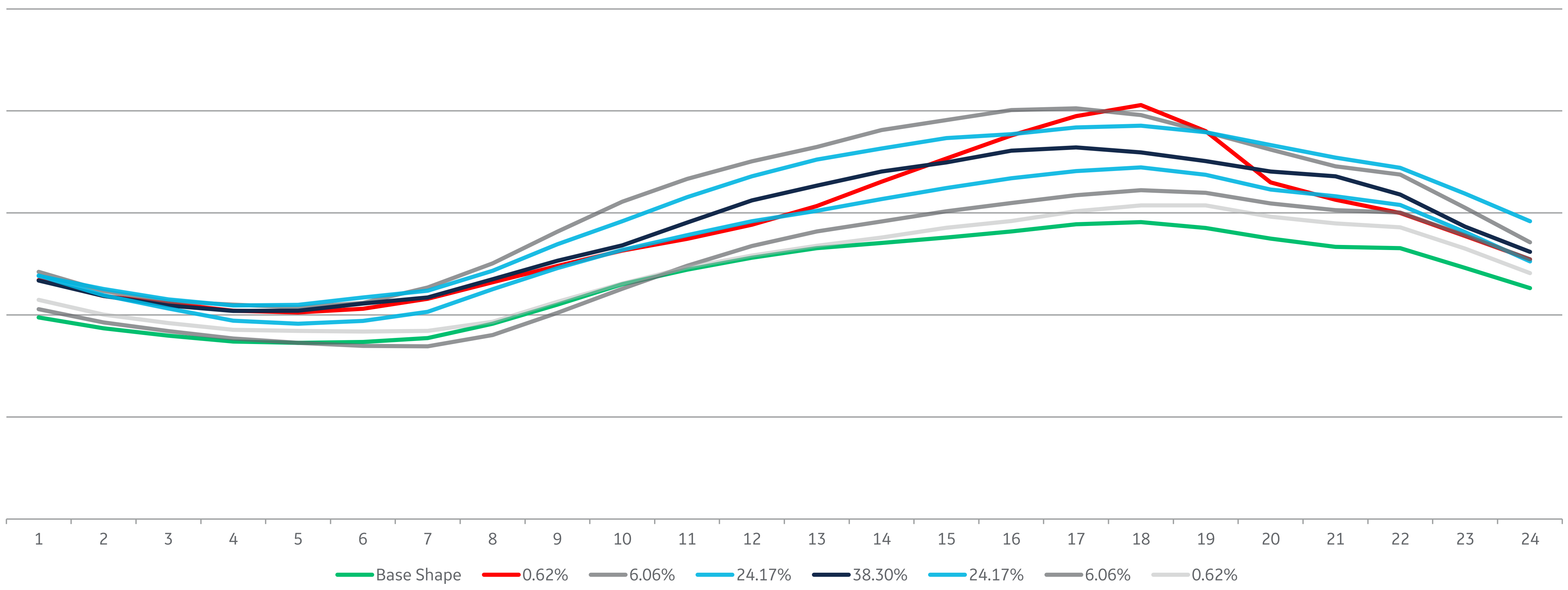


Load Forecast Uncertainty



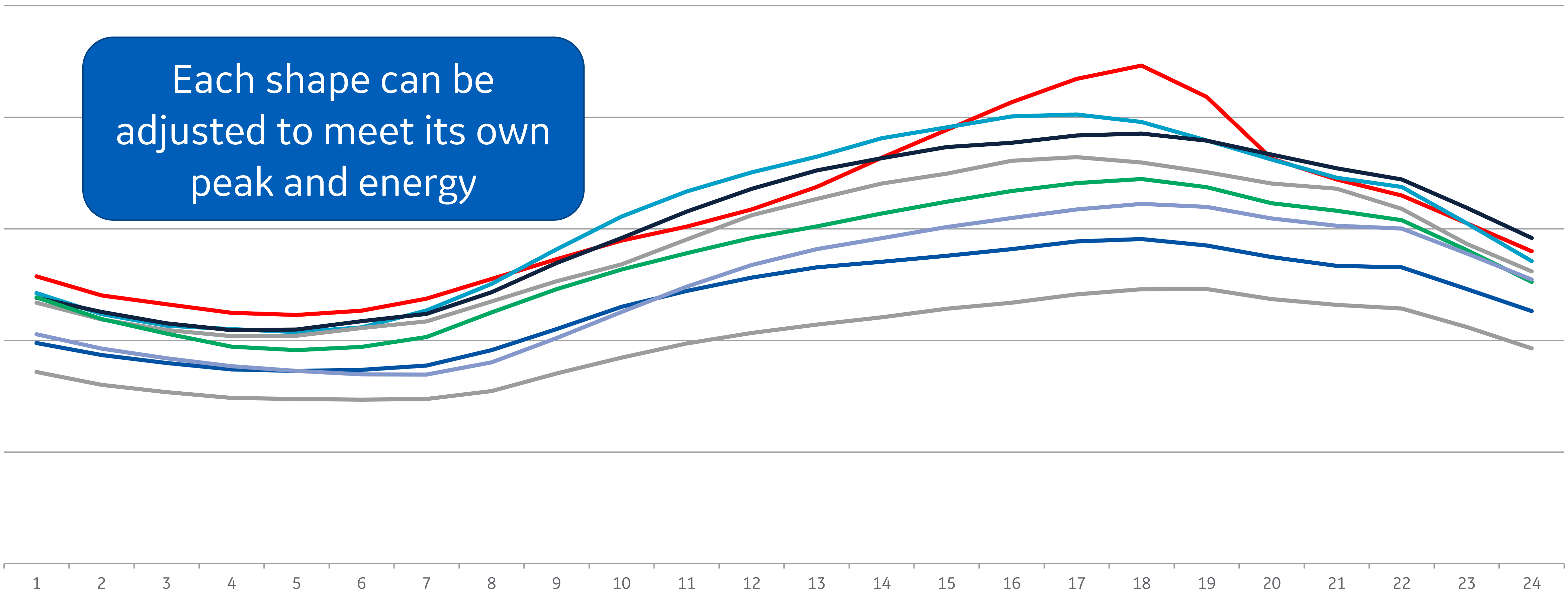
Load Forecast Uncertainty

Multiple Load Shape Model



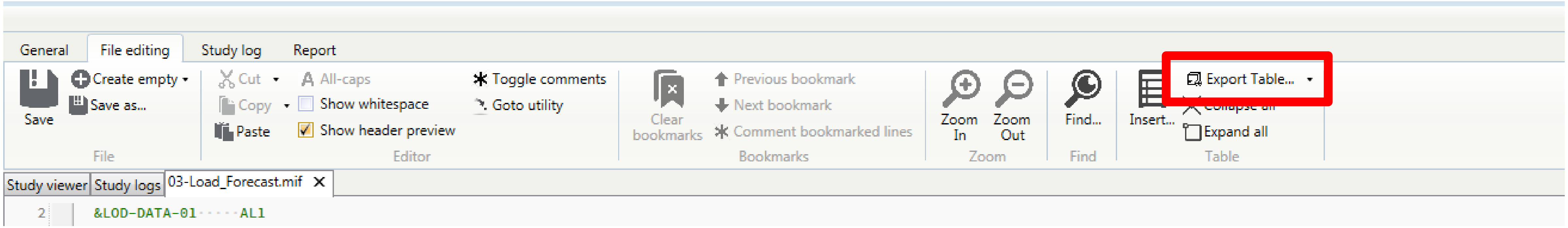
Load Forecast Uncertainty

Multiple Load Shape Model



Load Forecast Uncertainty

1) Open the 03-Load_Forecast.mif file and export the LOD-DATA-01 Table to a csv
2) Change the Load Level from 1 to 2
3) Save the csv



Load Forecast Uncertainty

4) Make a copy of the Load Forecast csv
5) Change the load level in the Copy to 1
6) Increase Peak Load by 10%
7) Increase Energy by 5%
8) Save the file

Load Forecast Uncertainty

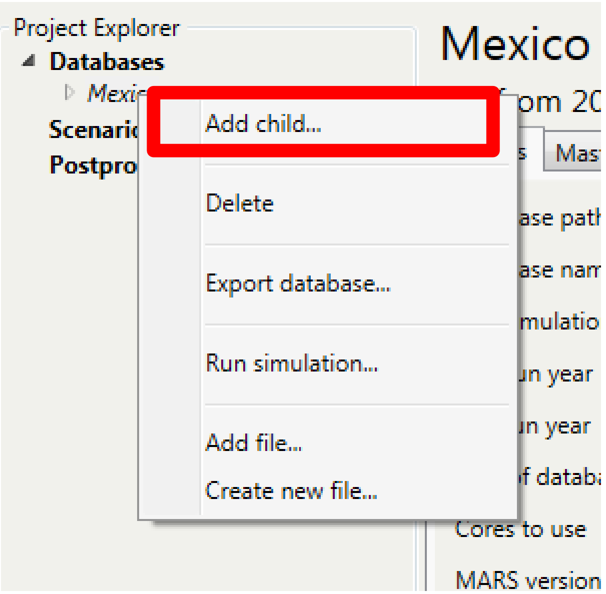
9) Make another copy of the Load Forecast csv
10) Change the load level in the Copy to 3
11) Decrease Peak Load by 10%
12) Decrease Energy by 5%
13) Save the file

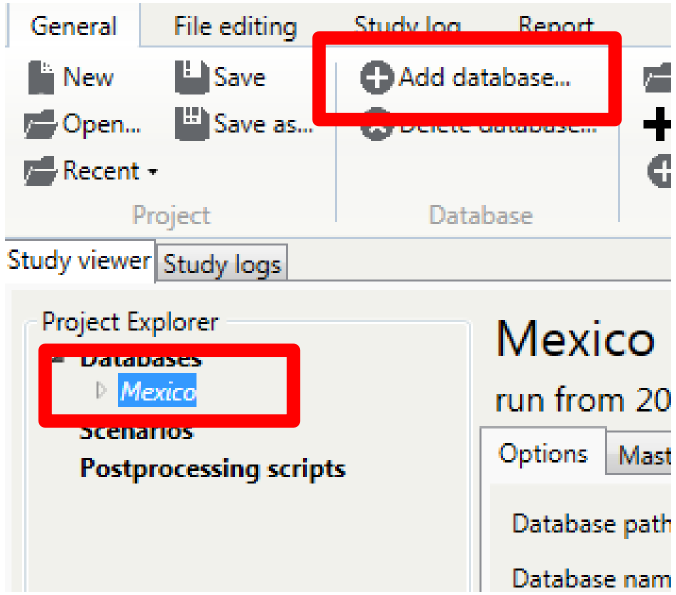
Load Forecast Uncertainty

14) Make a child Database called "Load Forecast Uncertainty" by either

a) Right clicking on the scenario you have and adding a child, or

b) Selecting your database and selecting "Add database" from the ribbon





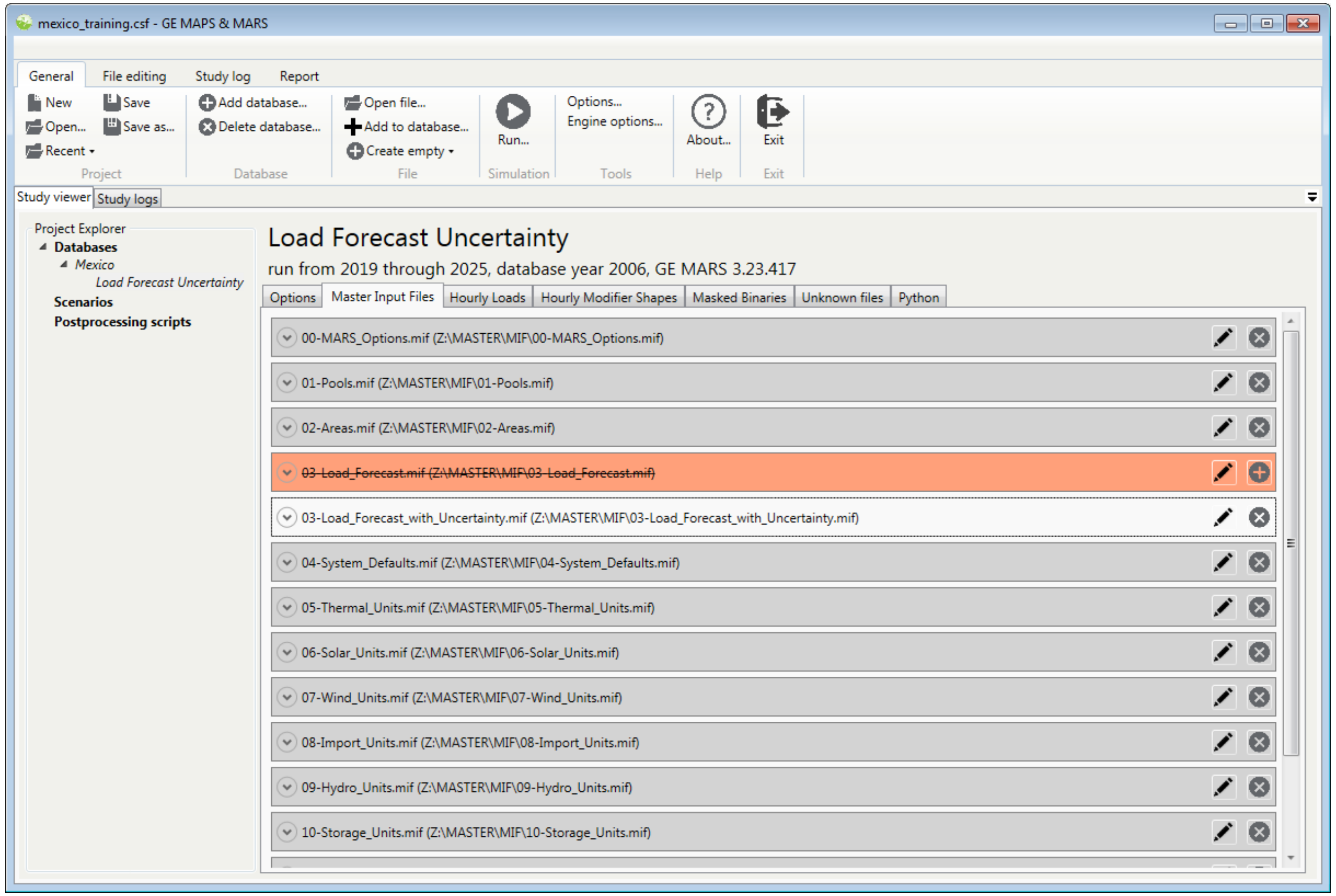
Load Forecast Uncertainty

14) Remove the file 03-Load_Forecast.mif

15) Create a new file called 03-Load_Forecast_with_Uncertainty.mif

16) Insert a LOD-DATA-01 table from each of the three csv files you created

Load Forecast Uncertainty



Load Forecast Uncertainty

18) Insert a blank LOD-UNCY-00 table
19) Set the load multiplier for load levels 1, 2, 3 to 1.0
20) Set the probabilities to 0.1, 0.8, and 0.1 respectively
21) Save the file

```
&LOD-UNCY-00     LDU
*     LOAD-FORECAST-UNCERTAINTY
*-----------------------------------
*           LOAD      PROBABILITY
*        MULTIPLIER      (P.U.)
*          (P.U.)
*-----------------------------------
*         ########     ########
*         --------     --------
   1 :        1.00         0.10
   2 :        1.00         0.80
   3 :        1.00         0.10

;;;; END OF LOD-UNCY-00 ;;;;
```

GE

Capacity Value and Effective Load Carrying Capability

Capacity Value and Effective Load Carrying Capability

Capacity Value

Measures the amount of Installed Capacity which could be replaced by the addition of a resource

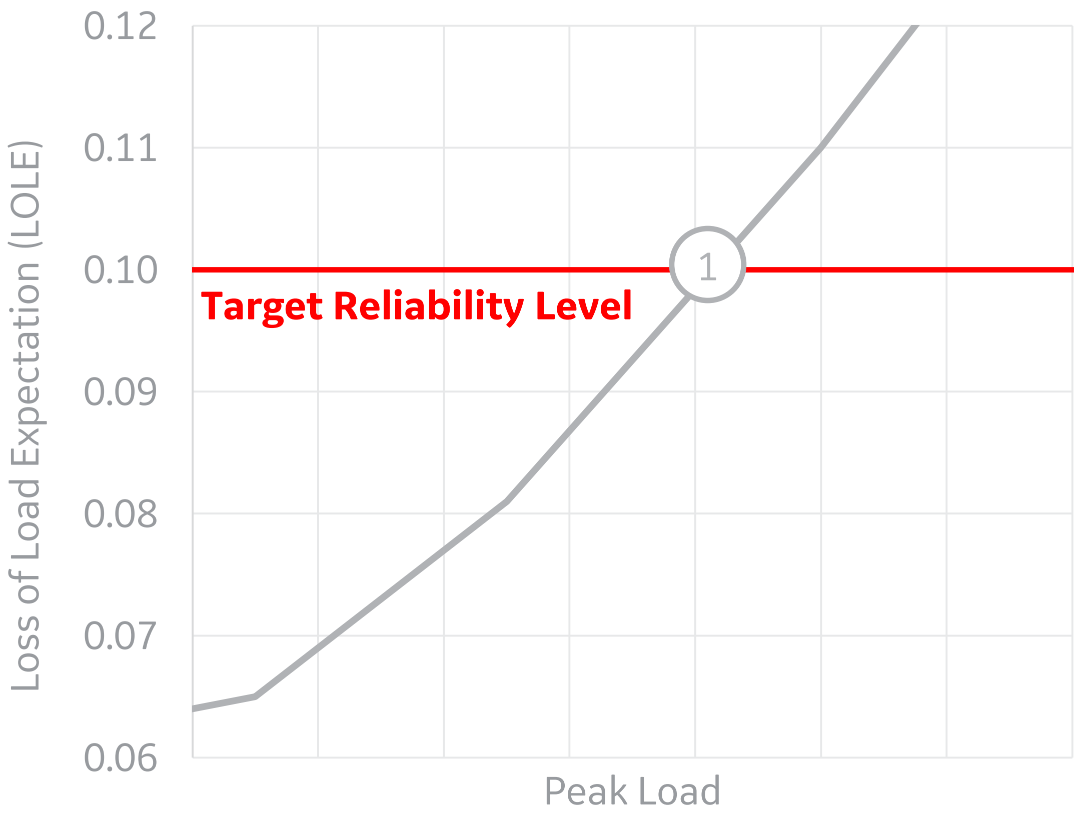
Analogous to the Unforced Capacity (UCAP) metric used by the NYISO

Effective Load Carrying Capability

Measures the amount of load that can be carried by the addition of a resource

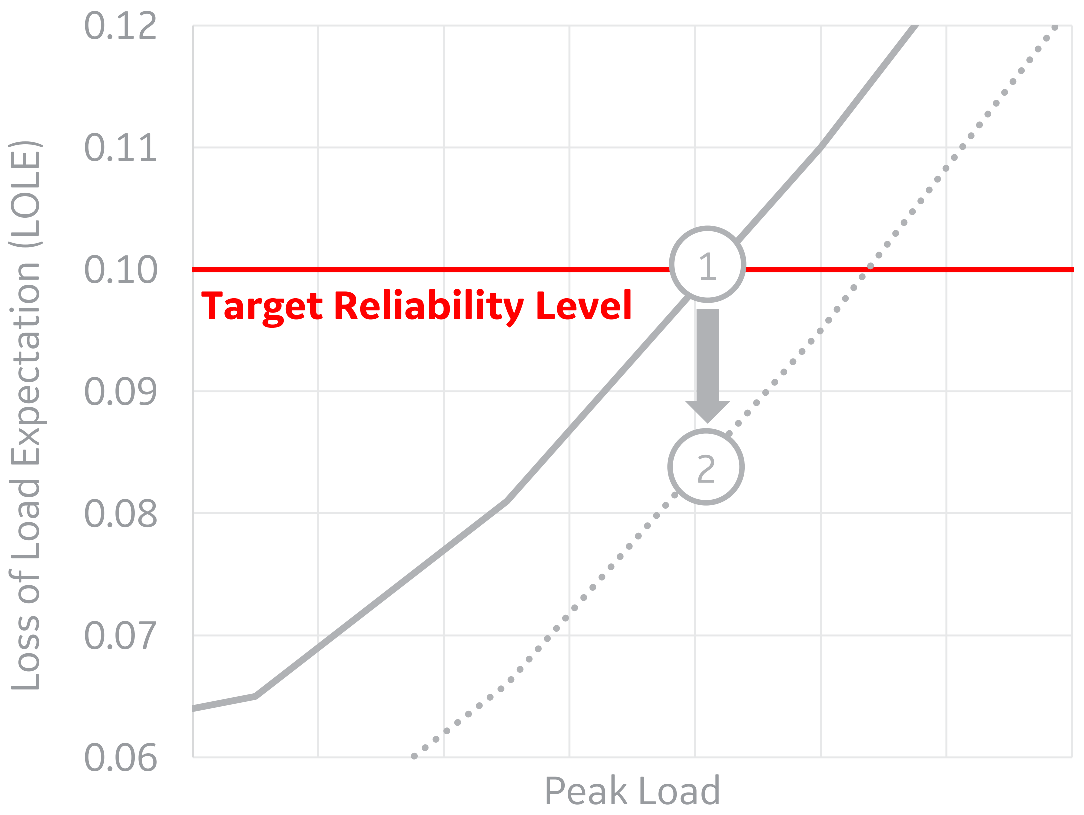
How is Effective Load Carrying Capability Calculated

1. Bring system to a reference point



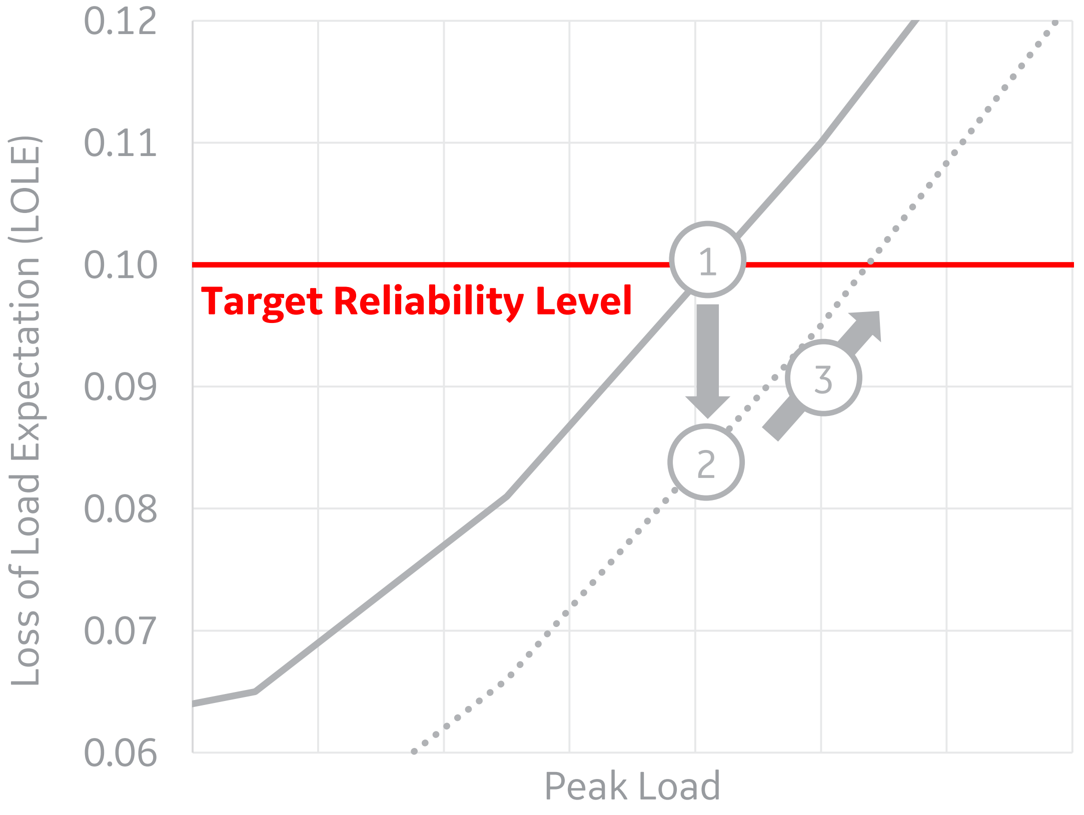
How is Effective Load Carrying Capability Calculated

1. Bring system to a reference point
2. Add a resource, reliability improves



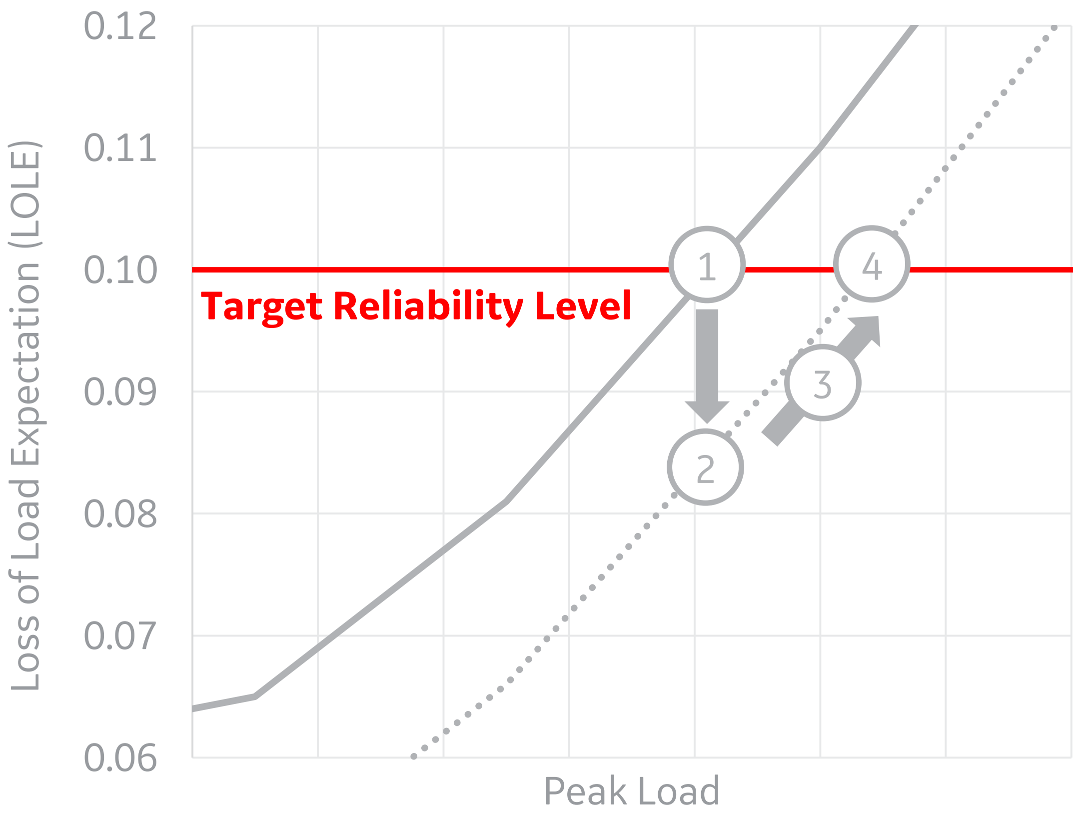
How is Effective Load Carrying Capability Calculated

1. Bring system to a reference point
2. Add a resource, reliability improves
3. Increase System Load maintaining the inherent load factor, reliability decreases



How is Effective Load Carrying Capability Calculated

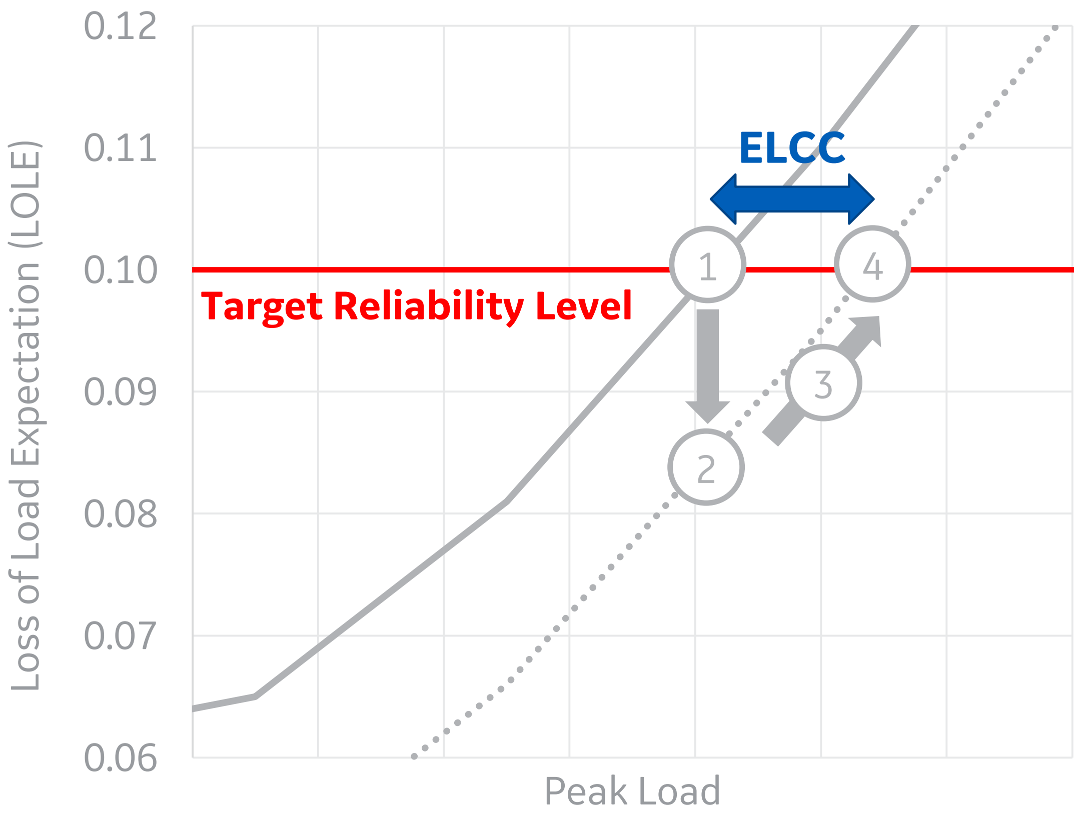
1. Bring system to a reference point
2. Add a resource, reliability improves
3. Increase System Load maintaining the inherent load factor, reliability decreases
4. Iterate until you match the initial system reliability for the metric you are considering



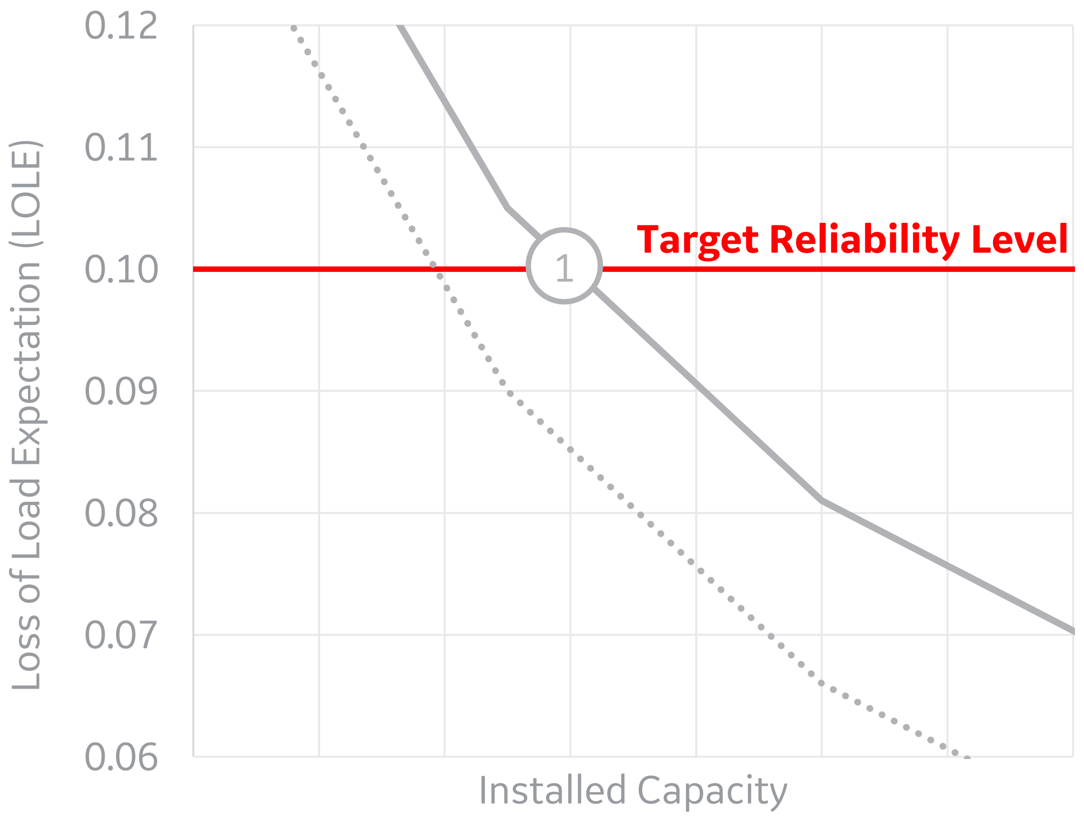
How is Effective Load Carrying Capability Calculated

1. Bring system to a reference point
2. Add a resource, reliability improves
3. Increase System Load maintaining the inherent load factor, reliability decreases
4. Iterate until you match the initial system reliability for the metric you are considering

Effective Load Carrying Capability is the amount of load added to the system to bring reliability back to the reference point

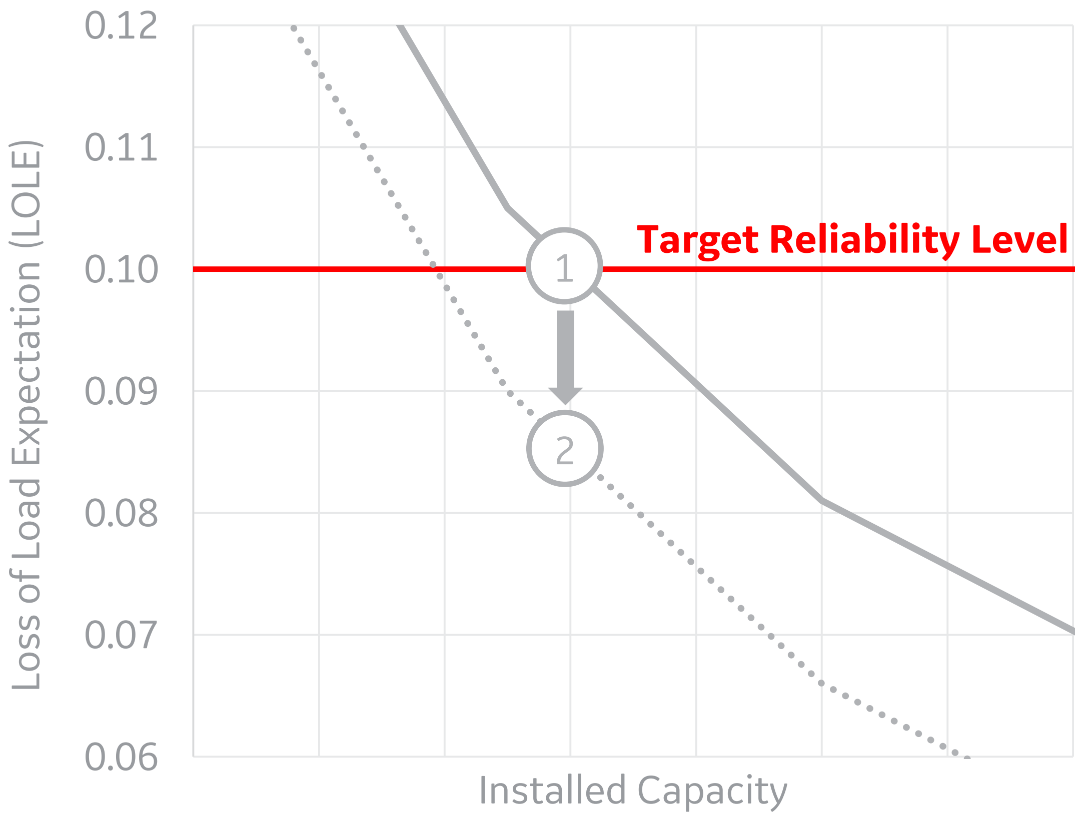


How is Capacity Value Calculated



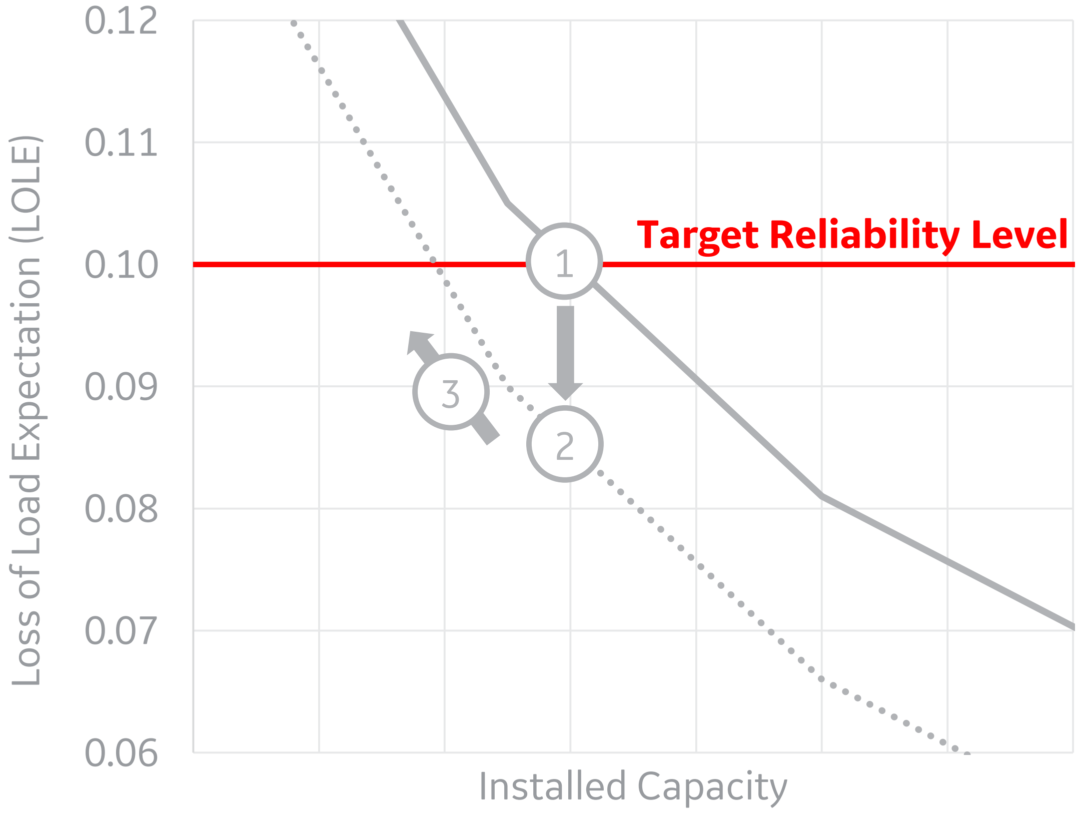
1. Bring system to a reference point

How is Capacity Value Calculated



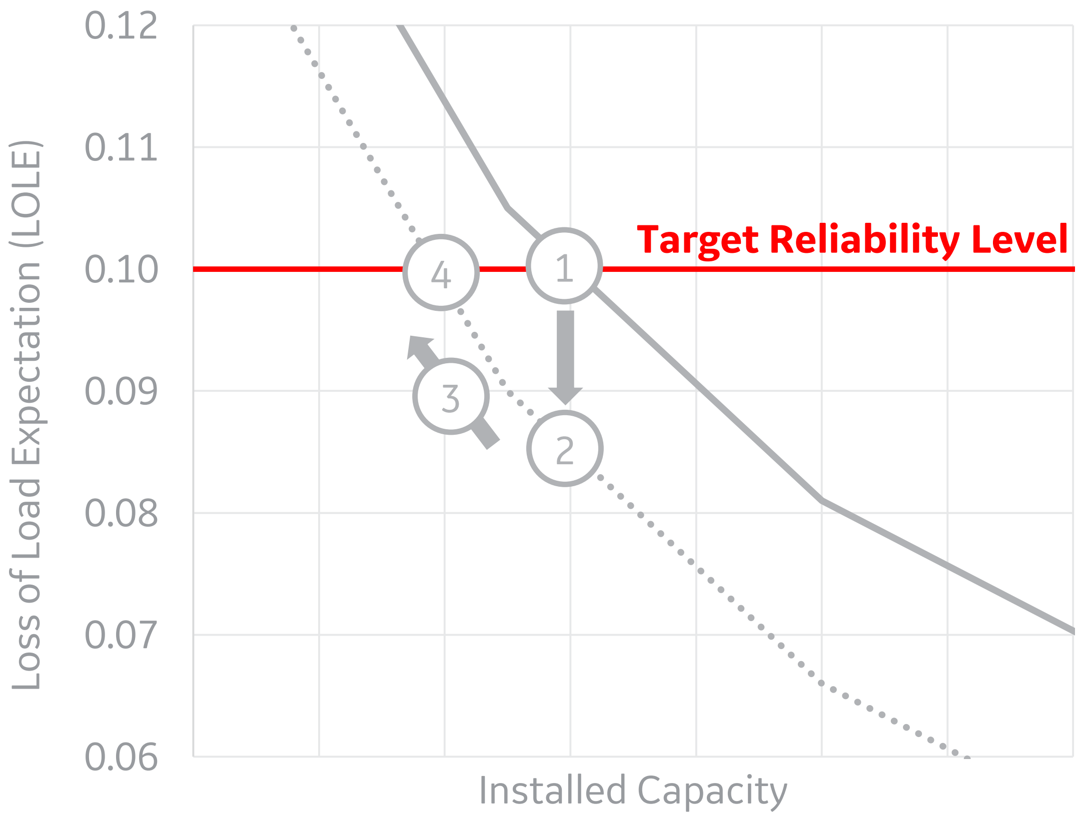
1. Bring system to a reference point
2. Add a resource, reliability improves

How is Capacity Value Calculated



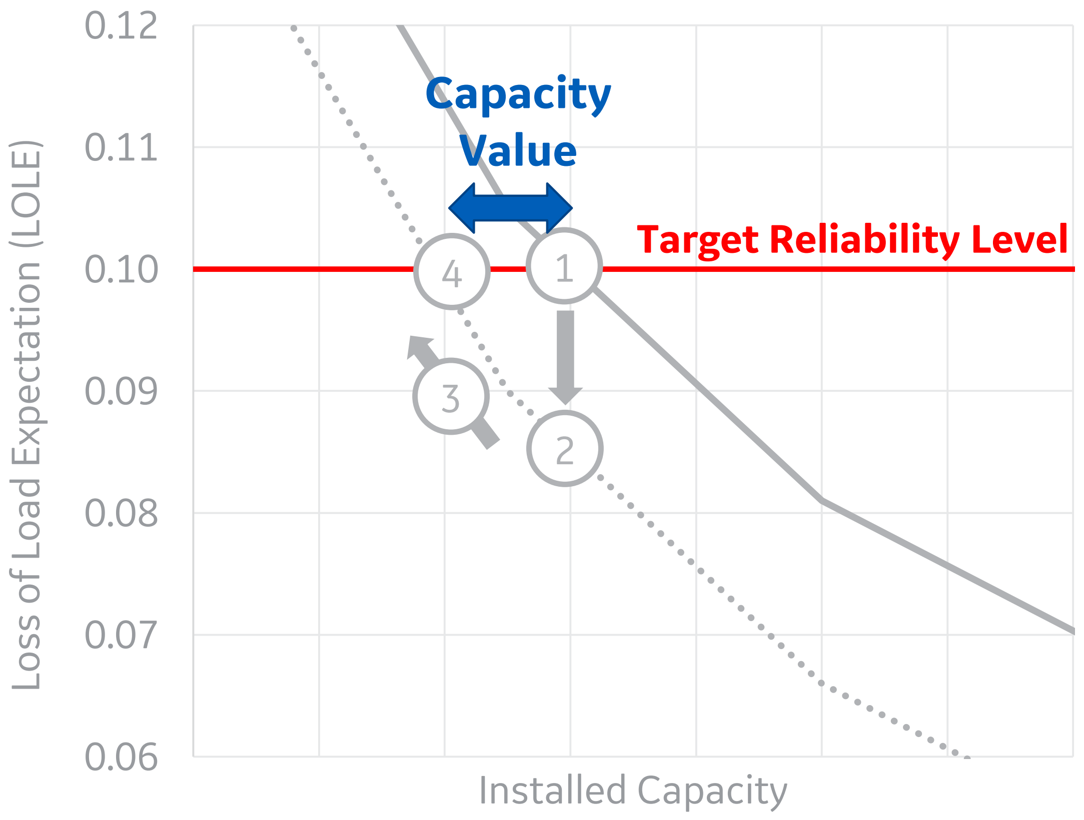
1. Bring system to a reference point
2. Add a resource, reliability improves
3. Decrease System Capacity by a constant MW amount in all hours, reliability decreases

How is Capacity Value Calculated



1. Bring system to a reference point
2. Add a resource, reliability improves
3. Decrease System Capacity by a constant amount MW in all hours, reliability decreases
4. Iterate until you match the initial system reliability for the metric you are considering

How is Capacity Value Calculated



1. Bring system to a reference point
2. Add a resource, reliability improves
3. Decrease System Capacity by a constant amount MW in all hours, reliability decreases
4. Iterate until you match the initial system reliability for the metric you are considering

Capacity Value is the amount of capacity removed from the system to bring reliability back to the reference point.

Approximation for Traditional Resources

$$CV = c - m \ln\left(\left(1 - \sum_{i} EFORd_i\right) + \sum_{i} EFORd_i e^{c/m}\right)$$

CV = Capacity Value

c = Capacity

m = Characteristic System Slope $\quad m = \dfrac{\Delta Load}{\ln(\Delta LOLE)}$

$EFORd$ = Effective Forced Outage Rate at the Time of Demand

i = Capacity States

Garver, L.L.. (1966). Effective Load Carrying Capability of Generating Units. Power Apparatus and Systems, IEEE Transactions on. 8. 910 - 919. 10.1109/TPAS.1966.291652.

Approximation for Traditional Resources

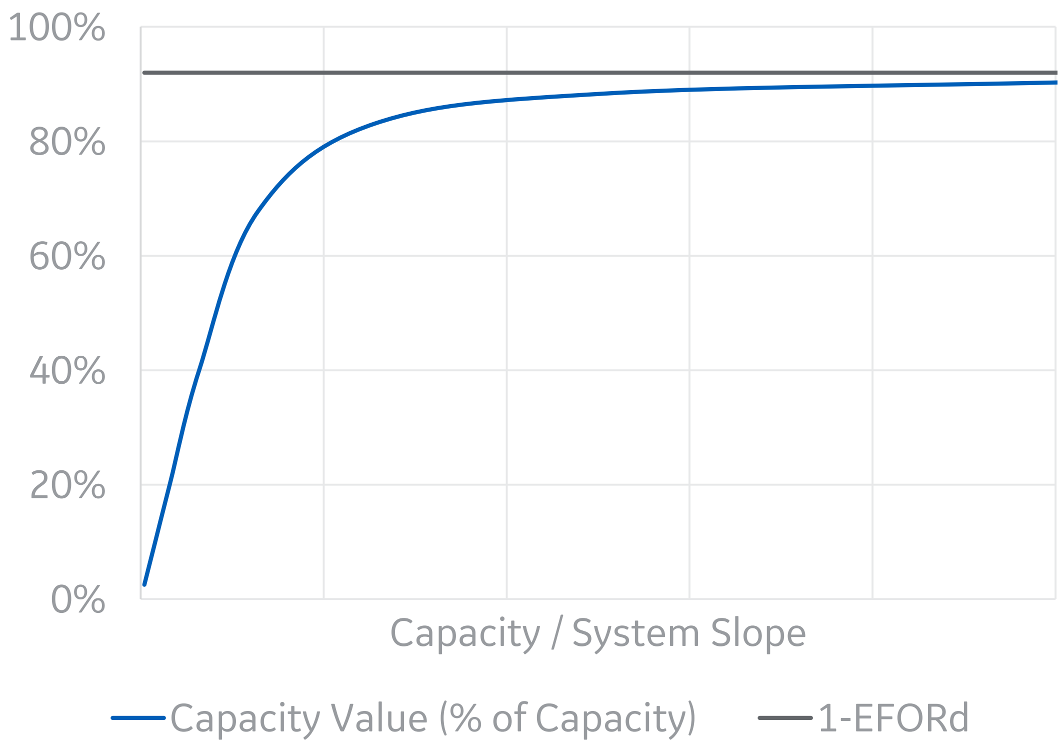
Characteristic System Slope

$$\lim_{c/m \to \infty} CV = c \times (1 - EFORd)$$

Factors that impact System Slope

- A more reliable system has a larger system slope
- Larger systems have larger system slopes

Capacity Value vs System Slope



Factors that affect Capacity Value

Size of the resource

- Large resources added to small systems will have low capacity value

Reliability of the resource

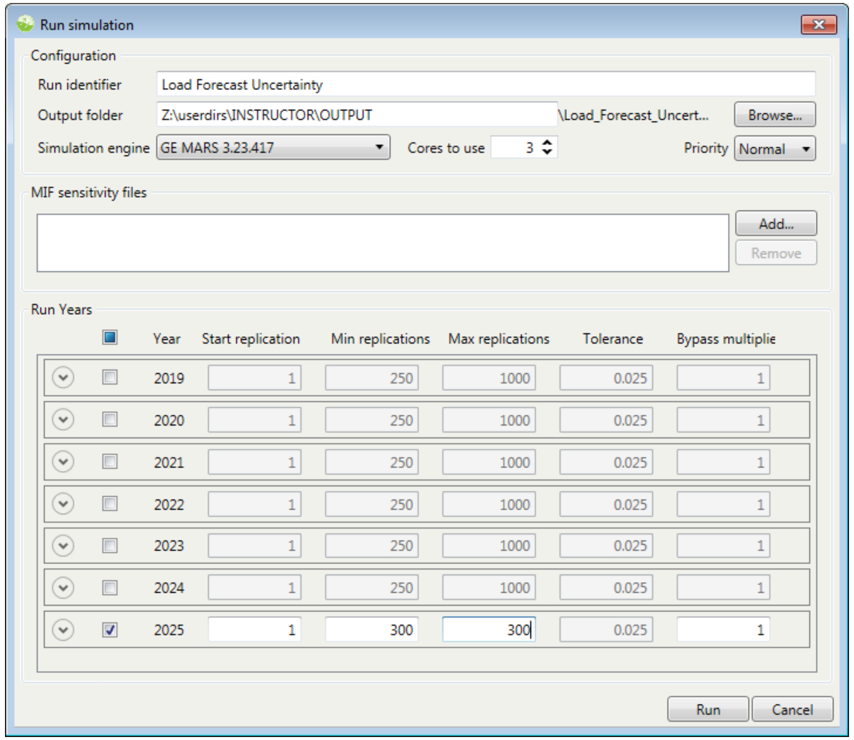
- Resources with less forced outages have higher capacity value

Reliability of the system

- The more reliable a system is the higher the capacity value of a resource will be

Capacity Value

1) Run the Load Forecast Uncertainty database for year 2025, 300 Replications, on 3 Cores

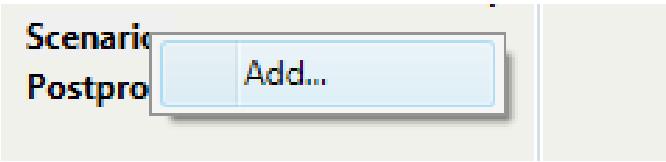


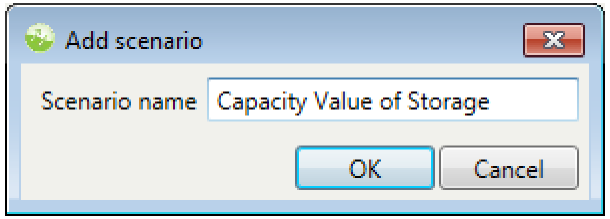
Capacity Value

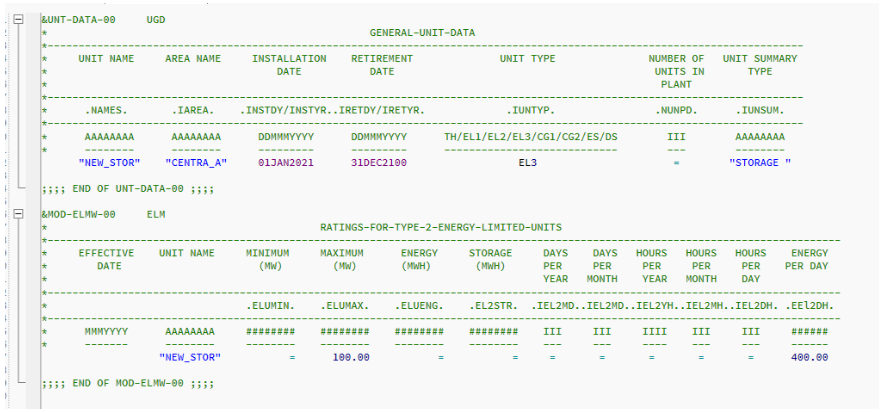
2) Add a new scenario called “Capacity Value of Storage” by right clicking in Scenarios and selecting “Add” from the dropdown”

3) Add a new master input file called “New_Storage.mif” and copy STORAGE1 from 10-Storage_Units.mif and rename as NEW_STOR

4) Decrease the capacity to 100 MW and Energy per day to 400MWh



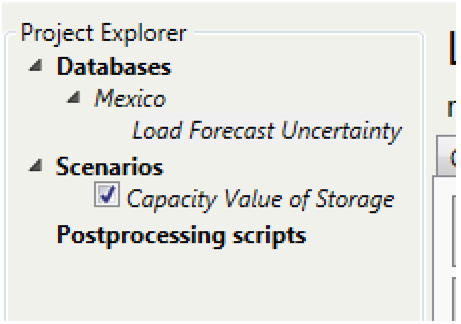




```
&UNT-DATA-00     UGD
*                                        GENERAL-UNIT-DATA
*-------------------------------------------------------------------------------------------------------------
*     UNIT NAME     AREA NAME     INSTALLATION    RETIREMENT              UNIT TYPE              NUMBER OF   UNIT SUMMARY
*                                     DATE           DATE                                        UNITS IN        TYPE
*                                                                                                  PLANT
*-------------------------------------------------------------------------------------------------------------
*      .NAMES.       .IAREA.    .INSTDY/INSTYR..IRETDY/IRETYR.            .IUNTYP.                .NUNPD.      .IUNSUM.
*-------------------------------------------------------------------------------------------------------------
*      AAAAAAAA      AAAAAAAA      DDMMMYYYY      DDMMMYYYY      TH/EL1/EL2/EL3/CG1/CG2/ES/DS       III        AAAAAAAA
*      --------      --------      ---------      ---------      ----------------------------       ---        --------
      "NEW_STOR"    "CENTRA_A"     01JAN2021      31DEC2100                  EL3                    =        "STORAGE "

;;;; END OF UNT-DATA-00 ;;;;

&MOD-ELMW-00     ELM
*                                   RATINGS-FOR-TYPE-2-ENERGY-LIMITED-UNITS
*--------------------------------------------------------------------------------------------------------------------
*     EFFECTIVE    UNIT NAME     MINIMUM     MAXIMUM      ENERGY      STORAGE     DAYS    DAYS    HOURS   HOURS   HOURS    ENERGY
*       DATE                      (MW)        (MW)         (MWH)       (MWH)       PER     PER     PER     PER     PER    PER DAY
*                                                                                  YEAR   MONTH    YEAR   MONTH    DAY
*--------------------------------------------------------------------------------------------------------------------
*                               .ELUMIN.    .ELUMAX.    .ELUENG.    .EL2STR.   .IEL2MD..IEL2MD..IEL2YH..IEL2MH..IEL2DH. .EEl2DH.
*--------------------------------------------------------------------------------------------------------------------
*      MMMYYYY      AAAAAAAA    ########    ########    ########    ########     III     III     IIII    III     III    ######
*      -------      --------    --------    --------    --------    --------     ---     ---     ----    ---     ---    ------
                   "NEW_STOR"          =      100.00           =           =       =       =       =       =       =    400.00

;;;; END OF MOD-ELMW-00 ;;;;
```

Capacity Value

5) Run the Load Forecast Uncertainty Database, and the Capacity Value of Solar Scenario together for year 2025, 300 Replications, on 3 Cores



Capacity Value

6) Create a new file in the Capacity Value of Storage scenario called "Remove Capacity"
7) In that file create a new Hourly Modifier of summary type "REMOVE " with the same area, installation date, and retirement date as NEW_STOR
8) Using MOD-MDMW-00 set the schedule to be -100 MW in all hours

Capacity Value

```
&UNT-DATA-00     UGD
*                                                     GENERAL-UNIT-DATA
*-----------------------------------------------------------------------------------------------------------------------------
*     UNIT NAME     AREA NAME     INSTALLATION     RETIREMENT               UNIT TYPE                NUMBER OF   UNIT SUMMARY
*                                     DATE            DATE                                            UNITS IN       TYPE
*                                                                                                       PLANT
*-----------------------------------------------------------------------------------------------------------------------------
*      .NAMES.       .IAREA.    .INSTDY/INSTYR..IRETDY/IRETYR.             .IUNTYP.                  .NUNPD.      .IUNSUM.
*-----------------------------------------------------------------------------------------------------------------------------
*      AAAAAAAA      AAAAAAAA      DDMMMYYYY      DDMMMYYYY     TH/EL1/EL2/EL3/CG1/CG2/ES/DS          III        AAAAAAAA
*      --------      --------      ---------      ---------     ----------------------------          ---        --------
      "REM_CAP "    "CENTRA_A"     01JAN2021      31DEC2100                 DS                         =        "REMOVE   "

;;;; END OF UNT-DATA-00 ;;;;


&MOD-MDMW-00     ESD     CONTINUATION     ASTERISK
*                                   ENERGY-STORAGE-DSM-MOD-MW
*------------------------------------------------------------------------------------------
*     EFFECTIVE     UNIT NAME        NET HOURLY LOAD MODIFICATION FOR TYPICAL WEEK (MW)
*        DATE
*------------------------------------------------------------------------------------------
*                                                   .ESUMOD/DSMMOD.
*------------------------------------------------------------------------------------------
*      MMMYYYY      AAAAAAAA      #########      #########      #########      #########
*      -------      --------      ---------      ---------      ---------      ---------
                   "REM_CAP "      168*-100

;;;; END OF MOD-MDMW-00 ;;;;
```

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Scenario Analysis

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Scenario Analysis

User Feedback

Please take the time to fill out the survey before you leave

Any and all questions can be sent to
mars-support@ge.com

THANK YOU FOR ATTENDING!!!!