GE VERNOVA

MARS OVERVIEW

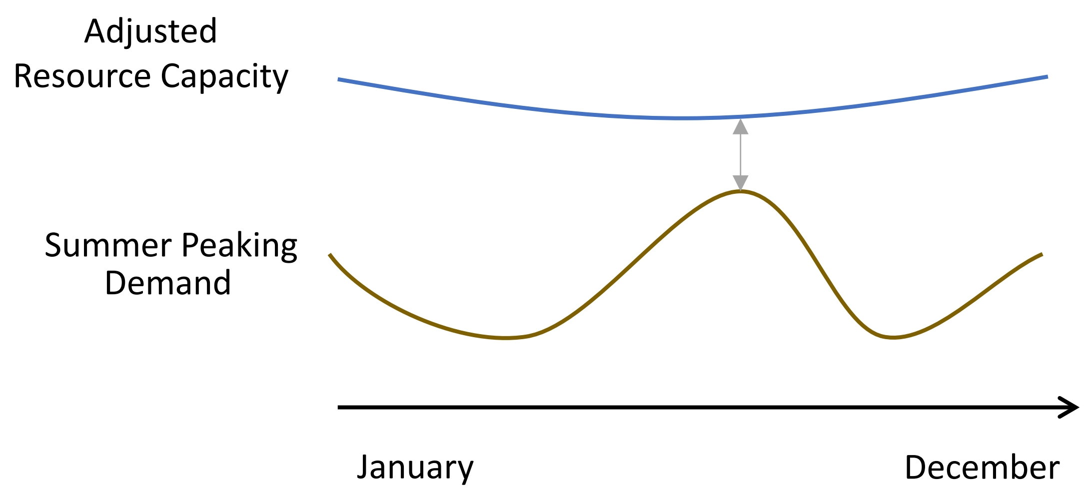
Topics -

- Resource Adequacy Theory (Brief)
- MARS Overview
  - Load
  - Resource Units
  - Transmission
  - Emergency Operating Procedures
  - Indices
- Simulation Process
- New Enhancements

This material represents a high-level visualization of the process associated with Resource Adequacy and Monte-Carlo algorithms. As such, the logic and math supporting these theories and this model are in some cases richer in content than what is provided.

RESOURCE ADEQUACY THEORY

Resource Adequacy Theory -
Deterministic Operation Analysis

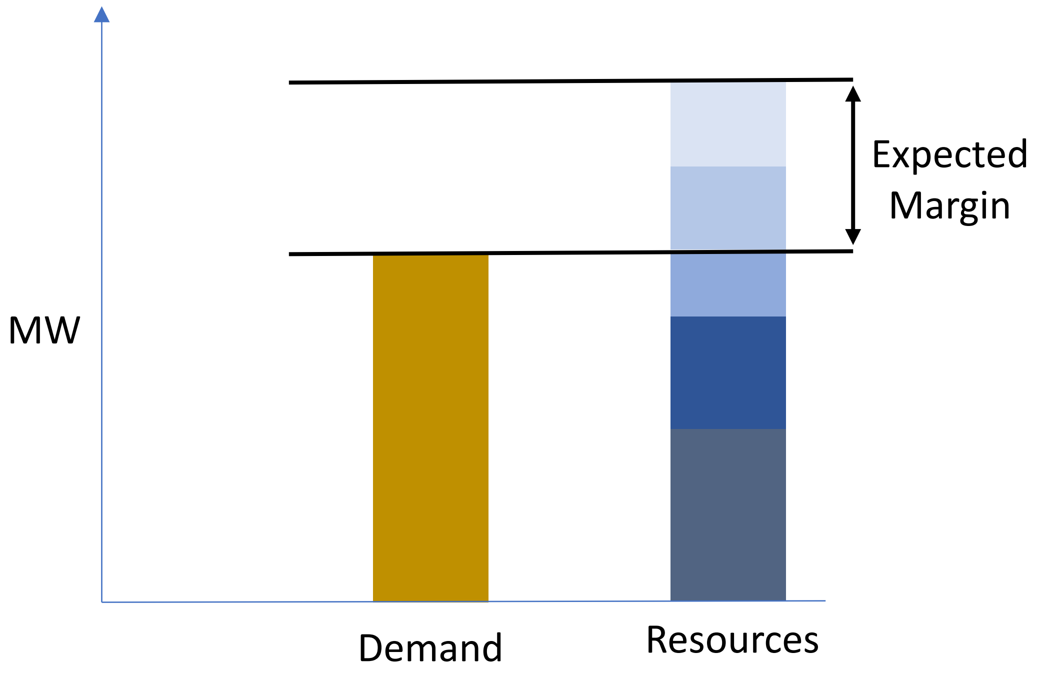


- Typically, would look at expected demand and resource capacity.
- For reliability determination, the thought was if the peak hour was reliable, all hours would be reliable.

Resource Adequacy Theory -

Stack Analysis

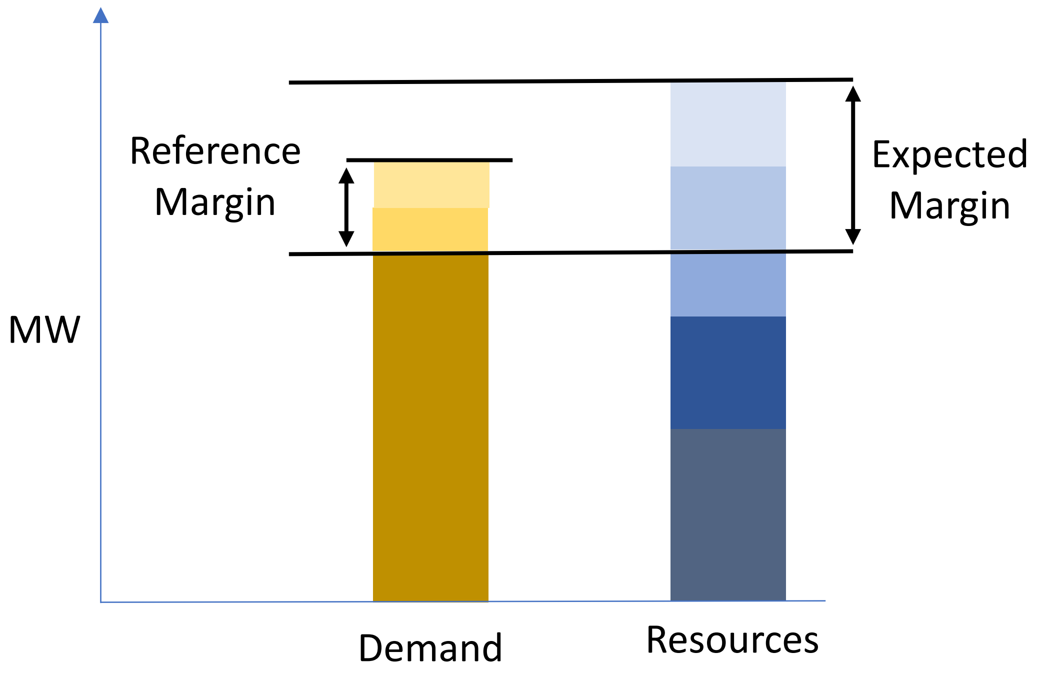
- On any hour, historically focused on the peak hour, compare demand for that hour to the availability of resources.
- Comparison of the total resource availability to the demand would provide the expected margin for that hour.



Resource Adequacy Theory -

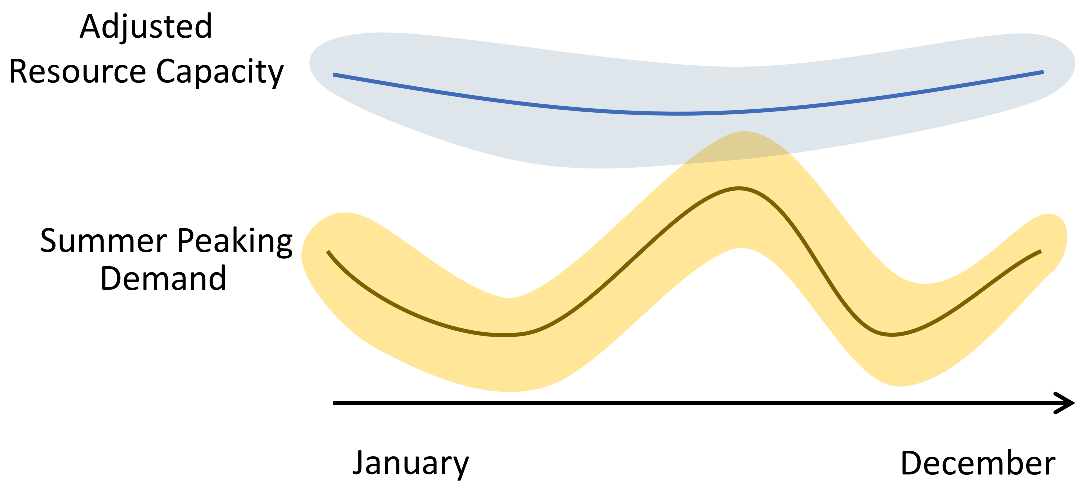
Stack Analysis

- Determine a reference margin to compare the expected margin against.
- Add additional items such as required reserves and forecast uncertainty.



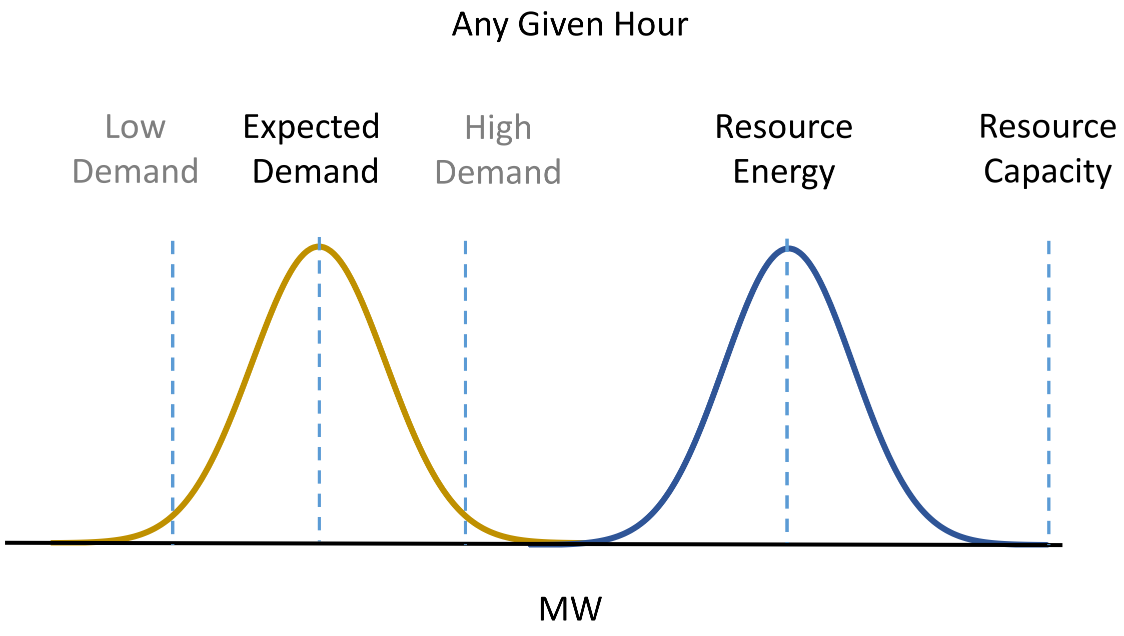
Resource Adequacy Theory -

Stochastic Operation Analysis



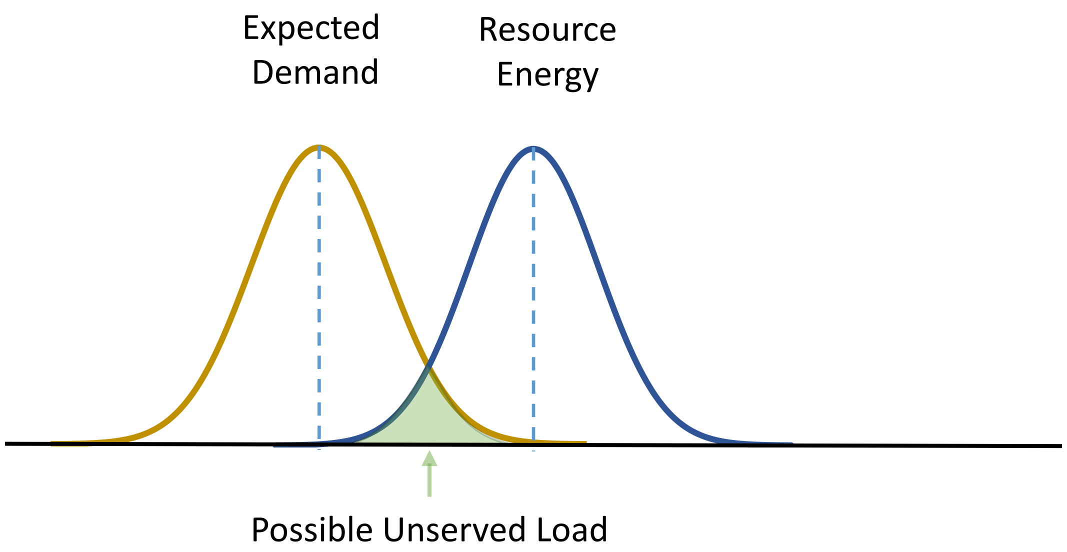
- While resource capacity and demand follow a predictable annual shape, there is variance for both based on specific conditions.
- The shaded areas represent variability around the expected levels.

Resource Adequacy Theory -
Distribution Analysis



- The range of variance from the previous slide can be represented as distributions of possibility for any given hour.
- Distributions provide different values that can be studied for both demand and resource availability.
- In this example, all possibilities for resource availability are higher than all possibilities for demand.

Resource Adequacy Theory -
Distribution Analysis

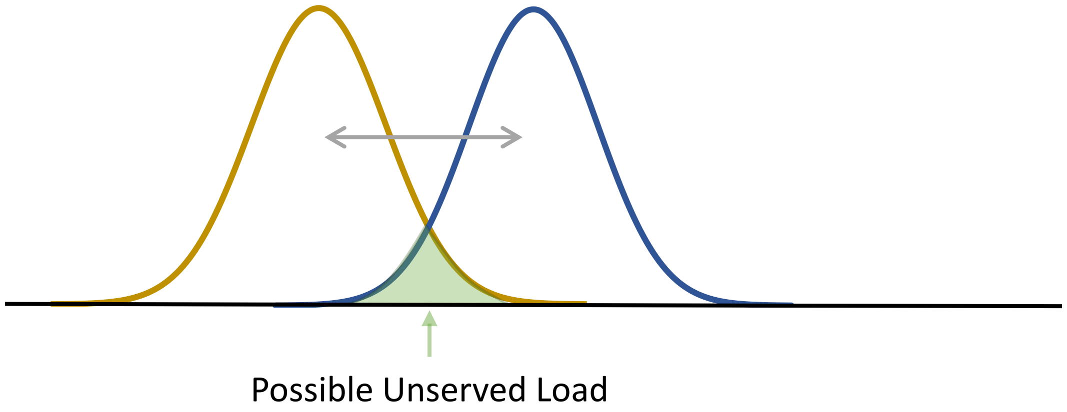


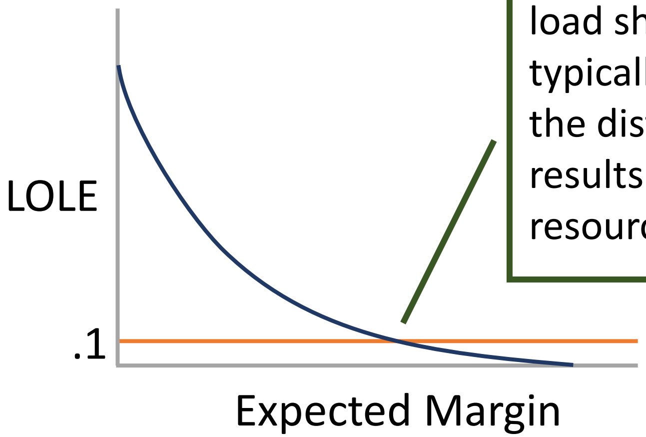
- If the margin is lower, the distributions of possible values begin to overlap.
- The shaded area represents possible levels of resource availability that may be less than the possible level of demand.
- If only expected conditions were studied, reliability concerns may be missed.

Resource Adequacy Theory -
Analytical Method

The area under these distributions can be described using: $(f * g)(t) := \int_{-\infty}^{\infty} f(\tau)g(t-\tau)\,d\tau.$

As the expected margin increases, the resulting Loss of Load Expectation (LOLE) decreases.

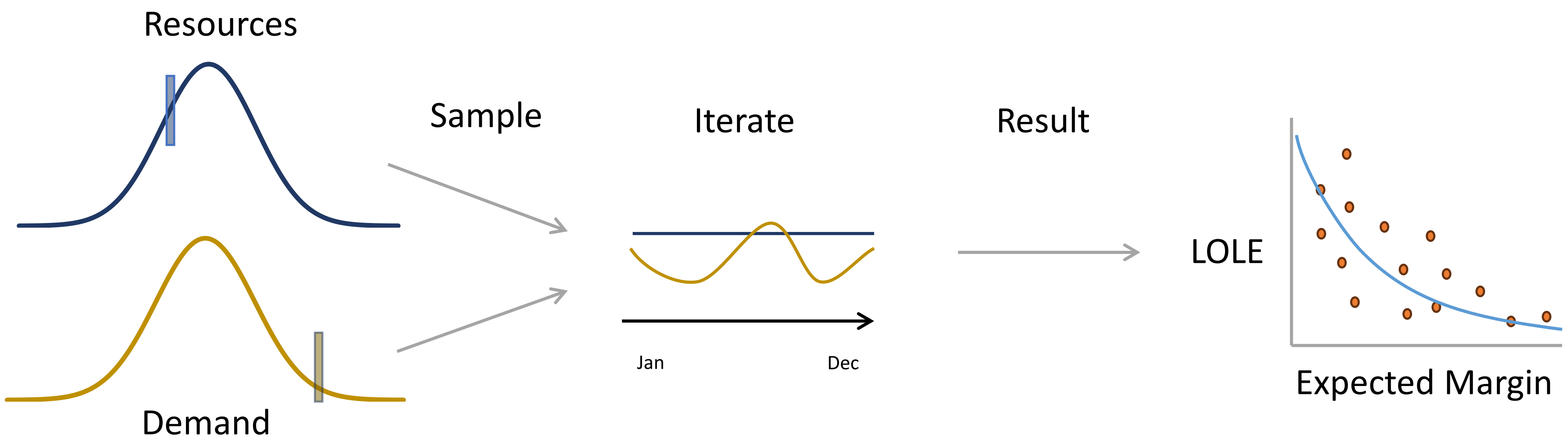




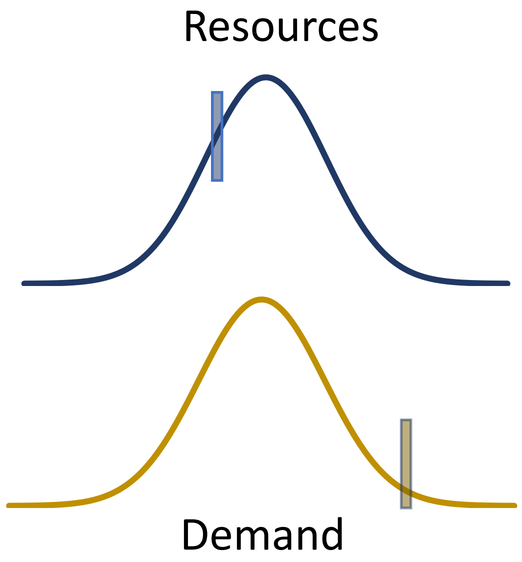
A reliability level of .1 LOLE days/year reflects infrequent load shed events. This typically occurs in the tails of the distributions representing results driven by extremes in resource adequacy models.

Resource Adequacy Theory -
Monte-Carlo Method

Use of random sampling and model iteration to determine probability of an event.



Resource Adequacy Theory - Complexities



- Conditional on time, these distributions may not be independent. For example, weather may impact both load and intermittent production meaning where one distribution is sampled may impact where the other is sampled. Distributions are never "normal".

- Some capacity availability is time dependent. Whether a limited energy resource can provide energy at a certain time may depend on whether it was generating in previous hours.

- Similarly, storage resource performance may not only need to consider past generation, but also when the resource can charge which affects load.

- The industry continues to evolve leading to additional variabilities that need to be considered.

MARS OVERVIEW

MARS Overview -

GE Multi Area Reliability Simulation (MARS)

- Chronological system simulation combining:
  - Randomly generated operating histories of units through time.
  - Hourly chronological load cycles.
  - Transmission interfaces.
  - State of charge for limited energy and storage resources.

- Random events to be considered;
  - Equipment forced outages.
  - Transmission interface forced outages.
  - Uncertainty in forecasted loads.
  - Uncertainty in renewable output.

MARS Overview -

Monte-Carlo Simulation (High Level)

- Chronological - Simulates time intervals chronologically accounting for events which are dependent on past events.
- System scenario is created by randomly drawing availability of equipment and comparing to different load levels.
- If the margin is negative, energy from as-needed resources is utilized and their state of charge is tracked for all load levels.
- Years are simulated until a convergence criterion is met, or for a set number of samples.

MARS Overview -
Load Data

- If an hourly profile is available, user can input directly into model.

- Otherwise, MARS can develop a load model with the specified peak and energy. The data can be specified on a monthly or annual basis.

- Several options are available for adjusting the energy.
    - Maintain monthly peaks while adjusting the remaining hourly loads in the month.
    - Maintain both the monthly peak and valley, with the loads mid-way between the peak and valley changing the most.
    - Maintain the daily peak and adjust the remaining loads during the day.

MARS Overview -

Load Forecast Uncertainty

- Load forecast uncertainty (LFU) is typically related to weather conditions in the near term and economic factors in the longer term.

- To represent different weather conditions in the near term, different hourly load profiles can be used for each LFU load level. Profiles can be randomly picked for each iteration and resulting intermittent resource profiles can be assigned.

- To represent the longer-term, uncertainty in the peak load forecast can be modeled by specifying different multipliers on the peak load and the associated probabilities of each load level occurring.

MARS Overview -
Resource Models

- Thermal Model (TH)
- Hourly Modifiers (DS)
- Cogeneration (CG1 and CG2)
- Energy Limited Models (EL1, EL2, and EL3)
- Energy Storage (ES)
- Hybrid Models (HYB)

- Important that the model develop a dispatch order when there are different types of resources.
- Example being resources that are dependent on if they were available in the previous hour and/or their state of charge.
- Limited energy and storage resources will be utilized if there is not enough energy from other resource types
- Conversely, storage resources can be charged when there is more energy than needed to meet load from other resource types.

MARS Overview -
Thermal Models

- Represent a plant(s) that utilize heat energy from different fuel sources (natural gas, LFG, coal, nuclear etc.) and converts it to electrical energy.

- Basic characteristics used for modeling are:
  - Capacity
  - Maintenance
  - Capacity States
  - Transitions Rates
  - Forced Outage Rates

- Basic characteristics <u>not</u> included in the model are:
  - Start-up Parameters
  - Heat Rates
  - Ramp Rates
  - Emissions
  - Market Prices: Fuel and Energy

MARS Overview -
Hourly Modifiers

- Represent intermittent renewables like solar and wind.
    - Each of the hourly modifiers have a specific net hourly load modification, either a typical week of 168-hour values or a yearly hourly profile of 8760 hours.
    - The load modification is subtracted from the hourly loads for a specified area; positive values decrease the load, and negative values increase the load.
    - Can be drawn from a probability distribution that can be linked to the load draw for the same hour.

MARS Overview -
Cogeneration Models

- Represent thermal models with associated hourly load demand.
- If the resource has available energy, associated demand will be met prior to adding additional margin to the system.
- Type 1 - System will back up cogeneration loads if cogeneration unit is not available.
- Type 2 - System will <u>not</u> back up cogeneration loads if cogeneration unit is not available.

MARS Overview -

Energy Limited Models

- Represent models whose operations may be restricted due to the availability of fuel.

- Type 1 - Thermal model with an energy probability distribution.
    - This unit type can be used to model a thermal unit whose operation may be restricted due to the unavailability of fuel, or a hydro unit with limited water availability.

- Type 2 - Model with specified capacity and available monthly/daily energy scheduled deterministically.
    - Typically used to model conventional hydro units for which the available water is assumed to be known with little or no uncertainty.

- Type 3 - Model with specified capacity and available monthly/daily energy scheduled as-needed.
    - To conserve fuel supply, resource will only be used to meet load when there is a negative margin based on the other resource types.

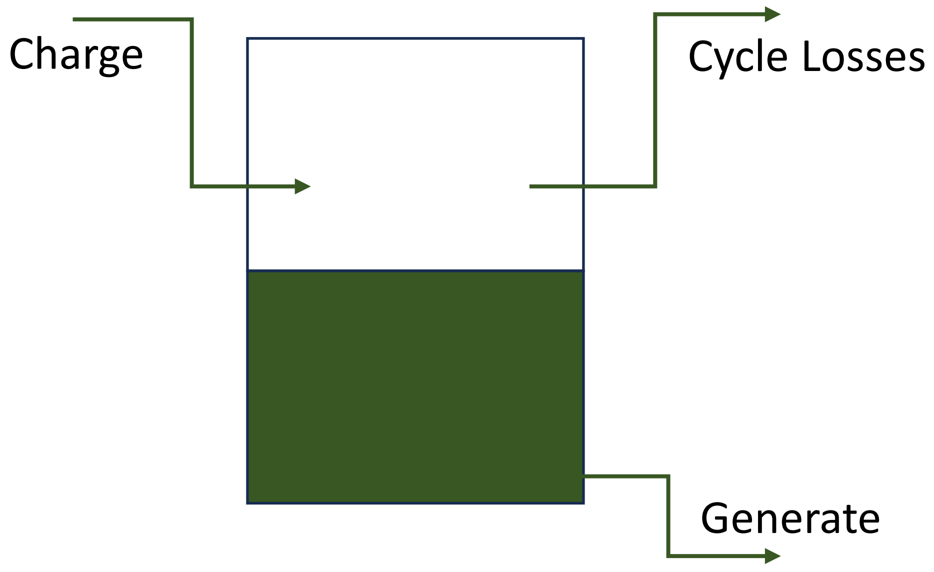
MARS Overview -

Energy Storage Models

- Represents resources that are operated by filling or charging energy into a reservoir or battery and drawing from that energy when there are shortages in the system.

- Like an Energy Limited Type 3 model but includes the ability to charge when there is a positive margin in the system and includes the losses associated with charge/discharge cycling.

- As a result, the model must track the resource’s state of charge for every hour and for every load forecast uncertainty level.

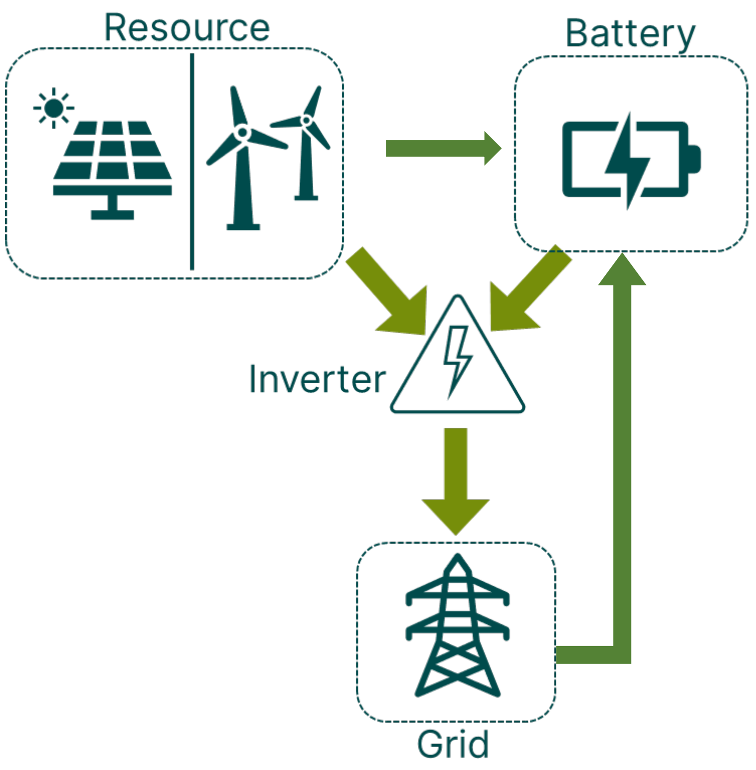


MARS Overview -
Hybrid Models

- Co-Located hybrid models simulate the combination of renewable generation and energy storage located behind the same inverter (connection point).

- Combines the shape-based generation of hourly modifier models with the as-needed generation and storage of energy storage models.

- Storage can charge from battery and/or grid and can include cycle losses.



MARS Overview -
Capacity Contracts

- Can be modeled as Type 2 energy limited models, as hourly modifiers, or as thermal models.

- User specifies:
  - Sending and receiving sub-areas.
  - Hourly contract profile or monthly energy targets.
  - Interchange path for delivery.

MARS Overview -
Energy Contracts

Firm Contracts

- Scheduled regardless of sending sub-area sufficiency, curtailed only due to interface limits.
- Included in isolated sub-area metrics.

Curtailable Contracts

- Scheduled only if sending sub-area has sufficient capacity or can receive them as emergency assistance from other sub-areas.
- If a sending sub-area's margin is negative after curtailable contract is scheduled, the contract will be curtailed in proportion to the sub-area's total shortfall.

MARS Overview -
Transmission

- MARS uses a zonal topology construct for transmission modeling. This is sometimes referred to as a “pipe and bubble” representation.
- A transportation model is used to determine if sub-areas with negative margins can be served by sub-areas having positive margins.
  - Constrained by the hourly/seasonal capacity transfer limits between sub-areas.
  - Sub-areas deficient in capacity will look for assistance by way of the shortest path possible.
  - No “Loss Sharing” is modeled.

Simulation Process -

Emergency Operating Procedures

- EOPs are steps taken as the reserve conditions on the system approach critical levels.

- May 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.

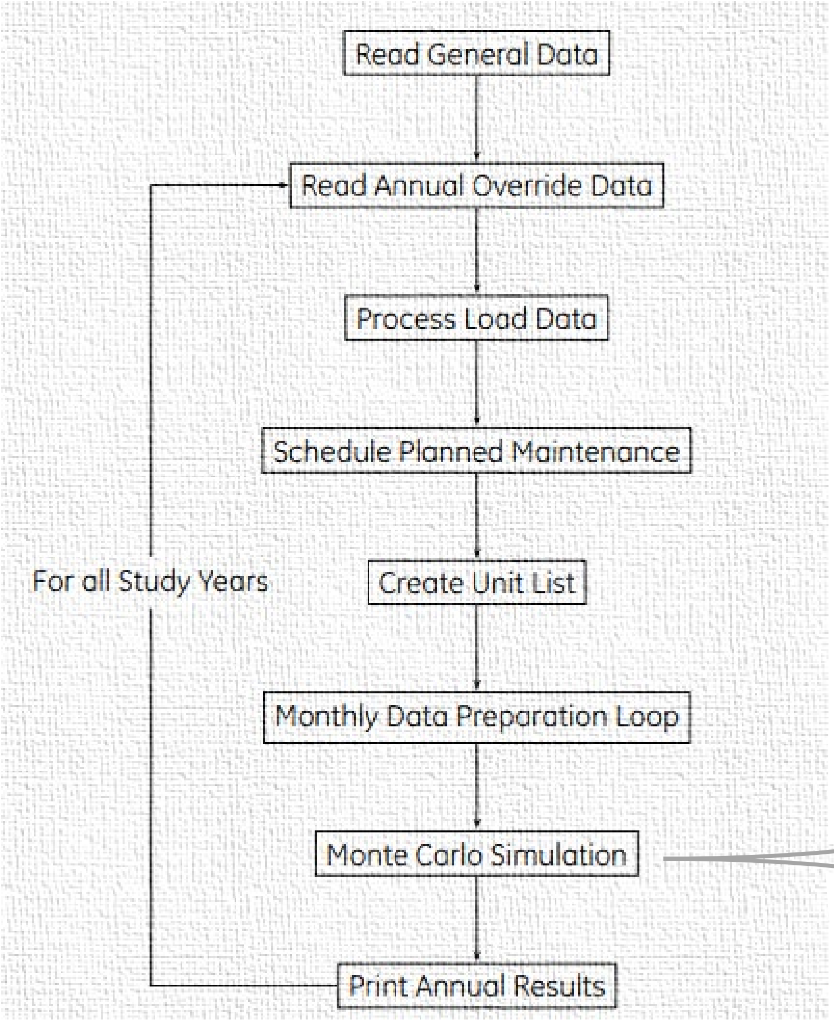
Reliability Indices -
Calculated

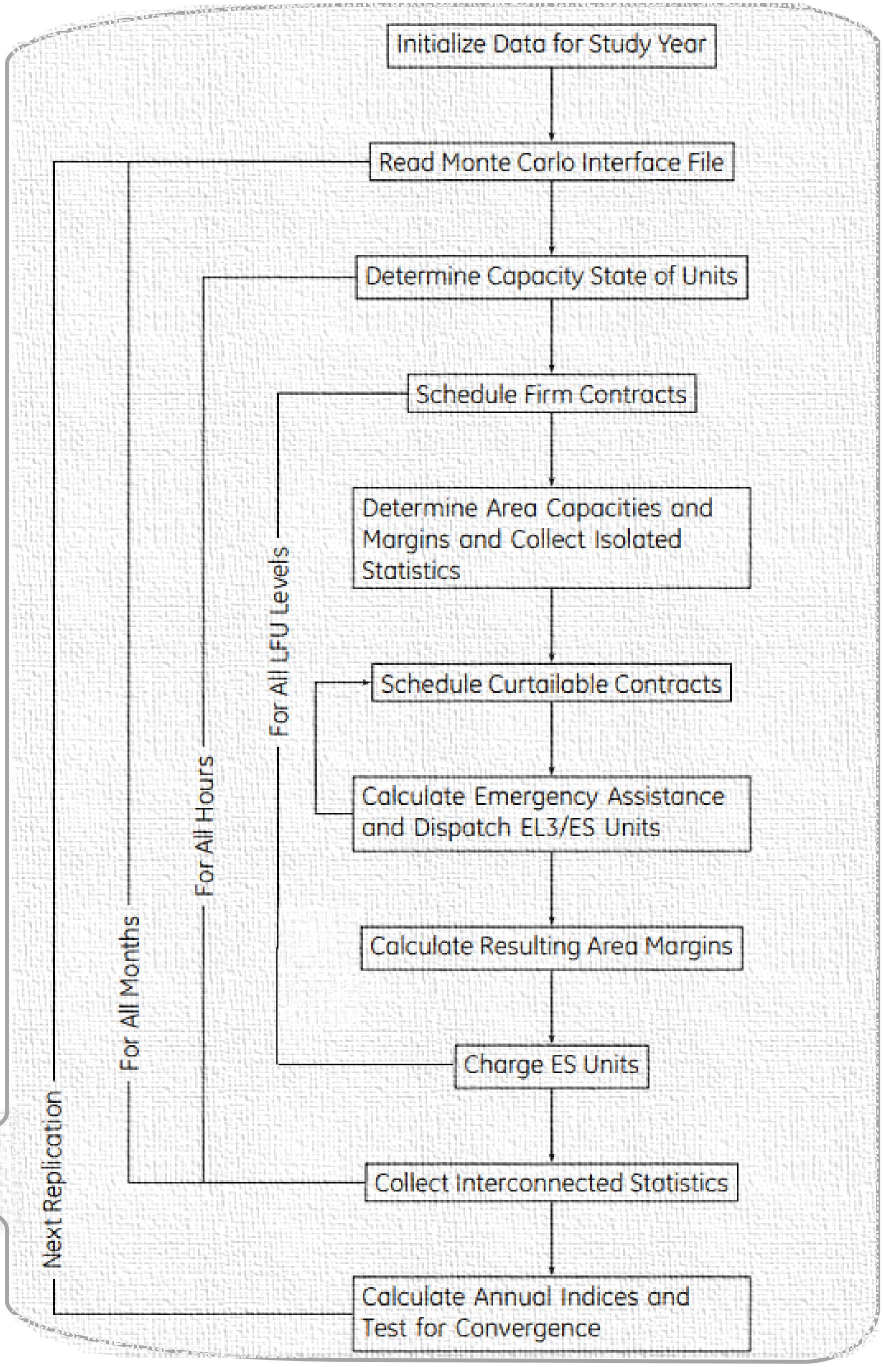
- Expected value and distribution of:
  - Daily Loss of Load Expectation (LOLE - days/year).
  - Hourly Loss of Load Expectation (LOLE - hours/year).
  - Loss of Energy Expectation/Expected Unserved Energy (LOEE/EUE - MWh/year).
  - Frequency (outages/year).
  - Duration (hours/outage).

- 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.

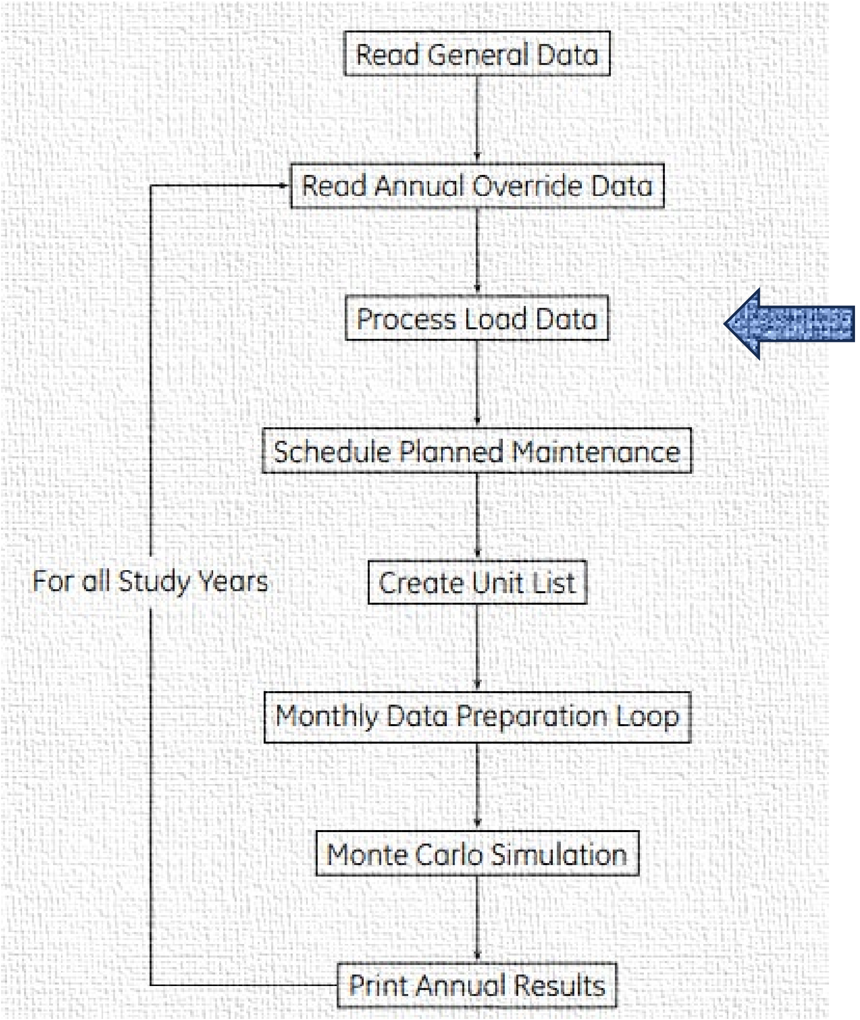
SIMULATION PROCESS

Simulation Process -
Overview



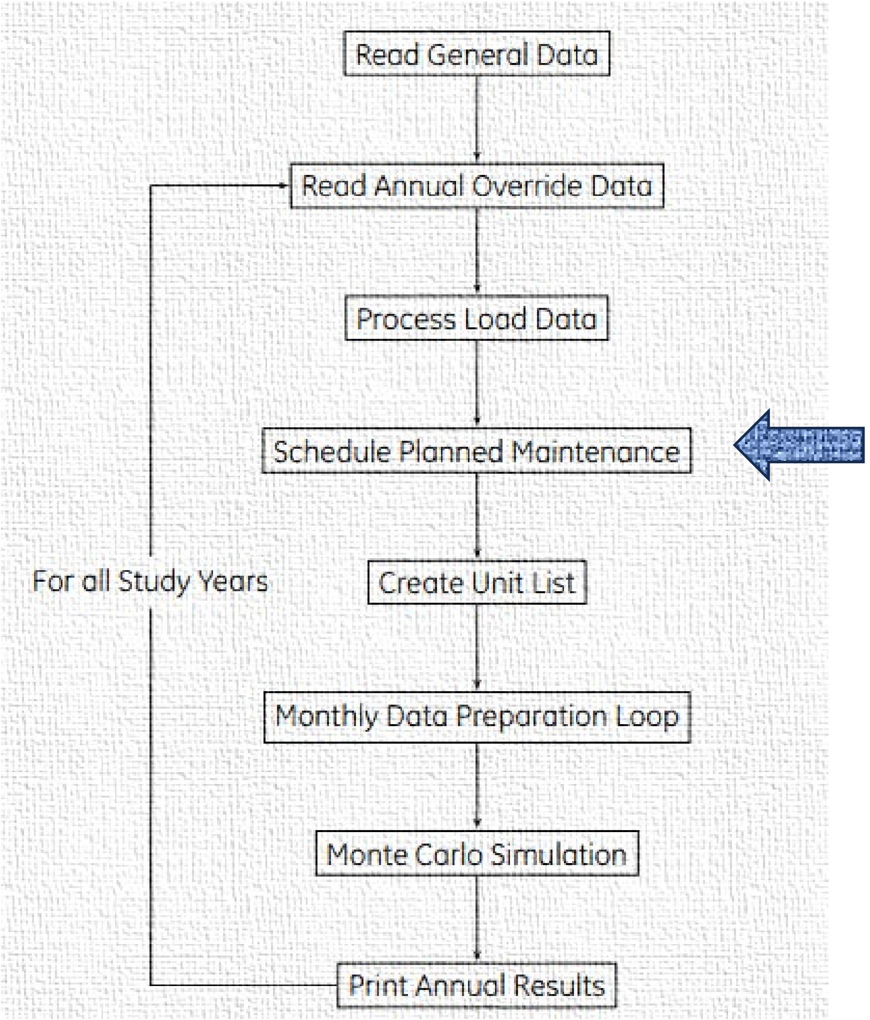


Simulation Process -
Load

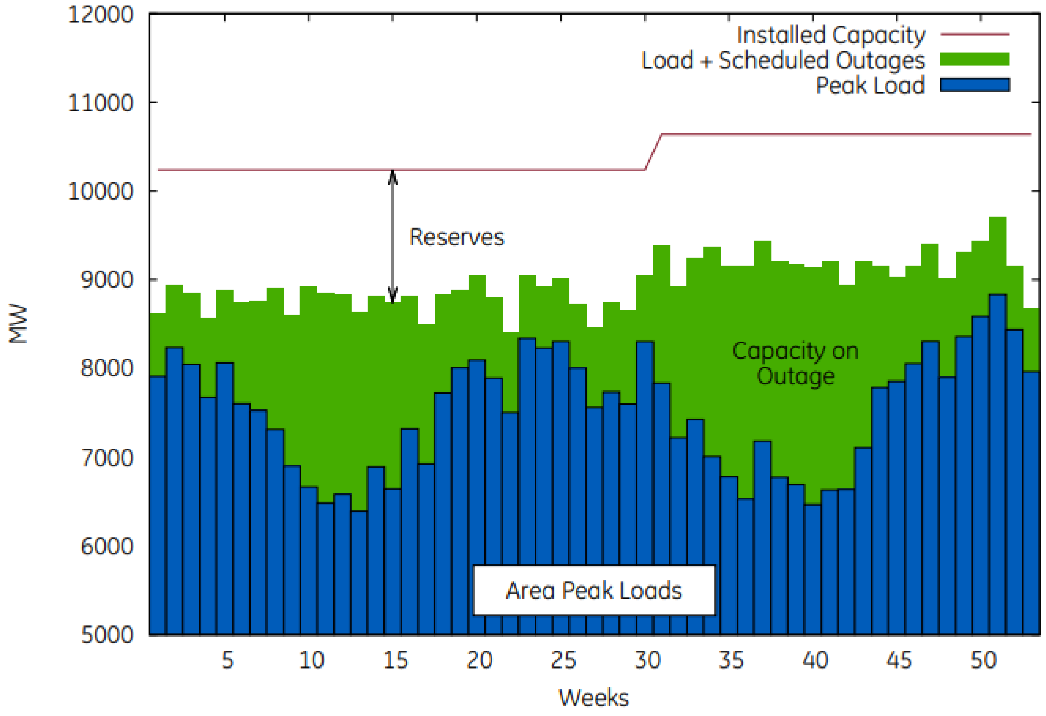


- Read hourly load file, if not specified, develop hourly load profile.

Simulation Process -
Maintenance Outages

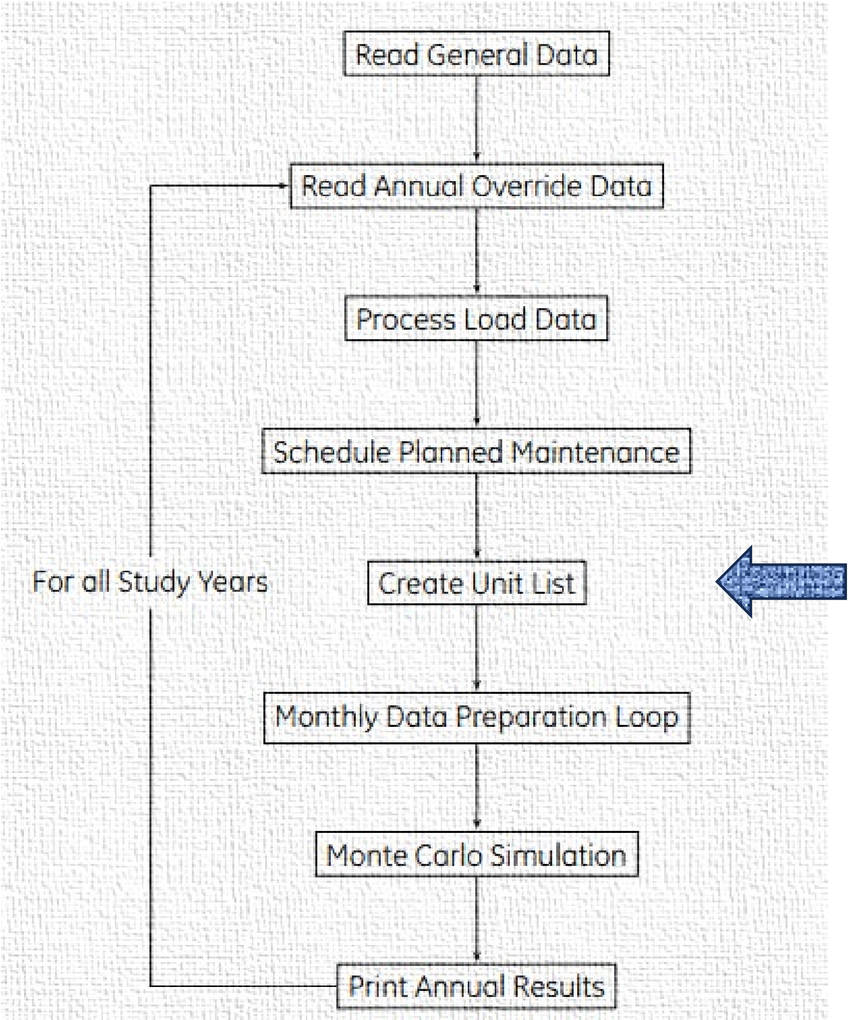


- Schedule planned outages to level weekly reserves, can be overridden by user.



Simulation Process -

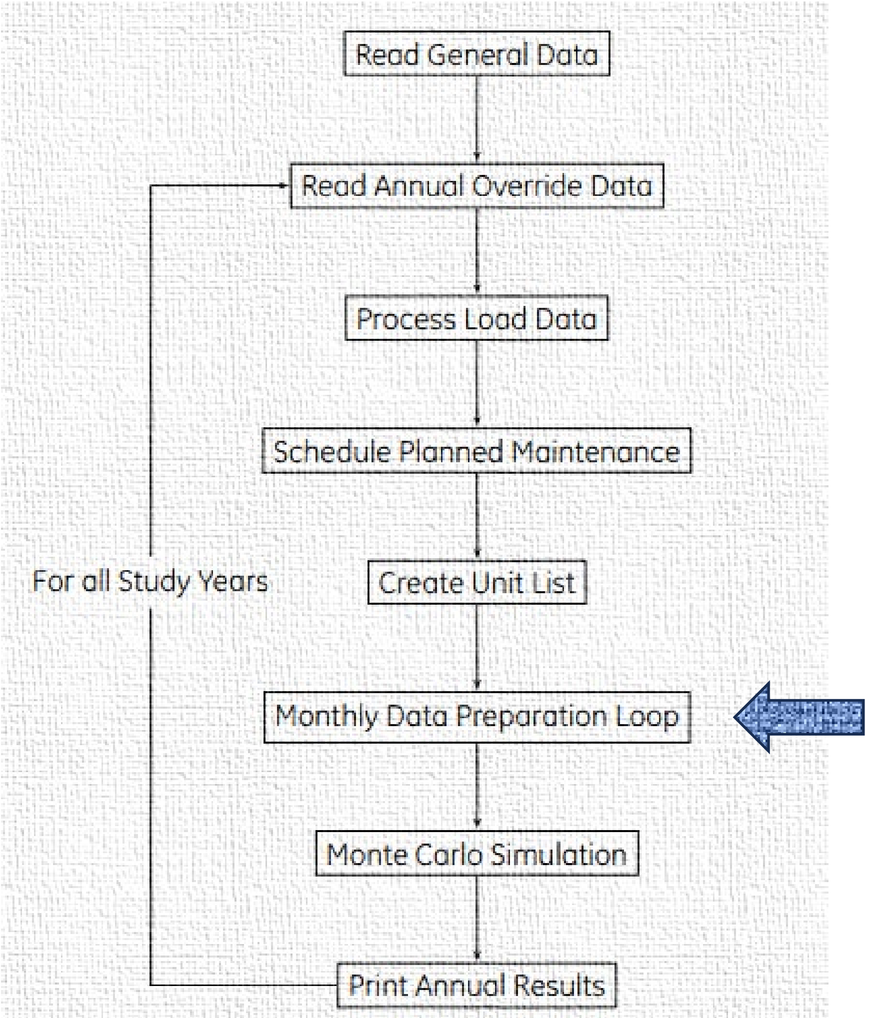
Create Unit List



- Determine which resources will modify loads, which resources will be modeled by the Monte Carlo simulation, and which resources will be used “as-needed” to mitigate negative margins.

- This list includes all units that are in service at some time during the year.

Simulation Process -
Monthly Data Preparation Loop

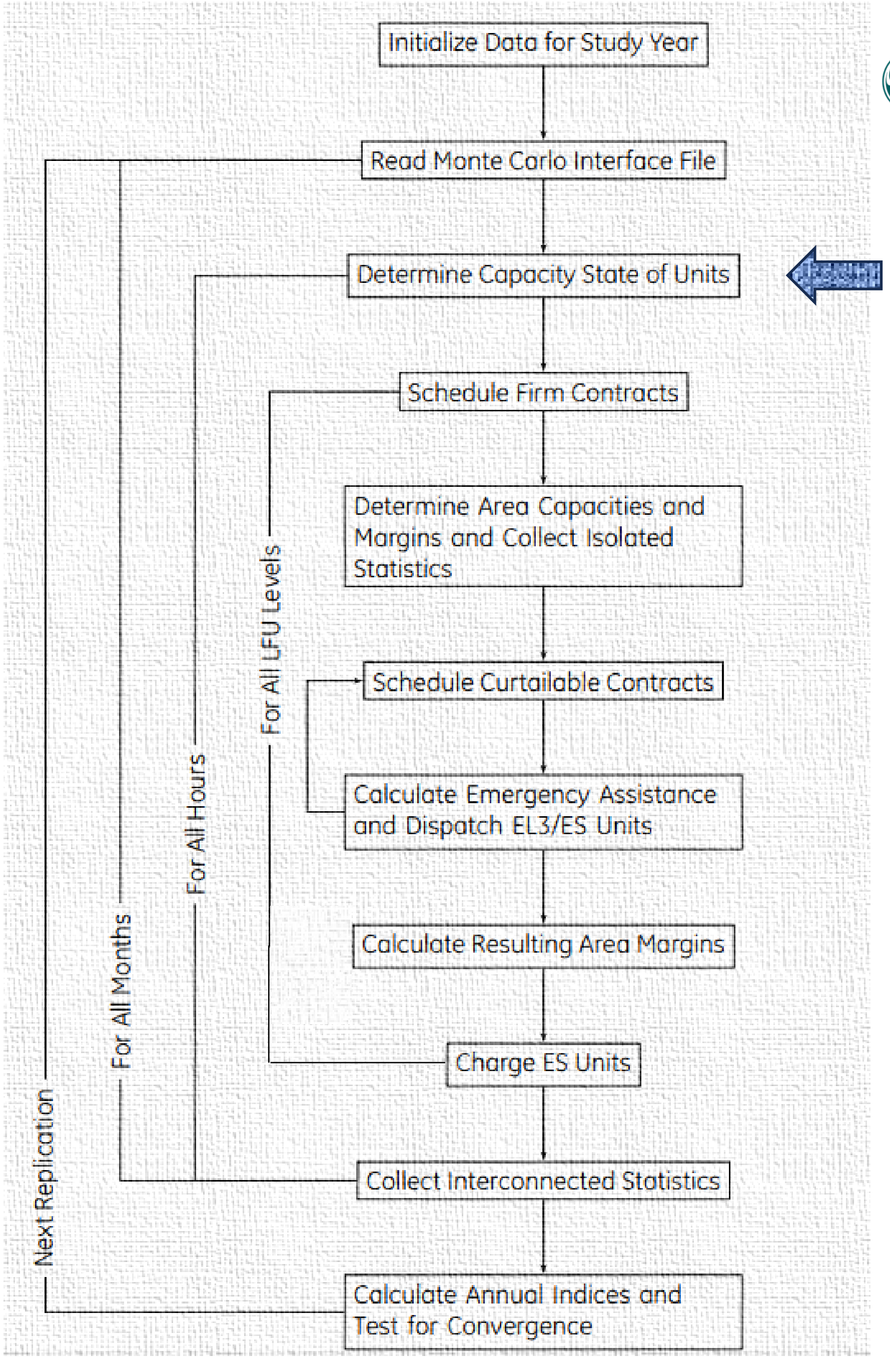


- Area loads are modified to account for the different types of units that are modeled as load modifiers. These Include:
  - Type 1 Cogeneration models
    - The demand portion of these resource modifies the load profile. The thermal availability portion of the resource will be determined during the Monte-Carlo simulation.
  - Type 2 Energy Limited models
    - Resources dispatched deterministically.
  - Hourly Modifier models
    - Includes the hourly modifier portion of hybrid models but the storage component will be used to remedy any negative margins at the end of the Monte-Carlo simulation.

Simulation Process -

Capacity State of Units

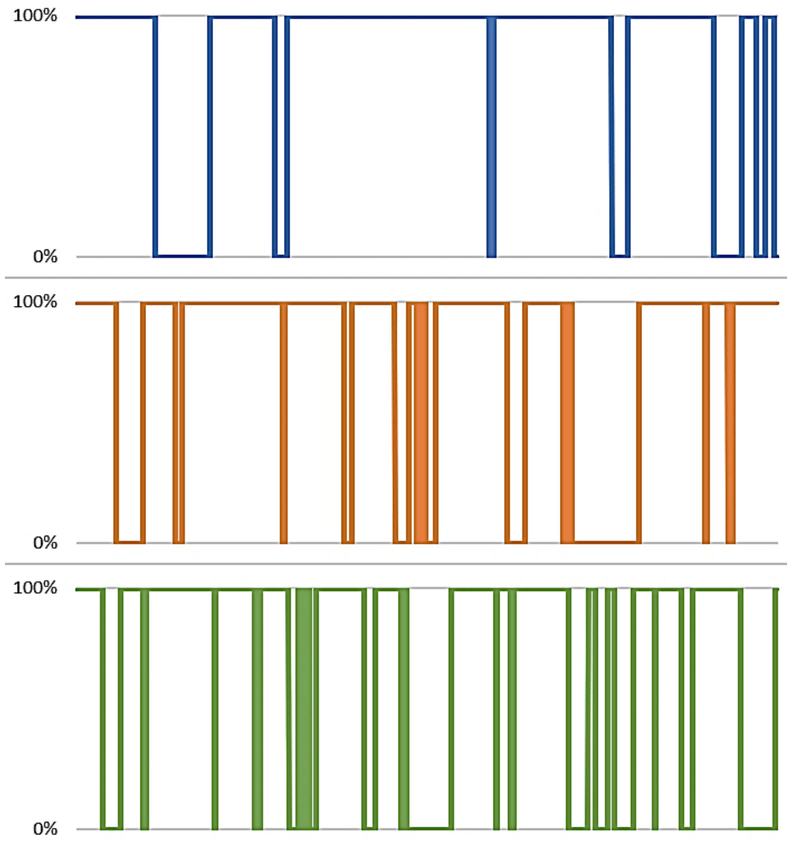
- Capacity states for resources not categorized in the “as needed” category are determined. These include:
  - Thermal Models
    - Includes the thermal portion of Type 1 Cogeneration models.
  - Type 2 Cogeneration Models
    - Capacity state of these models will be modified by that model's specific demand requirement.
  - Type 1 Energy Limited Models
- Based on initial capacity state of each unit and their transition rates.
- Operating histories are randomly generated for each unit in the system.



MARS Overview -

Forced Outages – Two-State

1. Determine the initial state of the unit
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

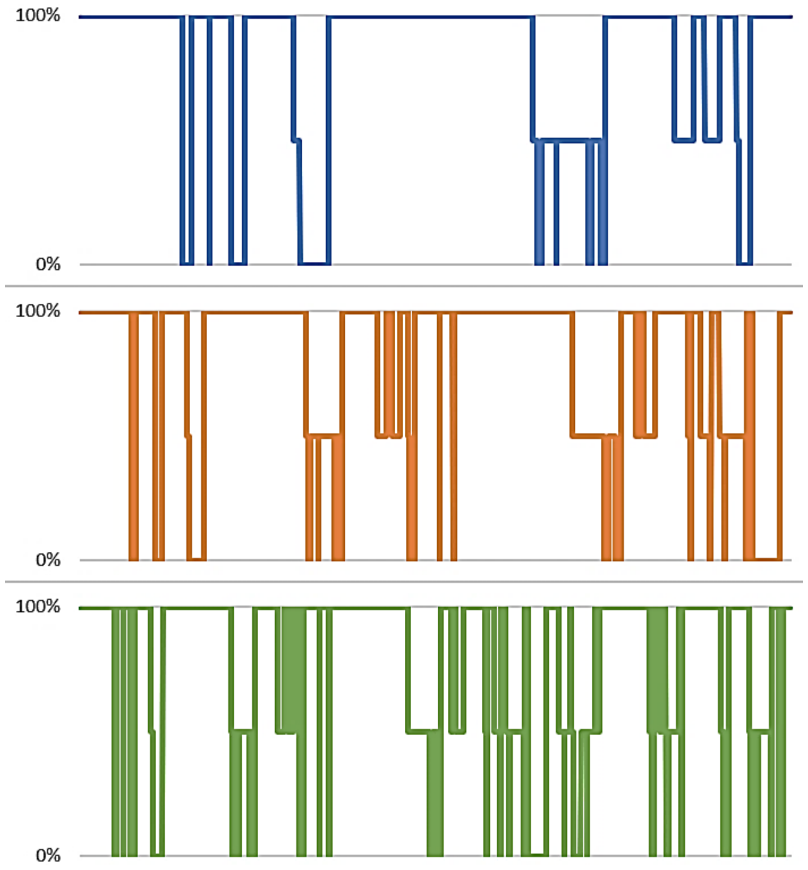


- Example shows three units sampled during one iteration or one unit iterated three times

MARS Overview -

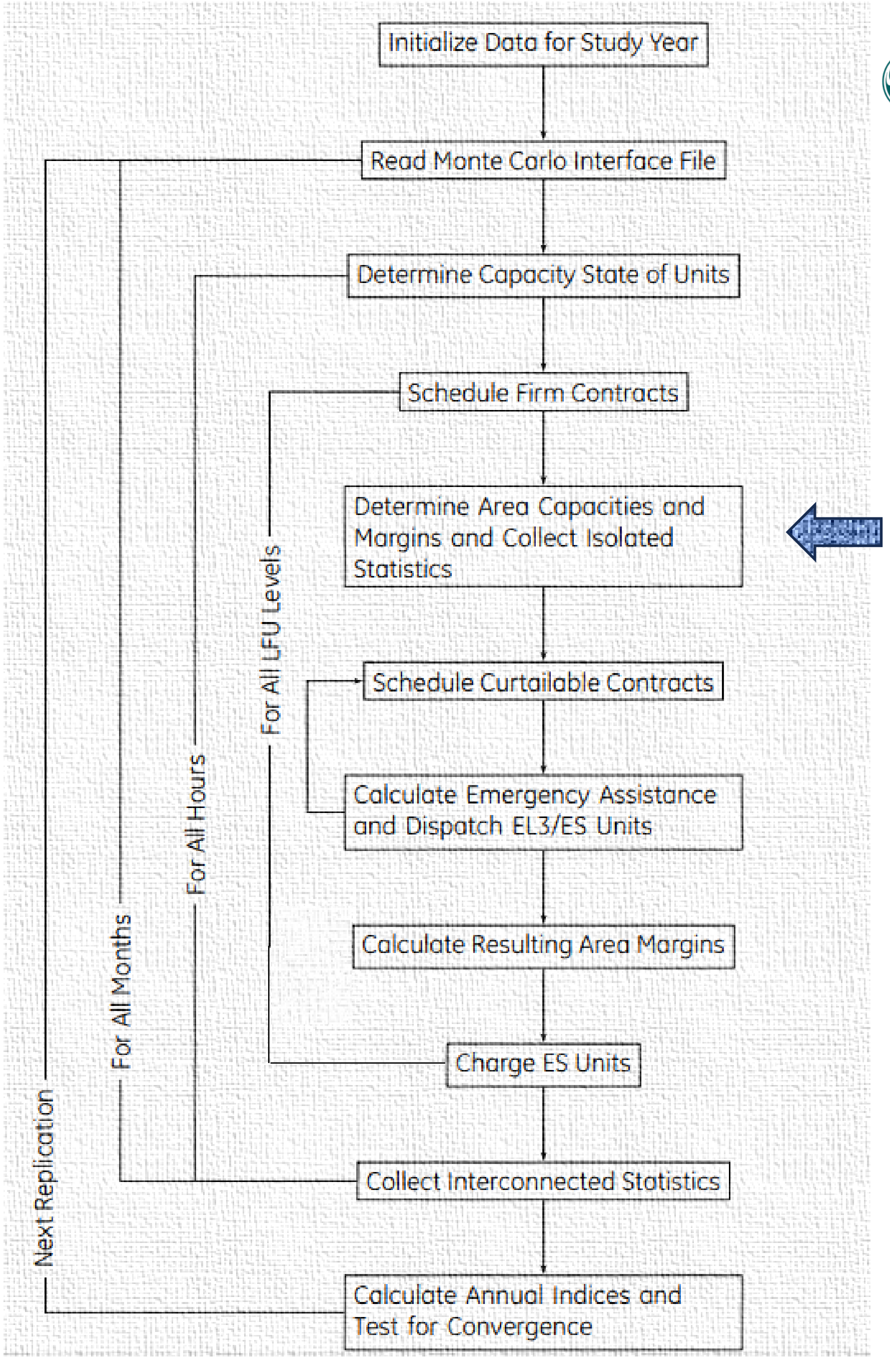
Forced Outages – Multi-State

1. Determine the initial state of the unit (state i)
2. Generate uniform random numbers in the range 0-1 for each state the unit may transition to (Ui,n, i ≠ n)
3. Determine the Time to Transition from the current state to each other state (TtTi,n) based on the transition rate Ti,n from the current state to each other state
4. $TtT_{i,n} = -\frac{1}{T_{i,n}} \ln(U_{i,n}) \quad for\ all\ n$
5. Transition to the next state after the shortest time to transition has elapsed
6. Go to step 2



Simulation Process -
Capacities, Margins, Statistics

- Model capacities are summed by sub-area.
- Load is subtracted from capacity to determine margin.
- Margins are adjusted to account for firm contracts.
- If margin is negative, statistics are captured for calculation of isolated indices.

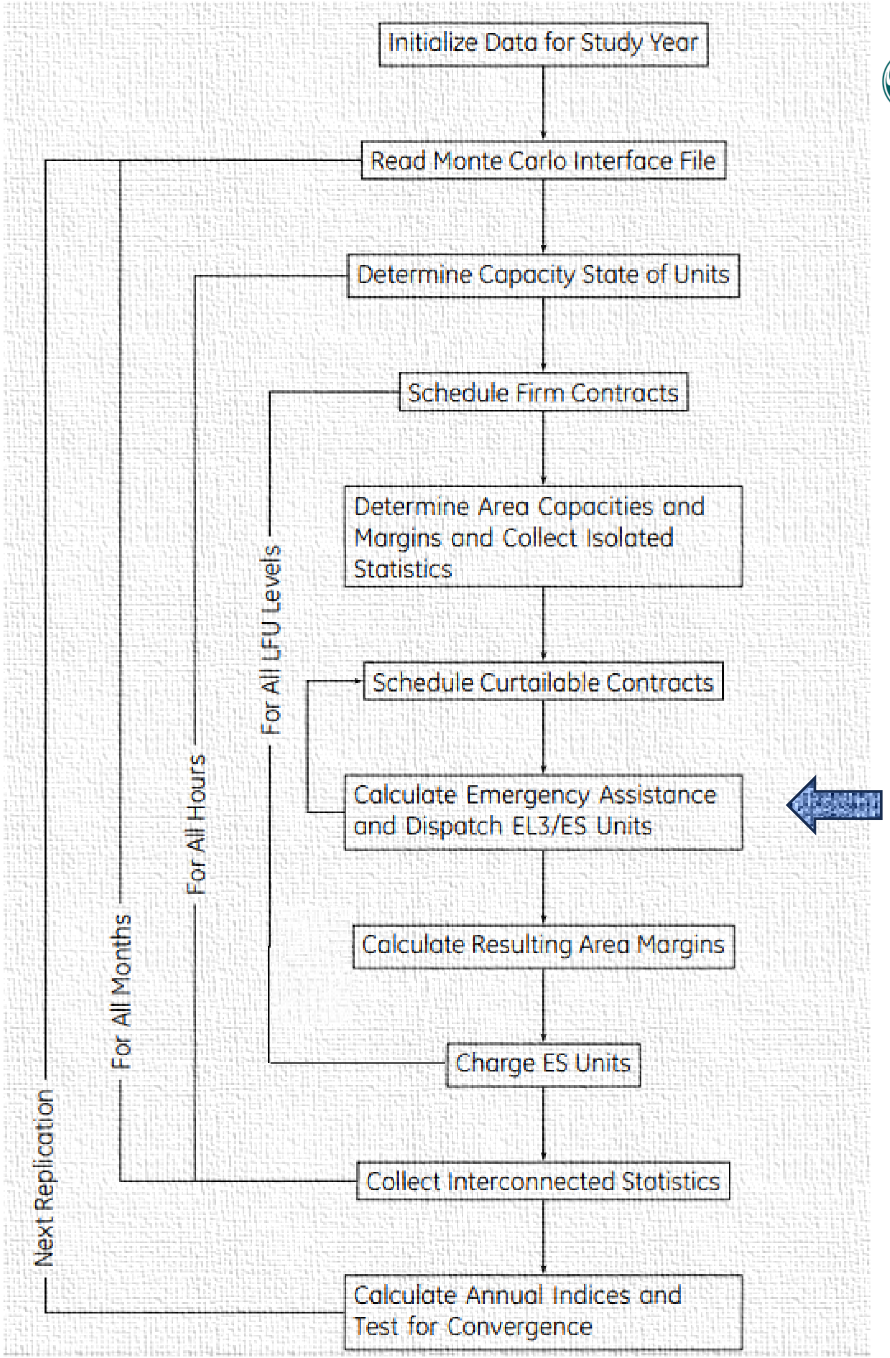


Simulation Process -
Remediation

- Utilize remaining “ as needed” resources to mitigate negative margins if energy inventory is available. These include:
    - Type 3 Energy Limited models
    - Energy Storage models
    - Storage component of Hybrid models

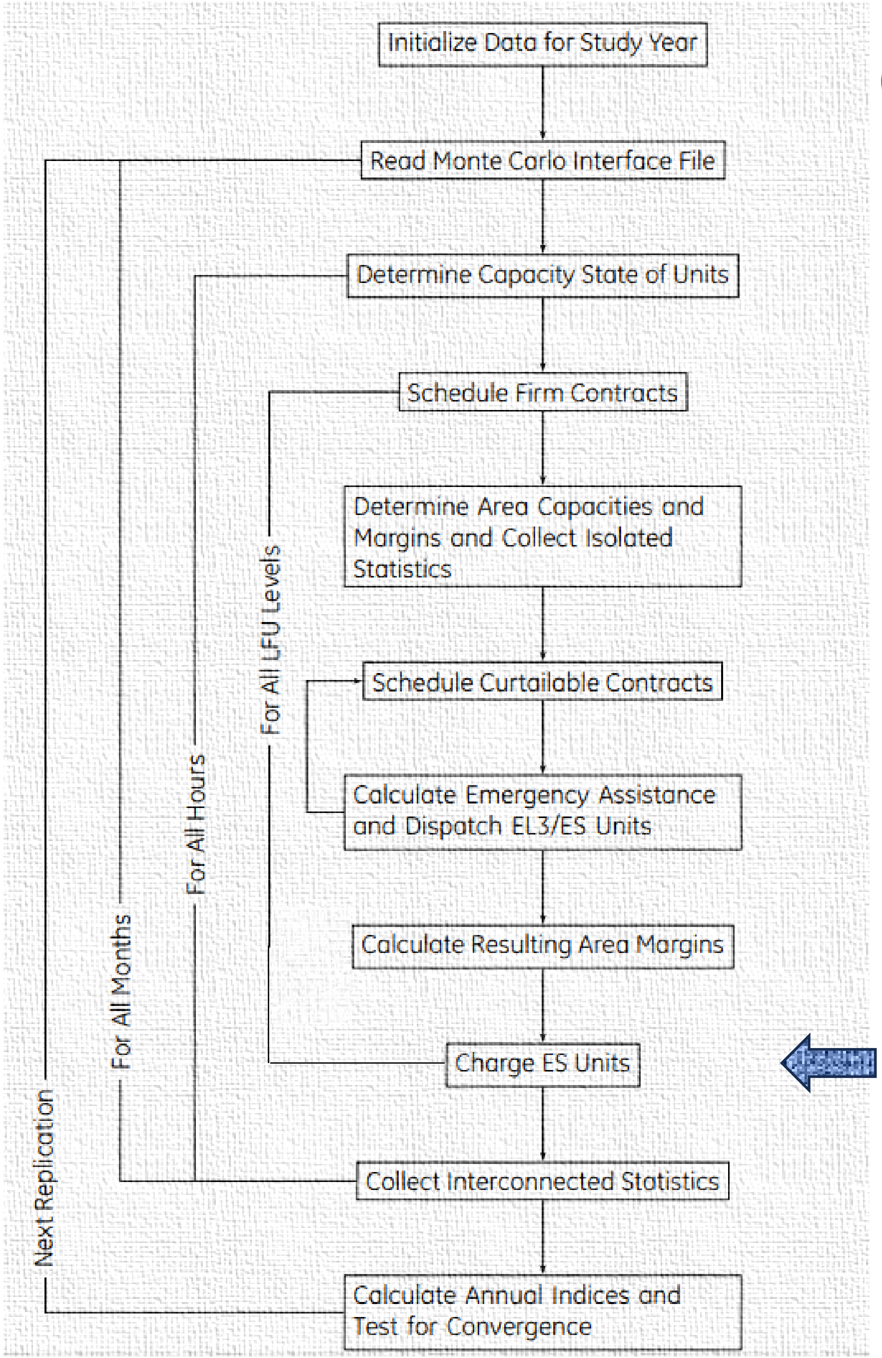
- If any area has a negative margin, calculate flows between areas and resulting area margins.

- Repeat for each Emergency Operating Procedure until all area's margins are positive, or a loss of load has occurred.



Simulation Process -
Energy Storage Models

- Energy storage models are charged for every load level modeled.
- Based on system conditions (positive margins) and state-of-charge of storage resources.
- State of charge is carried forward specific to each load level.



Simulation Process -

Annual Indices and Convergence

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

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

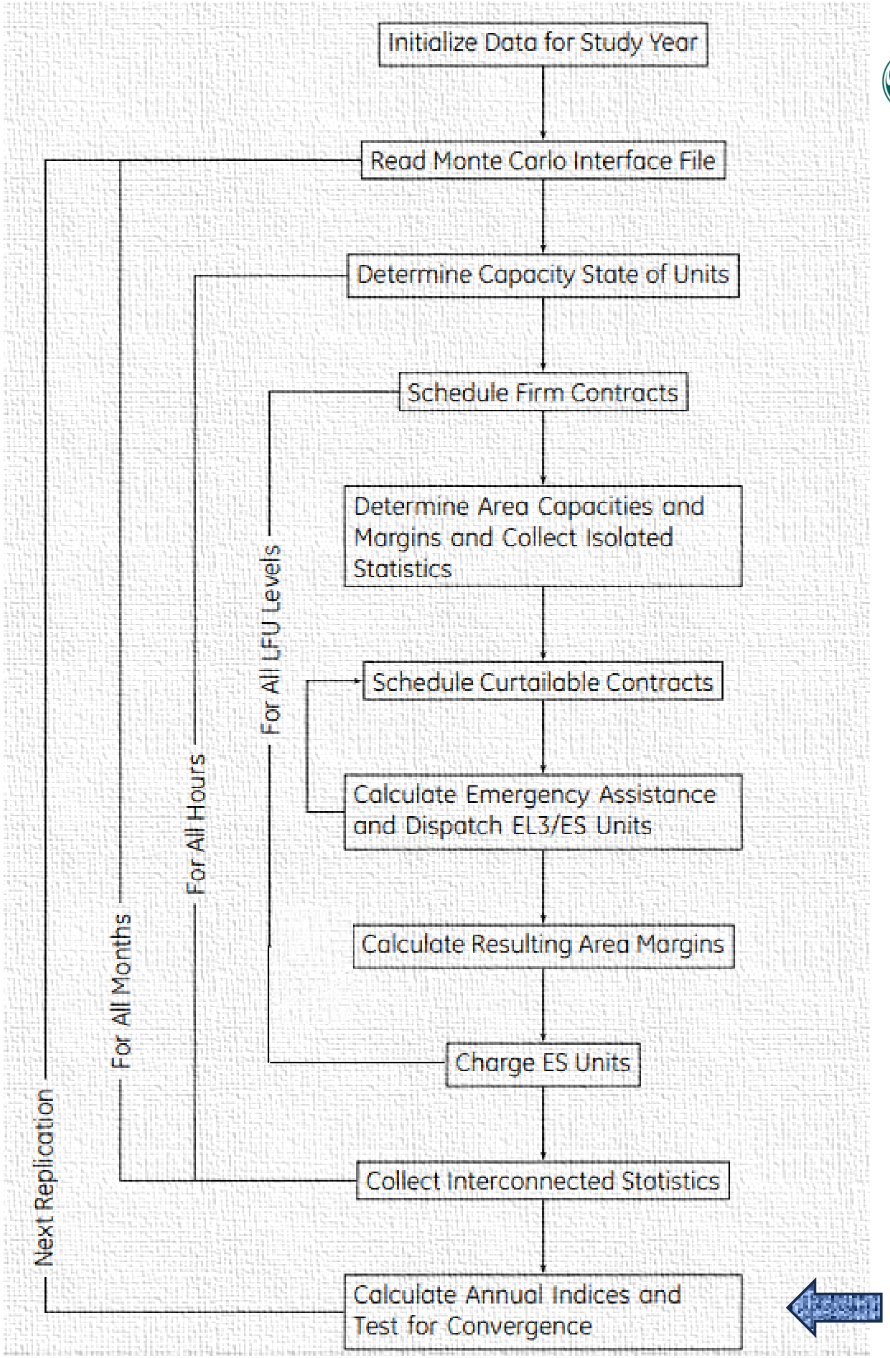
N = Number of times year has been simulated

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

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

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

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



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NEW ENHANCEMENTS

New Enhancements -

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- Added a co-located hybrid hourly modifier/energy storage type.
- Added the ability to group interfaces.
- Allow for interface limits to be modeled hourly.
- Allow for resource profiles to be correlated to load level.
- Added the ability to use multiple load shapes that can be randomly selected for areas.
- Added the ability to enable or disable dynamic conditions by load level.
- Added the ability to limit how effective energy limited and energy storage units are for different hours of a call.

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