PROBABILISTIC GRID RELIABILITY ANALYSIS WITH ENERGY STORAGE SYSTEMS (PROGRESS)

An Open-Source Tool for Assessing Reliability of the Electric Power Grid

Sandia National Laboratories

Exceptional service in the national interest

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Overview

- Motivation
- Background
- Key features of ProGRESS
- Example Workflow
- Distribution

Motivation

Energy storage systems (ESS) being widely deployed for **grid reliability and resilience** applications

- Mitigate short- and long-term variability of renewable resources
- Serve as backup power for critical infrastructure
- Mitigate outages during extreme weather events/extended periods of black-sky conditions

Modeling and integrating storage operation and failure characteristics crucial

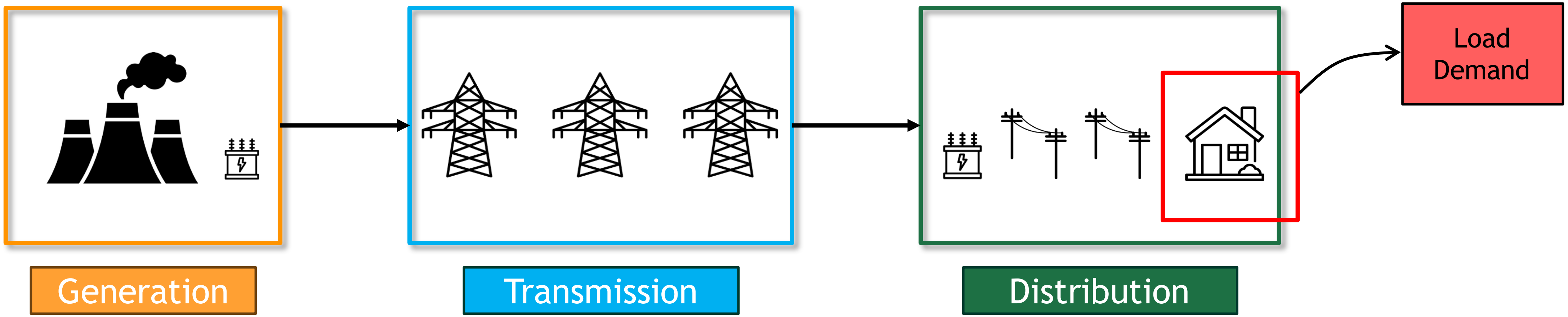
- Understand impact on grid reliability and resilience
- Plan effectively to achieve and maintain desired grid reliability levels

Objective: Develop **grid reliability assessment** tool with focus on

- ESS failure modeling
- capacity value/effective load carrying capability (ELCC) calculation of ESS
- sizing ESS for reliability applications
- valuation of ESS in enhancing grid reliability and resilience

BACKGROUND

What is Grid Reliability?



Definition: Reliability of a power system pertains to its ability to satisfy load demand under specified operating conditions and policies

Quantification: *Probability* and *frequency* of encountering failure states and the period of time system spends in failure states

Measure: *Loss of Load Probability (LOLP)*, *Loss of Load Expectation (LOLE)* in days/year, *Loss of Load Frequency (LOLF)* in failures/year, *Expected Unserved Energy (EUE)* in MWh/year

What is Grid Reliability?

- Transitions in system not deterministic, can only be predicted with a certain probability – **random process**
- System components have random behavior – modeled using random variables
- **Modeling considerations:** components, dependencies of components, representation of power system such as *power flow models*, *operating constraints*, *policies* and *contracts*

Thermal Generators

- Two- or multi-state models
- Maximum and minimum capacity ratings
- Fuel availability
- Fixed or variable forced outage rates

Transmission Lines

- Copper sheet/zonal/nodal models
- Fixed or time-varying limits
- Line outages considered for zonal/nodal models

Energy Storage & Renewables

- Multi-state model for energy storage and renewable resources
- Operational dynamics of storage with SOC and other constraints
- Specific models for wind and solar based on their inherent characteristics

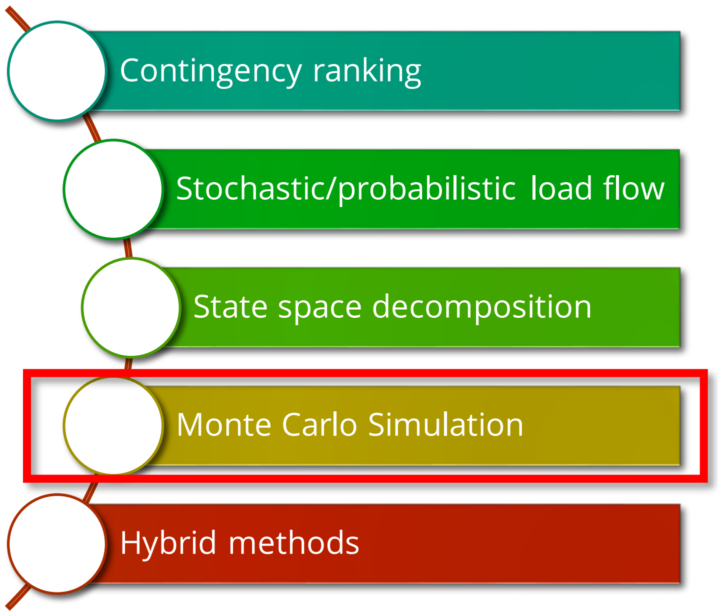


Figure: Methods used for large power systems

KEY FEATURES

Stochastic Monte Carlo Engine

The Probabilistic Grid Reliability Analysis with Energy Storage Systems (ProGRESS) software tool is a Python-based open-source tool for assessing the reliability of the evolving electric power grid integrated with energy storage systems (ESS).

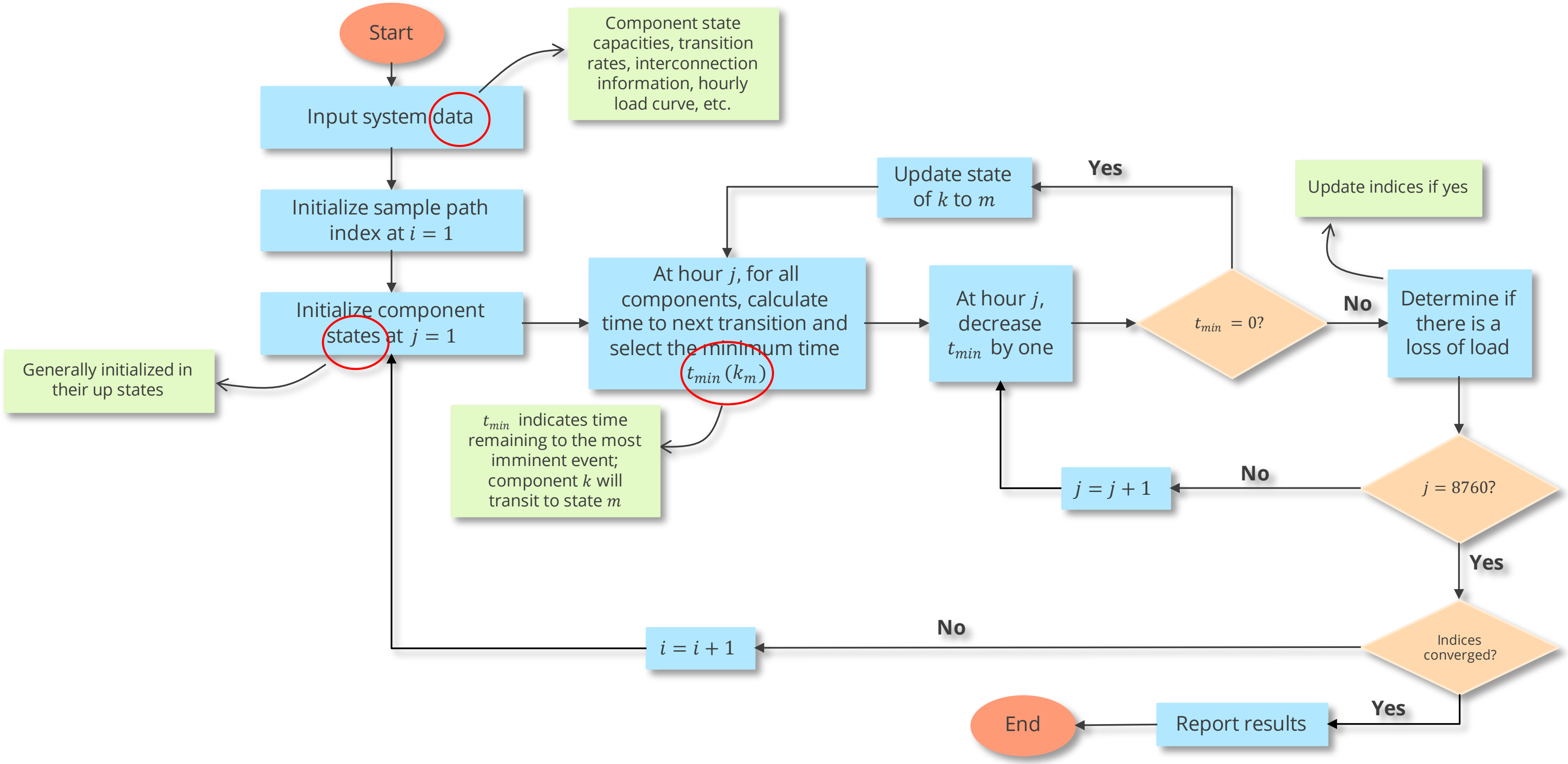


Figure: Mixed-time sequential Monte Carlo simulation algorithm

- ✓ Generate samples (scenarios) with diverse weather conditions, component failures
- ✓ Sequential time-series model, enable integration of energy storage systems smooth
- ✓ Each sample is one year long (8760 hours)
- ✓ Users can choose how many samples they want to run

Enhanced Renewable Energy Modeling

Solar Data

Solar weather data (DNI, GHI, DHI, etc.) downloaded from NSRDB using API

↓

Converted to solar power generation data using pvlib library

↓

In-built algorithm used to cluster generation data into similar days

↓

MCS engine picks days at random depending on the month

Wind Data

Wind speed data downloaded from WIND Toolkit using API

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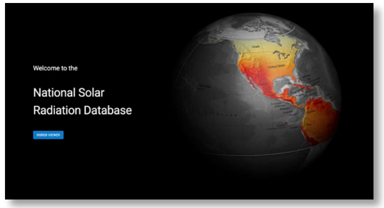
Transition rate matrix developed

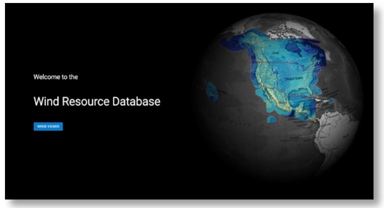
↓

Wind speed for next hour predicted

↓

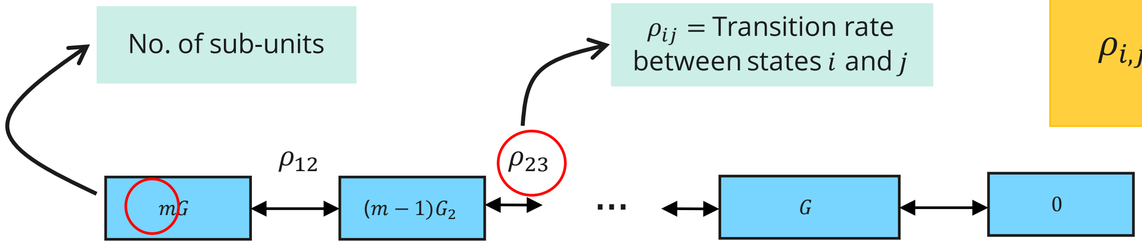
Wind speed converted to wind power generation





Energy Storage Modeling

- All ESS are li-ion batteries
- Each ESS is made up of several sub-units
- Each sub-unit could be either a 20- or 40- feet long container housing a 2.5 MWh or 5 MWh sub-unit respectively[1, 2]
- It is assumed that a sub-unit is the smallest unit that can fail
- ESS operates at derated state when one/more sub-unit faces outage
- Multi-state model of ESS developed
- *Operation*: ESS discharge only when there is a shortfall of generation; charge at all other times until they reach max SOC



$$\rho_{i,j} = \frac{N_{i,j}^{t}}{D_i}$$

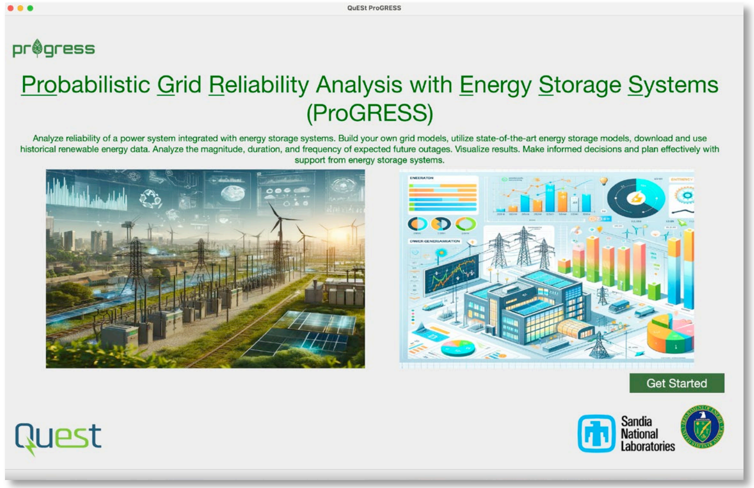
1. SAFT's 2.5 MWh ESS containers
2. 1 MW/2.5 MWh Energy Storage System

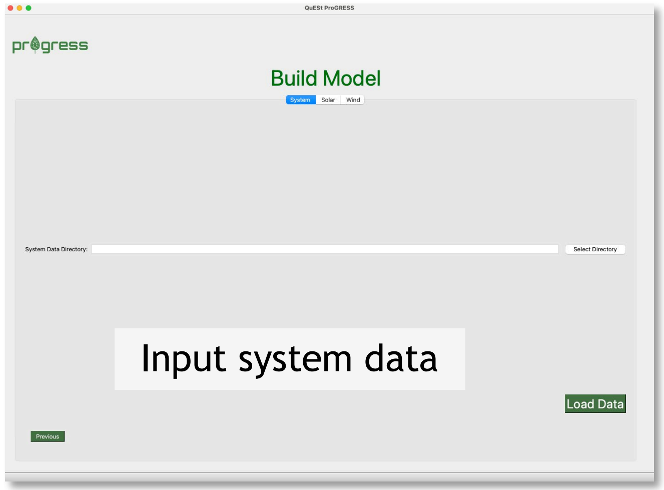
Other Key Features

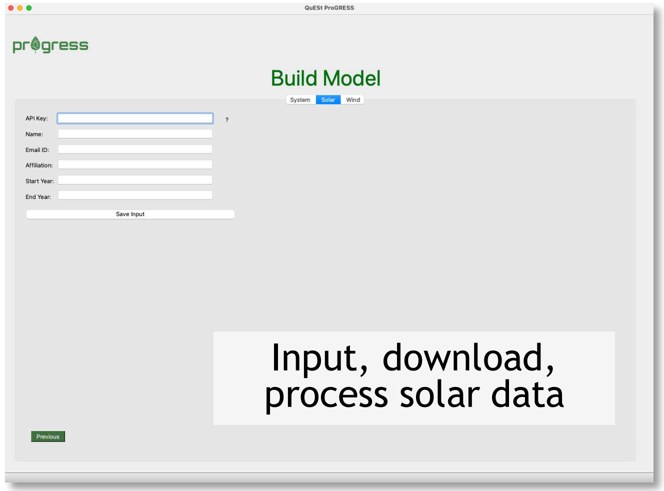
Feature	Description
Modular Structure	ProGRESS developed using Object-Oriented Programming (OOP) structure with a modular design – enables users to easily modify backend programs and meet specific requirements
Model Flexibility	Power systems can be represented using a transportation or a copper-sheet model
User-friendly GUI	Interactive Graphical User Interface (GUI) simplifies the process of input data upload, model building, and results interpretation
Parallel Programming	Modules provided for parallel programming, allowing users with access to high-performance computing resources to run longer simulations with larger systems for more accurate results
Data Input	Data can be input using csv files. Standard data formats following IEEE test cases is used.

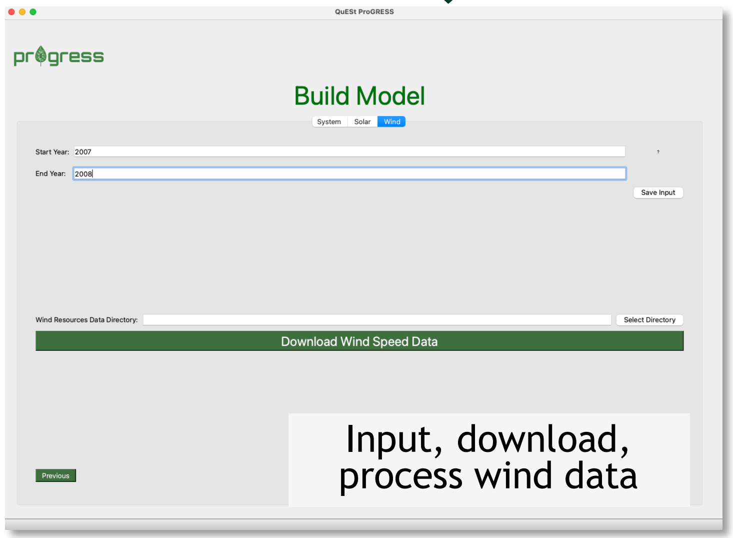
WORKFLOW

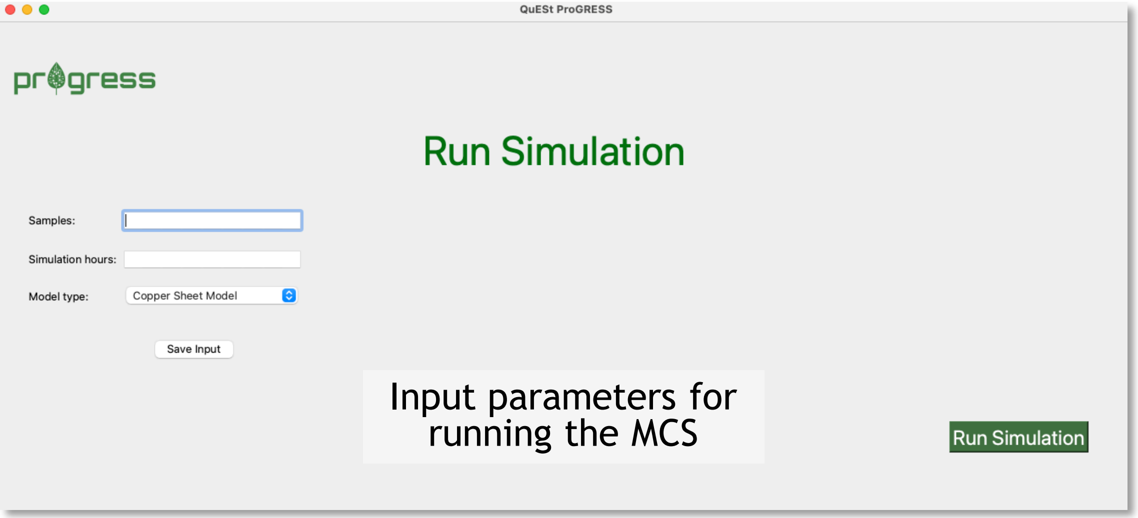
Workflow with GUI



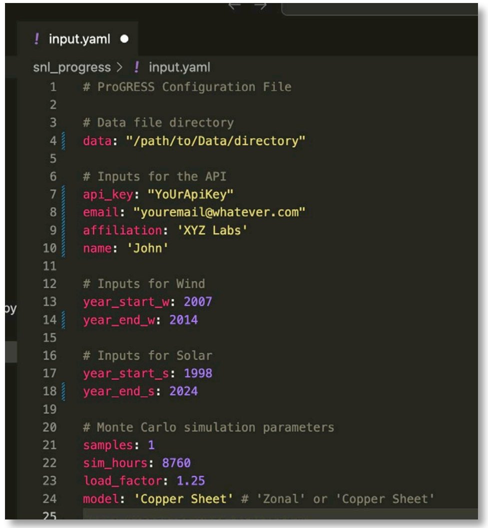




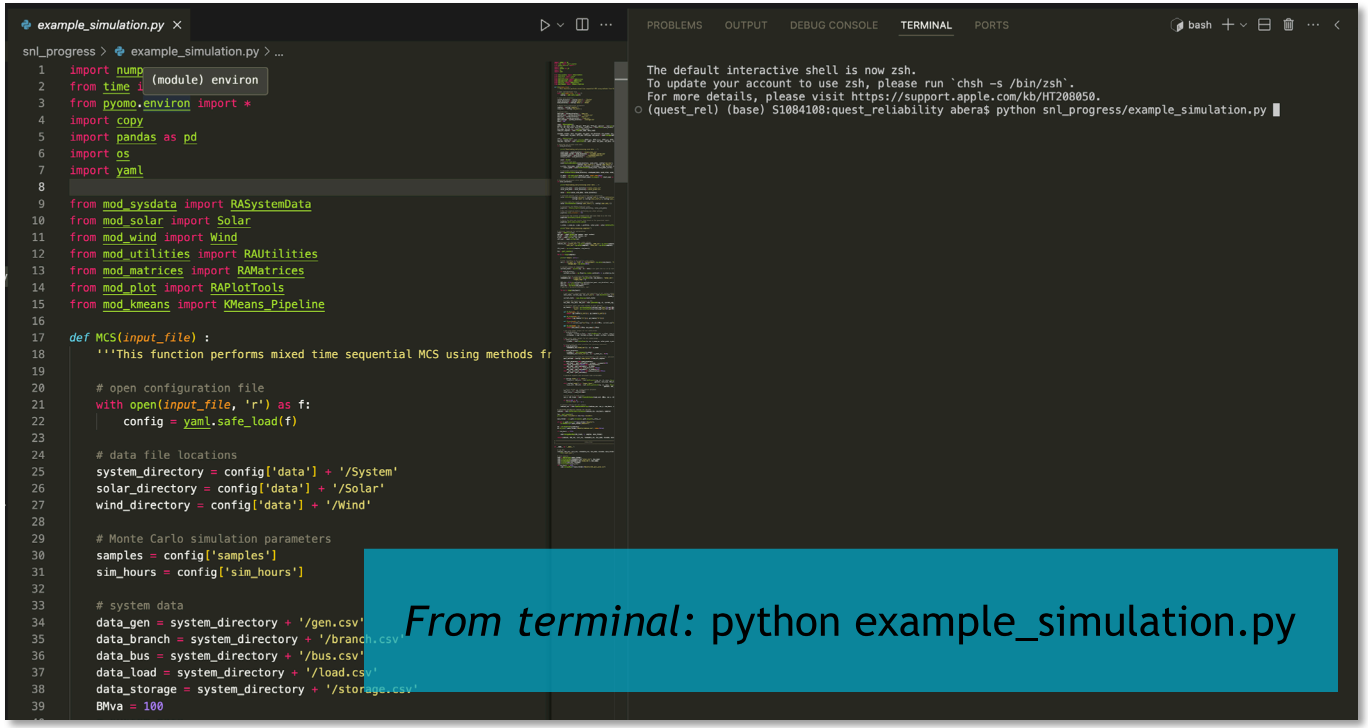




Workflow without GUI



Configure inputs using .yaml file



From terminal: python example_simulation.py

ProGRESS allows **Parallel Processing using High Performance Computers (HPC)** with the 'mpi4py' library. Example scripts and bash files for running jobs are available in the repository with detailed instructions.

Example Results

Quantification of System Reliability

Index	Description
LOLP	Loss of Load Probability
LOLE	Loss of Load Expectation
MDT	Mean Down Time
nEUE	normalized Expected Unserved Energy
EPNS	Expected Power Not Served
LOLF	Loss of Load Frequency

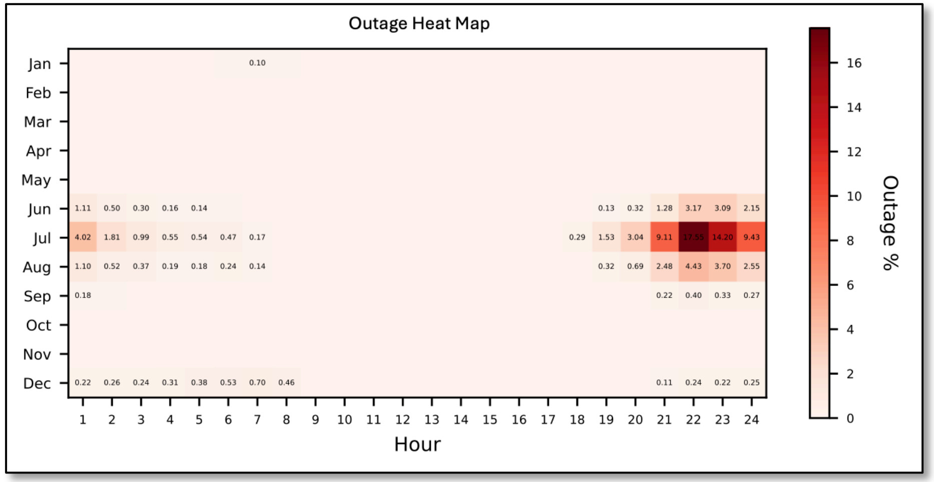
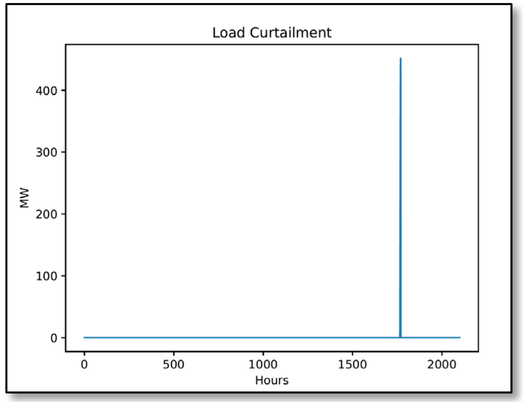
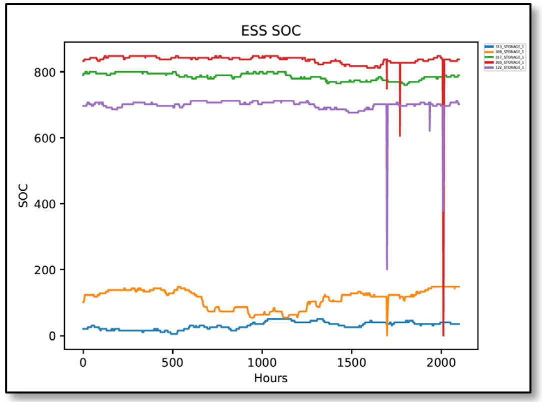
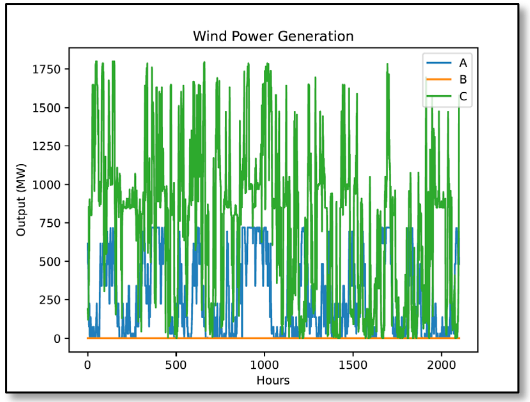
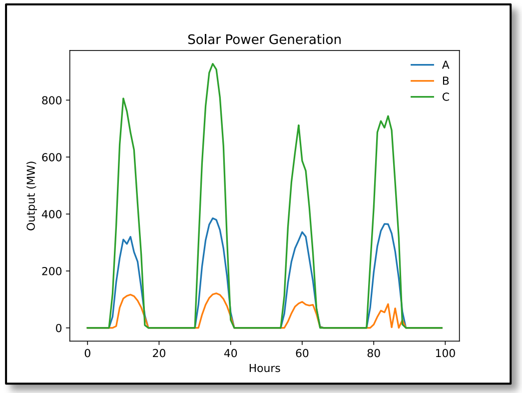


Figure: Distribution of Outages







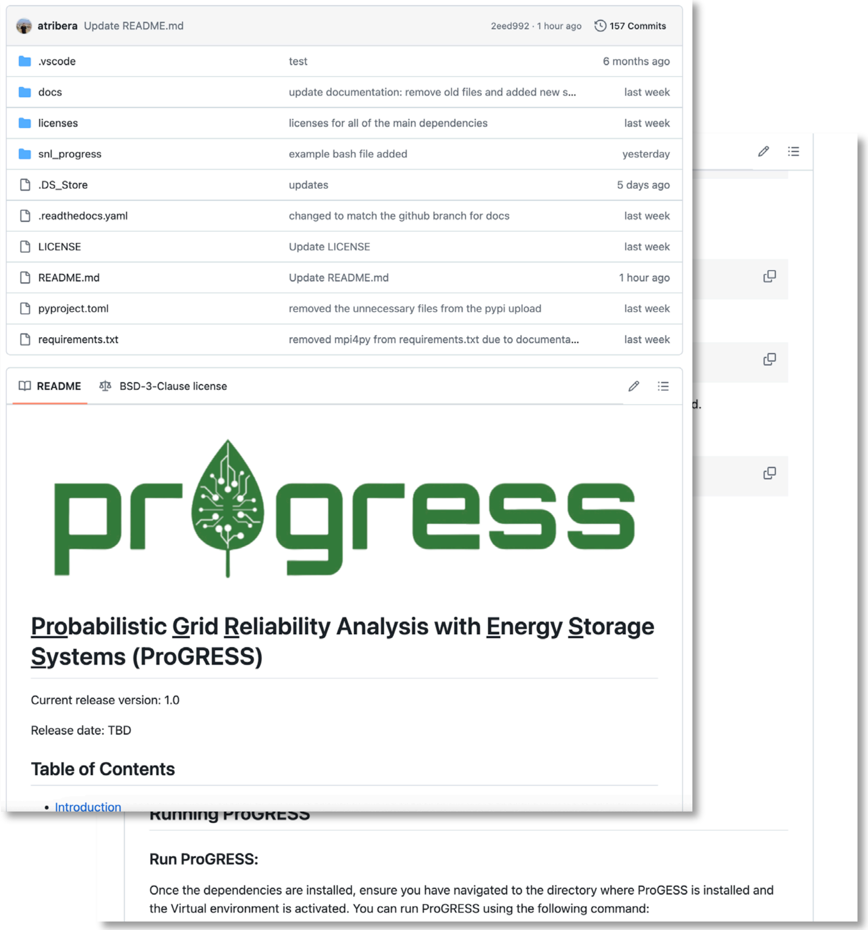


In-depth Analysis

DISTRIBUTION

Distribution & Documentation

- Available on GitHub
- Available via QuESt 2.0 platform
- Available on pypi, can be pip installed
- Executable version (.exe file) to be released soon
- Documentation available on GitHub, readthedocs.io



Quest | python Package Index | GitHub | Read the Docs

Development Timeline and Future Work

FY23

- Code development started

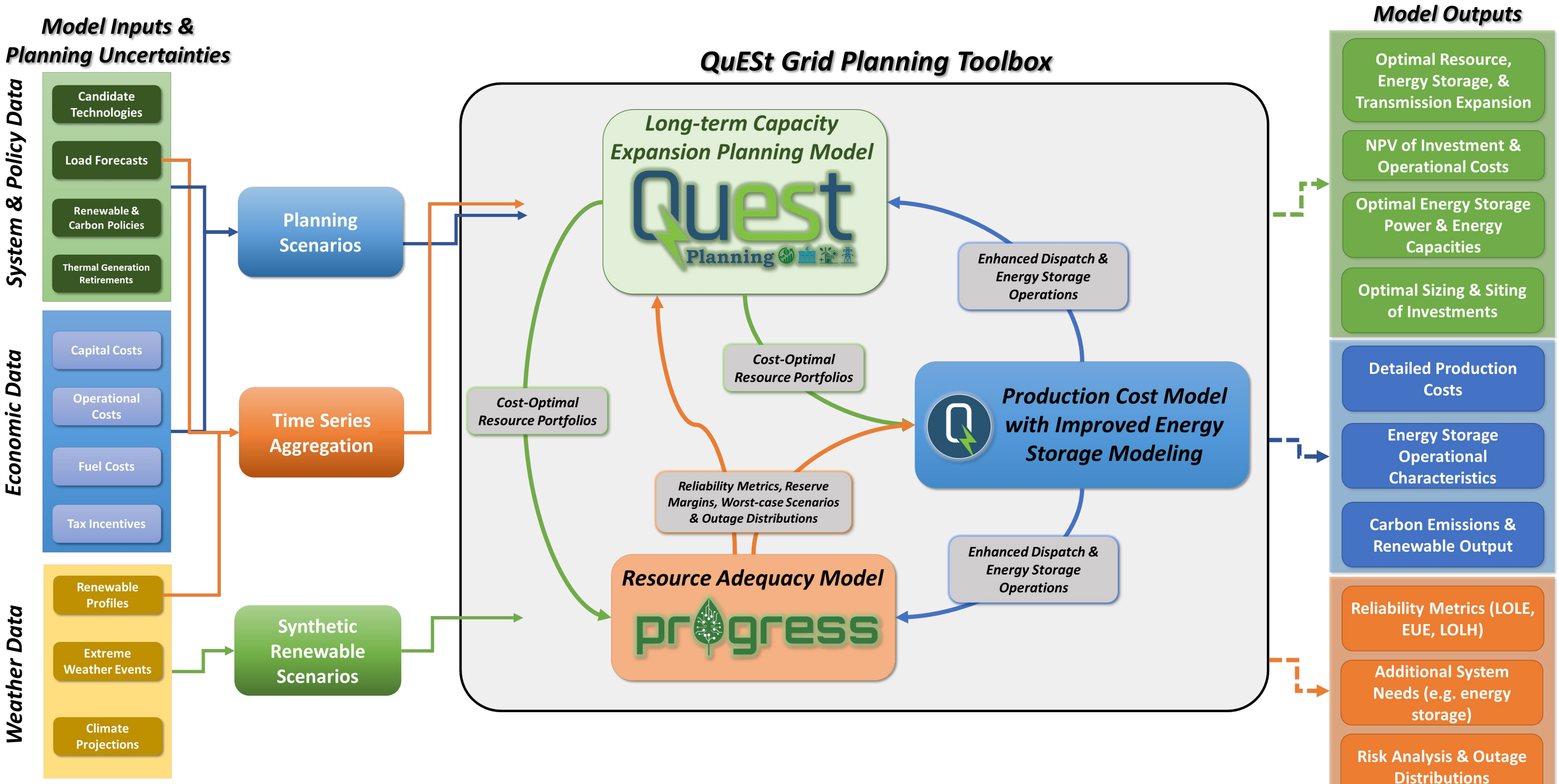
FY24

- Backend with stochastic MCS engine completed, GUI developed
- ESS multi-state failure model integrated
- Tool tested with Public Service Company of New Mexico (PNM) data
- **Accomplishments:** Release v1.0, paper at SPEEDAM 2024, EESAT 2024 abstract accepted, panel presentation at 2024 IEEE PES General Meeting, invited talk at IEEE P762 standards meeting

Future Work

- Integrate models for valuation and sizing of ESS, including LDES, for reliability and resilience applications
- Enhanced ESS failure models—factors behind failure, optimize model with real-world data, new technologies
- Improve MCS engine for more efficient ESS ELCC calculations
- Advanced renewable energy scenario generation with data-driven Generative Adversarial Network—capture impact of extreme weather and extended black-sky conditions on LDES sizing

Grid Planning Tool Suite



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Thank You!

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