SIMULACIÓN GRÁFICA_SGF1

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# SG1_Team2

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Github repository: https://github.com/DavidCT9/Green_Grid_Simulation.git

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**Abstract**

This project demonstrates the ability to use Python and SimPy to generate a Digital Twin simulation of a residential energy system with solar panels. Under erratic environmental and behavioral conditions, the system mimics the dynamic interactions among solar generation, battery storage, household load consumption, inverter limitations, and grid exchange. The simulation makes it possible to use multiple energy management techniques and their effects on financial results, reliability and technical performance. The digital twin offers a useful framework for evaluating smart home energy systems and as a basis for upcoming machine learning integration by including realistic constraints like inverter clipping, round-trip efficiency, cloud coverage variation, and unpredictable load spikes.

**Introduction**

The integration of renewable energy into residential systems contains a significant amount of challenges due to mismatch of generation and demand. Solar energy production is based on predictable diurnal patterns, while household consumption is random and driven by human behaviour. This mismatch generated the need for smart energy management solutions capable of balancing storage, consumption and grid interaction.

The objective of this project is to successfully design and implement a Digital Twin of a solar-powered home using discrete-event simulation. The system replicates real world constraints such as battery limits, random behaviour,and weather variability. The model enables multiple scenario testing and performance anañysis across different operation strategies.

**System and Design**

The structure of the simulation is modular, object-oriented. Each physical element is modeled as a separate Python class. This allows ease of maintenance, testing, and additions

| Component | Description |
|---|---|
| Solar Panel | Simulates the time of day, cloud coverage (seasonally weighted random selection), inverter constraints to model the conversion from light to electricity and failures of the converter. Uses a sinusoidal curve for the diurnal solar cycle. |

| | |
|---|---|
| Battery | Stores the excess of solar energy generated during the day and supplies electricity when there is not enough solar production. It has efficiency losses and has safety limits to prevent overcharging or deep discharging. |
| Inverter | Converts and regulates the solar energy before it is used or stored. It limits the maximum output and can have random failure events, temporarily stopping solar production for a configurable amount of time. |
| House Load | Represents the electricity consumption of a home, includes a constant base load for appliances,probabilistic evening consumption spikes, and gaussian random noise. This helps to prevent unrealistic flat consumption.. |
| Grid | Allows the house to import electricity when generation and storage are not enough and export energy when production is higher that it needs. It can also operate in zero-export mode if the configurations do not allow energy export. |

The simulations uses three kinds of energy management systems, each with different operational priorities leading to different system performance characteristics, which are:

**Load Priority Strategy**

The main goal is to power household loads first. Any solar energy produced is first used to meet consumption needs. Any excess energy is used to charge the battery, with the excess then being exported to the grid. The battery will discharge to cover any energy deficits prior to any imports being drawn from the grid. This strategy minimizes reliance on the grid while maximizing load reliability.

**Charge Priority Strategy**

Battery charging is the focus here. Any solar generation is used to charge the battery before any energy is used to power household loads or is exported to the grid. Only after the battery is full can it be used to serve household loads. This strategy maximizes energy storage for evening use. However, this strategy may cause imports to increase during daytime energy consumption.

**Produce Priority Strategy**

This strategy aims to maximize grid exports to the set limit. Any remaining solar generation will first be used to charge the battery before being used to power household loads. Any deficits will be filled by a discharge from the battery and an import from the grid. This strategy aims to maximize revenue from solar generation while potentially compromising energy independence.

**Simulation Methodology**

The simulation runs for a configurable period of time, preferably, with a default duration of 30 simulated days and advances in 60-minutes intervals. At each time step, the systems calculates he current in the following manner:

- Determine the current hour and season
- Select the cloud coverage for the day
- Calculate solar generation
- Calculate household demand
- Apply the chosen energy management strategy
- Update the battery state
- Exchange energy with the grid if needed
- Compute the financial cost and revenue
- Generate all the relevant metrics

All of the values are recorded in a structured CSV file. After the simulation is completed, a reporting file analyses the logged data and generates summary metrics and visualizations.

## Code Execution and Results

```
--- Configuration Menu ---
1: Use Default Configuration
2: Customize Configuration
Enter your choice (1 or 2): 2

Press Enter to keep default value.
LOG_FREQUENCY (Default: False): False
BATTERY_SIZE (Default: 13.5): 15
PEAK_SOLAR_GENERATION (Default: 5.0): 4
ENERGY_BASE_LOAD (Default: 0.5): 0.5
RANDOM_SPIKES_MAX (Default: 3.0): 5
BATTERY_ROUND_TRIP_EFFICIENCY (Default: 0.9): 1
INVERTER_MAX_OUTPUT_LIMIT (Default: 4.0): 6
GRID_MAX_EXPORT_LIMIT (Default: 2.0): 3
GRID_MAX_IMPORT_LIMIT (Default: 30.0): 20
SIM_DURATION_DAY (Default: 30): 40
TIME_STEP_MIN (Default: 60): 60
INVERTER_FAILURE_FREQUENCY (Default: 0.005): 0.01
INVERTER_FAILURE_DURATION (Default: 21): 50
SIM_START_DAY (Default: 0): 0
COST_ENERGY_EXPORTED (Default: 0.5): 0.5
COST_ENERGY_IMPORTED (Default: 0.75): 0.75
IS_ZERO_EXPORT (Default: False): False
```

Image 1. Customize configuration

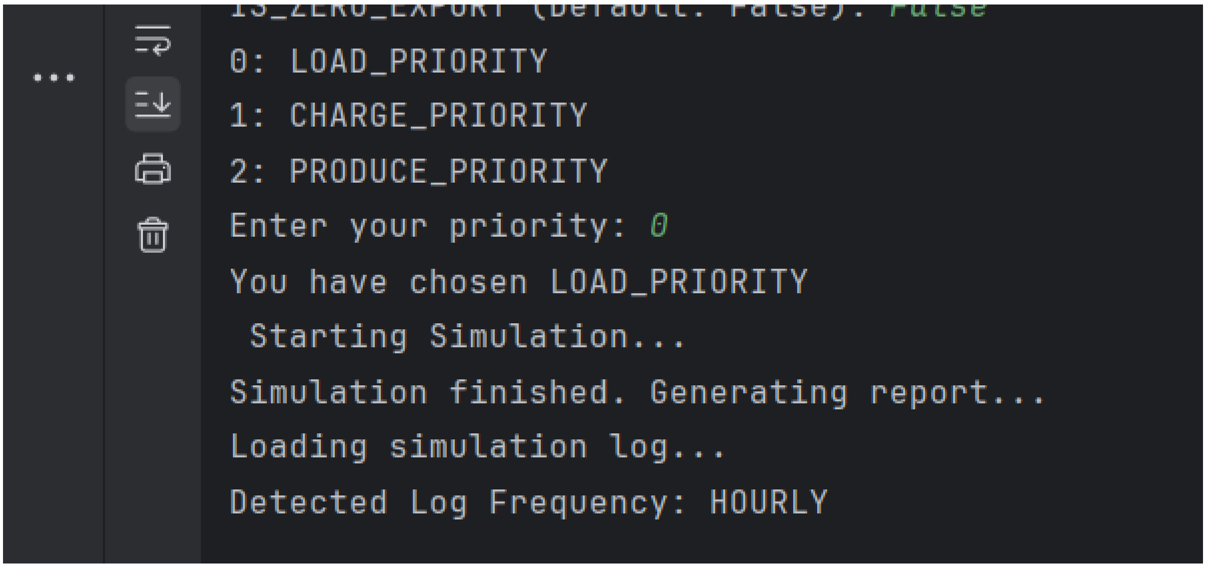


Image 2. Setting the energy management stategy

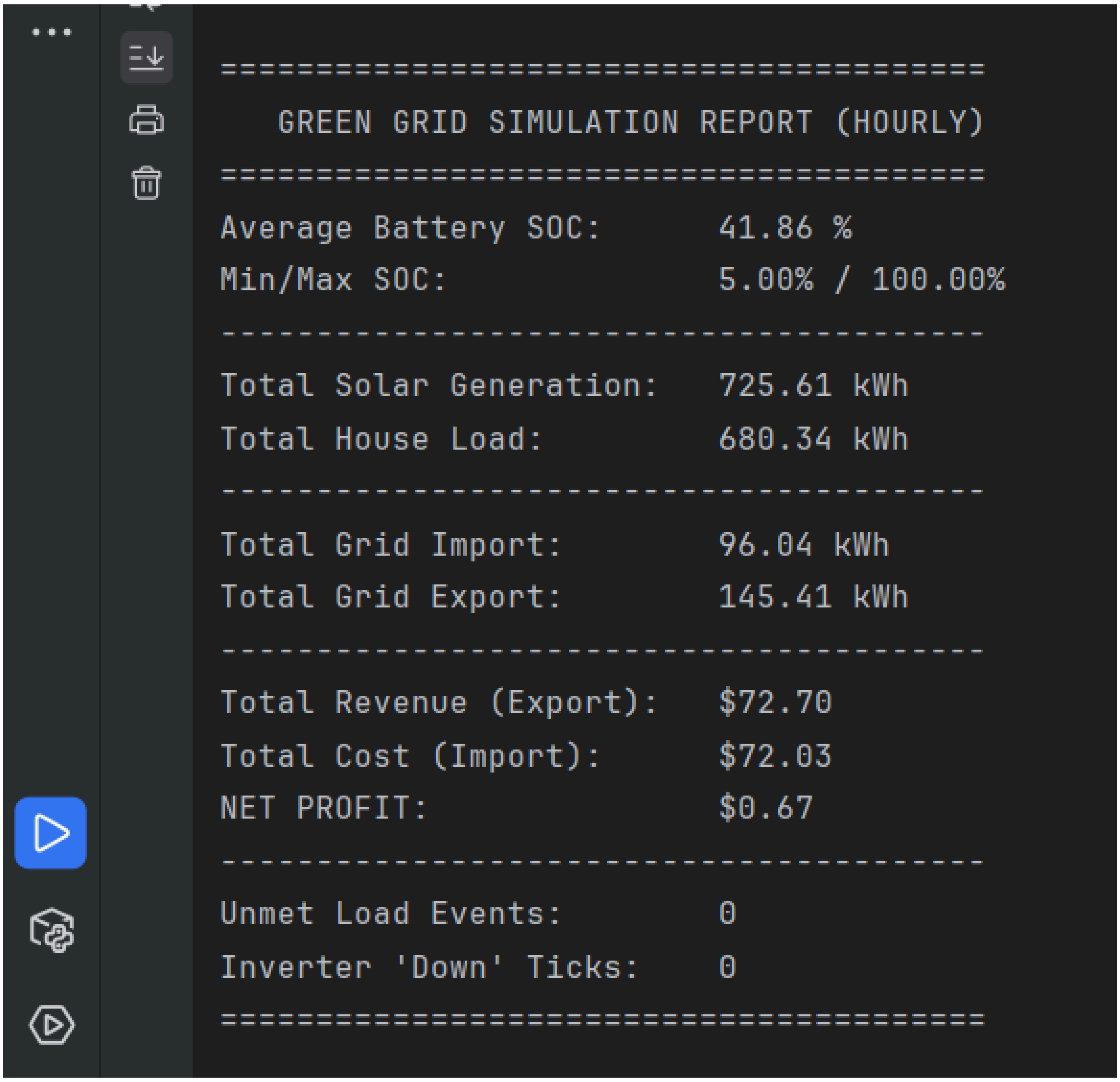


Image 3. Simulation report

```
Saved chart: report_soc.png
Saved chart: report_energy.png
Saved chart: report_financial.png

Reporting complete.
```

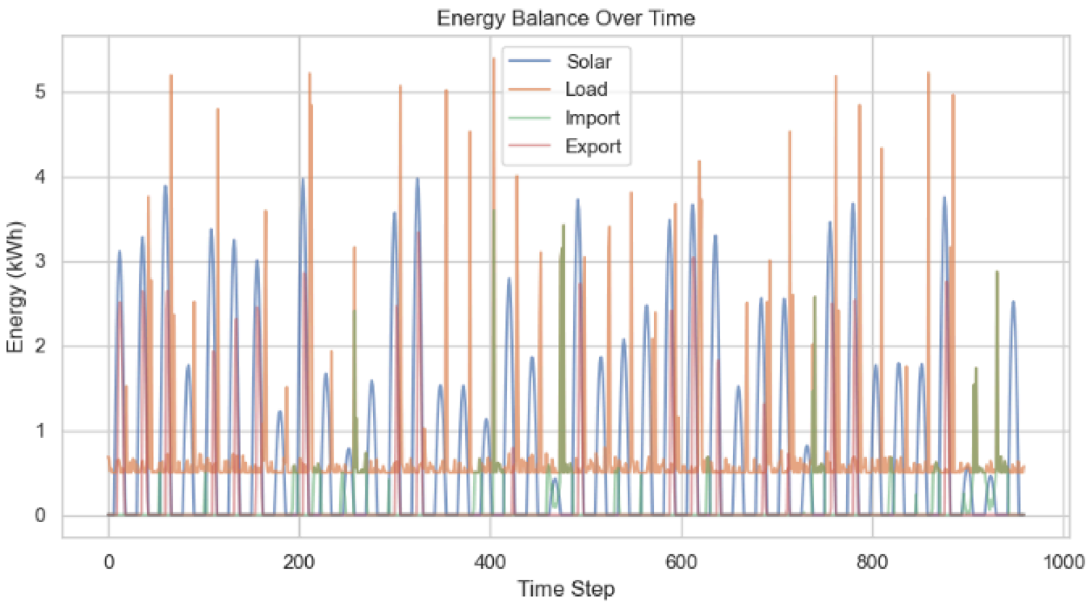


Image 4. Energy over time balance sheet

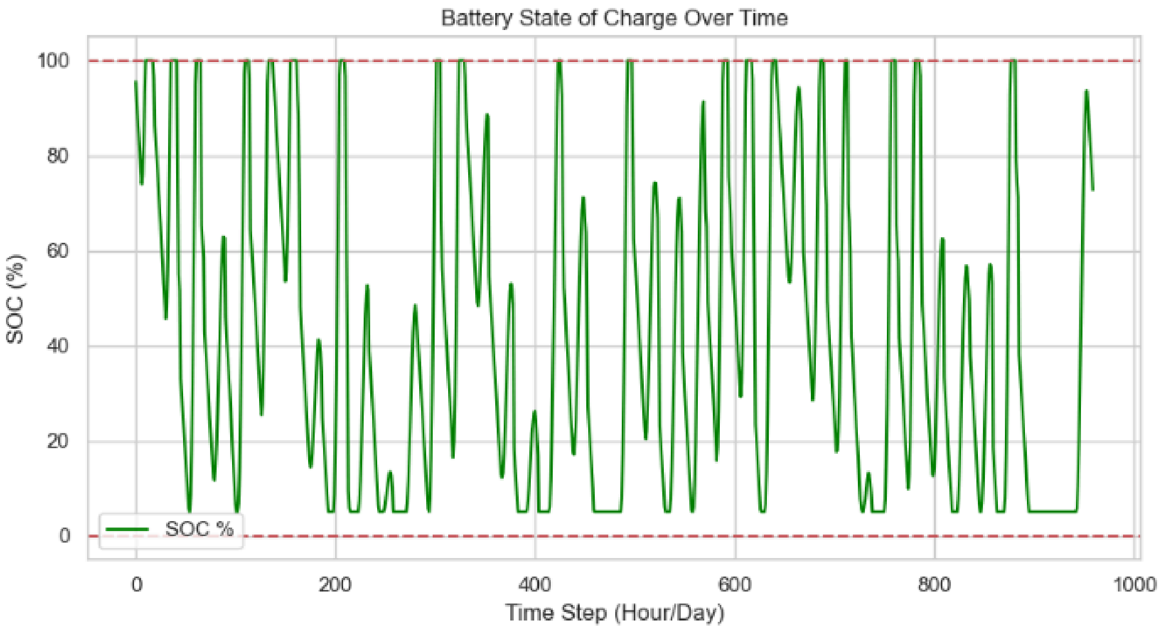


Image 5. Battery state over time sheet

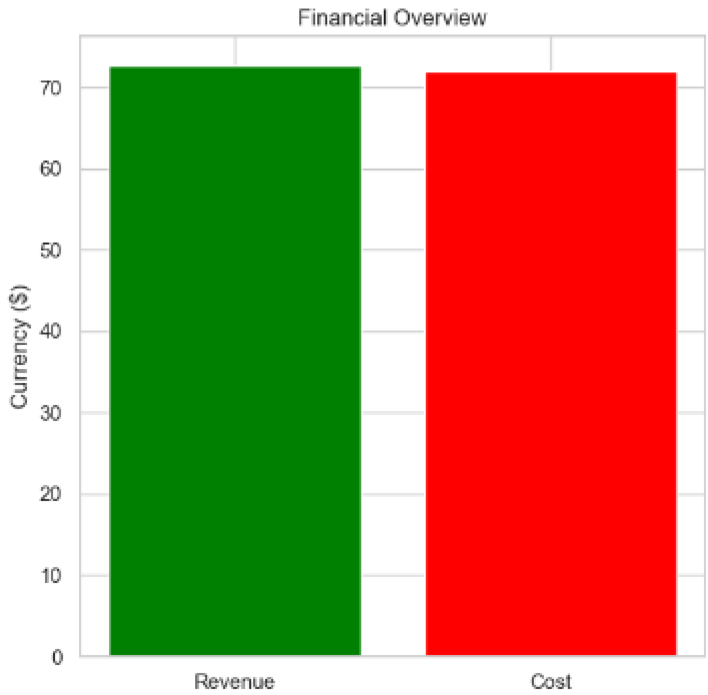


Image 6. Financial Overview

**Personal Reflection**

David Contreras Tiscareño: An important lesson learned by building the Green Grid simulation was the value of modular design. By breaking up each element of the system into their own stand-alone classes, it was easier to comprehend, debug and enhance any given part of the project. The design also mirrors actual energy systems that are made up of stand-alone but interrelated components. By utilizing this architecture while developing the Green Grid Simulation, I re-affirmed the need for writing clean, well-organized and maintainable code

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Emiliano Flores Castellano: One thing that I learned was the impact of energy management strategies and economic performance. The order in which energy flows are classified like direct consumption, battery charging or grid interaction, directly influences battery cycling, grid dependency and cost metrics . This shows how control logic is just as important as hardware capacity.

Ana Maria Guzman Solis: The use of random variables such as cloud cover and load variability leads to increased realism. Modeling uncertainty results in a more accurate system behaviour over time and allows one to evaluate performance under less than perfect conditions.