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Math 2121 Final Project

May 2022

Solar Generating Power Plants

Introduction:

Motivation:

Electricity moves at nearly the speed of light, a system impossible to model or with inconsequential micro-interactions. This project extends the motions of electric current to a numerically and visually comprehendible system. While requiring many simplifications, it allows one to see properties emerge from agent-agent and agent-environment interactions.

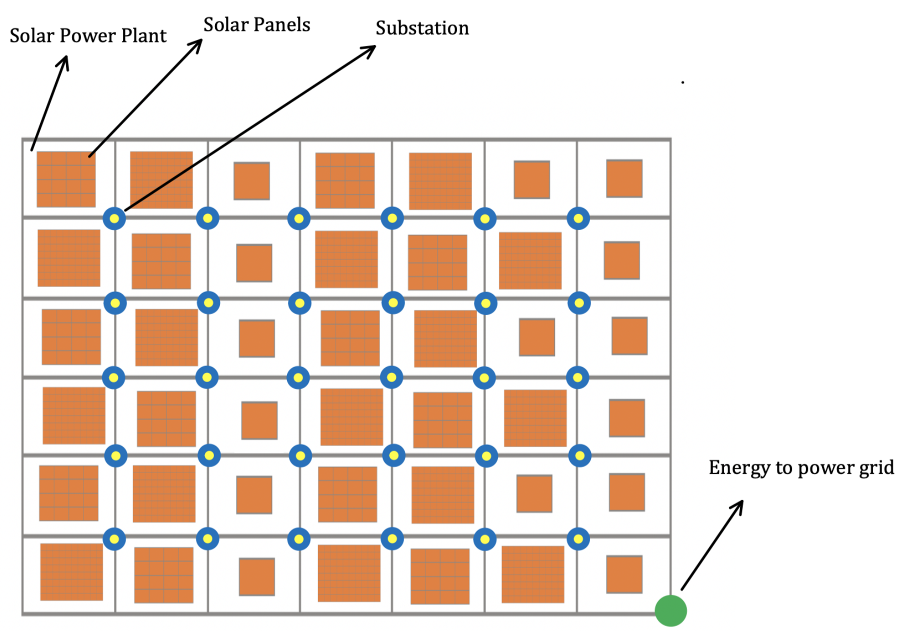
Similar Projects and Tools:

Matlab itself has a set of tools in Simulink used to model electrical circuits and systems. I found these tools to have great utility but produced deterministic outputs, so I decided not to integrate these into my project.

Agent-based electricity models that I found online consist of financial market simulations of generation, utility transfering, and consumption of electricity. After reviewing these, I knew that my project was feasible. Still, given my limited background on the subject, I needed to identify and limit my project to a specific niche to see successful results.

Abstract Description of the Simulation:

How could the generation of electric potential and its subsequent motion be simulated from a macro perspective? This program models a set of independent solar power producers transferring their electricity into a grid by way of substations. The substations prioritize transferring the least amount of electricity during each timestep as large transfers from high to low electric potential are costly to the substations. Power producers that send first are rewarded by receiving more solar panels; those late to send, find a portion of their solar panels taken away.



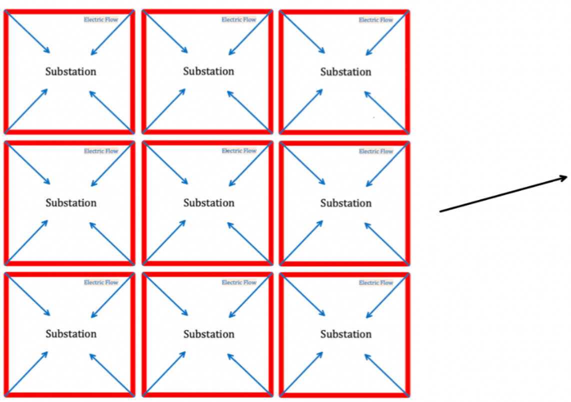
Methods:

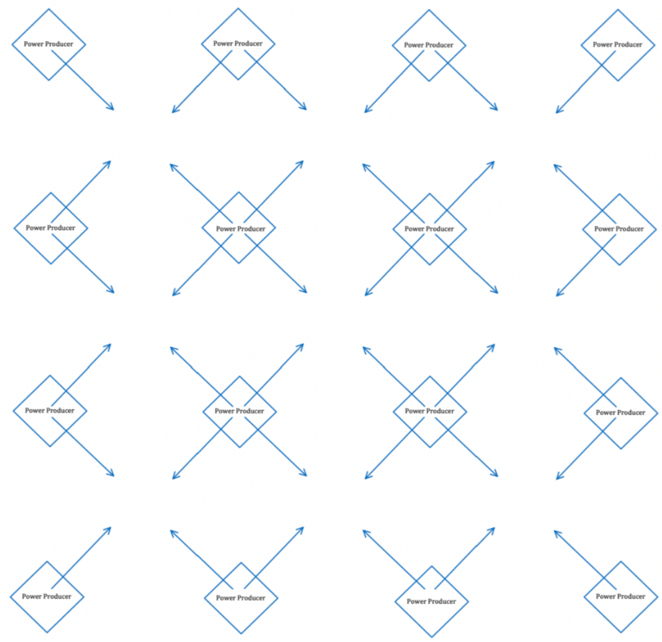
<u>Set Up:</u>

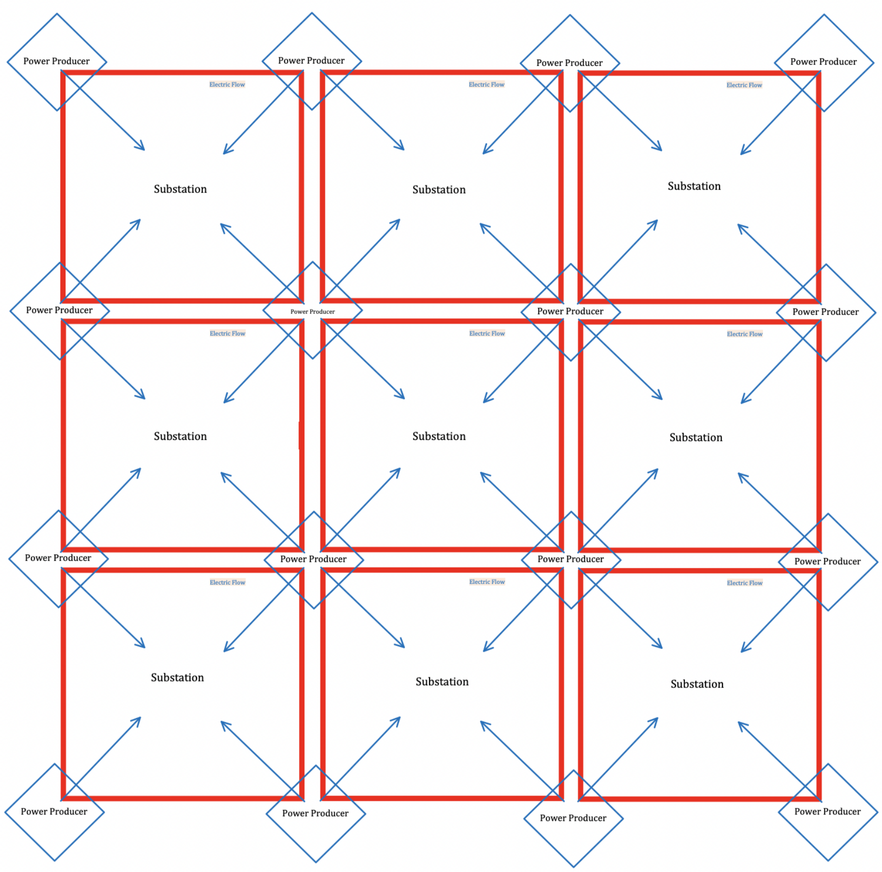
A matrix, grid-like set exists. Each matrix element is a substation, the 'middlemen,' whose job is to transfer electricity from solar power producers to the electricity grid.

Each of these substations receives energy from four power producers. Thus, another grid-like matrix, four times the size of the substation matrix, is created where each of these power producers is also a matrix element.

The matrix grid of substations is combined with the matrix grid of power producers







Agents:
Defining the agents is open to interpretation. The power producers and substations, having attributes and independent objectives, could be considered the agents; or the electricity, consisting of parts whose motion is defined by rules and which coalesce, could be the agents.

Agent Attributes:
For every hour of the year, the solar generating ability of each plant is initially defined by data collected from the website https://pvwatts.nrel.gov/. Based on any location in the United States, the site uses historical climate data to predict the estimated solar insolation for every single hour of the year. By downloading this excel file and placing it into the simulation folder, the program will open the file in its original format and read the predicted solar insolation (amount of sunlight hitting the ground) for each hour.

Month	Day	Hour	Beam Irradia	Diffuse Irrad	Ambient Ten	Wind Speed	Plane of Arra	Cell Tempera	DC Array Output (W)	AC System Output (W)
1	1	0	0	0	0	1	0	0	0	0
1	1	1	0	0	0	1	0	0	0	0
1	1	2	0	0	0	1	0	0	0	0
1	1	3	0	0	1	1	0	1	0	0
1	1	4	0	0	2	2	0	2	0	0
1	1	5	0	0	2	2	0	2	0	0
1	1	6	0	0	3	3	0	3	0	0
1	1	7	0	0	3	3	0	3	0	0
1	1	8	0	4	5	3	3.781	3.182	14.329	0
1	1	9	0	55	6	3	52.207	5.422	195.937	171.827
1	1	10	363	147	7	3	414.551	15.5	1473.114	1416.127
1	1	11	0	106	7	3	102.526	8.839	379.125	351.231
1	1	12	0	110	8	3	106.633	9.079	393.898	365.686
1	1	13	438	139	7	4	470.83	16.066	1669.234	1605.856
1	1	14	768	65	6	3	523.366	18.253	1801.271	1733.388
1	1	15	380	57	4	2	232.982	10.321	801.745	763.931
1	1	16	151	15	2	2	62.976	2.456	205.257	180.963

But, since the power plants are placed in different locations, the climate may slightly differ between locations. Thus, a level of per hour randomness factor, whose magnitude is defined by the user, is implemented. In addition, consider that some plants, based on factors such as age or maintenance, will have different solar generating abilities. Thus, randomness, whose magnitude is also user-defined, is implemented to remain constant throughout the entire simulation. In summary, the three random factors consist of the randomness stemming from the historical weather patterns, the hour-by-hour climate randomness between locations, and the constant per power plant randomness.

The generating abilities for each power plant, as defined above, represent the electricity production of having one solar panel at each power plant. The user specifies the range in the number of solar panels each power plant can have, and the program randomly determines the starting number of panels for each plant from this range.

Each power plant has a defined connection to between one and four substations based on position, and each substation has a defined connection to exactly four plants.

Each substation also has a list defining the by-hour order in which it will accept electricity from each power plant.

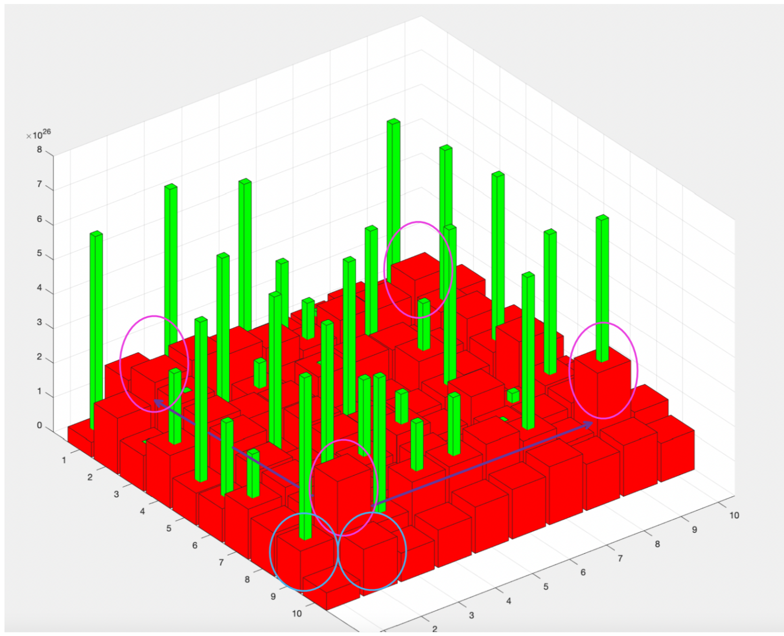
<u>Strategy: Substation Order and Market Phenomena:</u>
To create a system in which the substations work as a group to minimize the change in electric potential and reward plants that substation desire, I implemented the following generalizations and rules. Substations slated to import the least electricity, pull first and draw from each of their four connected plants in order from least to greatest electric potential. Meaning, that substations proceeding the first, which were previously predicted to pull more electricity, may now pull less. These proceeding substations are likely connected to plants with no more electric potential, and a portion of plants have sent their electricity to an already activated substation. Power plants that can get better deals for their electricity succeed, and this simulation assumes that plants that send their electricity first will thrive by receiving this better deal. To generalize these market phenomena, every hour, the order in which power plants send their electricity is recorded, and those that send first are rewarded with more solar panels and those that send later loose panels.

<u>Strategy: Visualization of Emerging Trends:</u>
Behaviors emerge from this simulation based on different user-defined variables such as the number of power plants, range in panel count, and location. These behaviors can be visualized with three seperate graphs, all of which will be described in the next section. Note that each graph must be turned on or off by setting each representative variable to true or false, on/off, in the run.m file.

Results:
<u>One Example of an Emergent Property:</u>
The plotInteraction feature, which can be set to true (on) in the run.m file, provides a visualization of the changing amounts of electricity that each power plant sends and each substation received during each time step.

Though plants start by producing very different amounts of energy, this distribution will slowly converge into a relative state of equilibrium. A very distinct phenomenon will almost always emerge, where four distinctly positioned power plants will begin to outperform all others. Each four sit one position diagonally inwards from each of the four corners of the grid and are marked with the color pink below. Then, the following best performers sit along the paths connecting these four inner corners to their closest two others, illustrated with a purple arrow below.

Such behavior is reasonable since the substations connected to the four cornering plants must always be activated since these substations are the only options for these cornering plants to send electricity to. Note that the four most successful plants described above are attached to these substations.



This implies that these substations reap the rewards from this interaction. Notice how the others remaining, marked in blue, do not prosper as well. This is likely due to the pink-marked plants getting pulled earlier from another substation.

These interwoven connections between power producers and substations result in emergent phenomena like this that I cannot fully explain.

<u>Other Visualizations to See Emergent Properties:</u>
To demonstrate the phenomena of the variance in active substations (those pulling electricity) versus those remaining off, I included a graph labeled plotActiveSubstations in the run.m file.

Since the graph showing the power production does not sufficiently describe the success of the plants, I included a diagram labeled plotPanelCount, to visualize how the number of solar panels each power plant has, changes through time.

<u>Active Substations: An Indication of Success:</u>
Any viewer of the active substation graph will have the desire to understand the patterns emerging from this rapidly changing diagram. To find a pattern, I worked through each time step. I consistently found that more substations are active for the initial 5 - 20 iterations (with varying numbers of power plants) than for later iterations. After further analysis, it is clear that the same substations are repeatedly activated during these first initial iterations. The goal of the rules set in the simulation is to minimize the changes in electrical potential and limit the number of transfers in electricity. The simulation takes on a life of its own by determining the best way to accomplish this, decreasing in number and constantly

changing which substations are active. Since the model is effective, pausing is required to see this behavior as it quickly emerges at the start of the simulation.

Conclusion:

Limitations:

While the simplifications made to this electrical grid interaction will allow for insight, the generalizations required to get to this point surpass the limit for the direct utility of modeling the interactions between power plants and substations.

Use Case:

The value of this simulation is its ability to model physical phenomena such as electricity on an agent level. The electricity agents interact with their environment, the power plants, and substations, which can also be viewed as agents themselves. How could the concept of energy be placed into an agent-based model? This simulation is an example.

Extend this concept to something like water, where there are clusters of H_2O molecules whose grouping constantly changes and whose clusters can be viewed as agents that interact with the environment of agents such as living organisms.

The direct utility of this model is limited. Still, the concepts extending from this simulation offer new ideas of what can be defined as an agent.

Sources:

- Provides data for simulation
    - https://pvwatts.nrel.gov/pvwatts.php
- Agent based model referred to for ideas
    - https://www.sciencedirect.com/science/article/abs/pii/S136403211501552X
- Agent based model referred to for ideas
    - https://ceeesa.es.anl.gov/pubs/42769.pdf
- Guide to how substations work
    - https://practical.engineering/blog/2019/8/26/how-do-substations-work