Modeling And Simulation

AGENT-BASED SIMULATION OF SMART GRID RESILIENCE: CREATING AGENT-BASED MODELS TO SIMULATE AND ANALYZE THE RESILIENCE OF SMART GRID SYSTEMS.

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WHAT IS SMART GRID ?

- Smart Grid is a smart electric grid system or in simple words an electric network that comprises and uses digital technologies, sensors to match the supply and demand of electricity in real time.
  It helps in maintaining the stability and reliability of the grid and minimize costs.

- Within the Smart Grid, the term “Grid” refers to the electric grid which is a network of transmission lines, substations, and transformers that deliver electricity from power plant to our homes and businesses.

- A smart grid’s key features include:
  - Load Handling: The total of the power grid load is not stable, and it varies over time. In case of heavy load, a smart grid system can advise consumers to temporarily minimize energy consumption.
  - Demand Response Support: Provides users with an automated way to reduce their electricity bills by guiding them to use low-priority electronic devices when rates are lower. For eg: it is cheaper during the very early and late hours of the day, so it would be advised to use machines with heavy load and low priority during those hours of the day.
  - Decentralization of Power Generation: A distributed or decentralized grid system allows the individual user to generate onsite power by employing any appropriate methods such as solar systems.

OBJECTIVE OF OUR STUDY

- The main objective of our project is to accurately study and recreate the various behavioral components of the smart grid:
  - Determining the impact of various external disturbances on the grid
  - Identifying system sensitivity and weakness

Enhancing the resilience of smart grid systems for various factors such as Extreme Weather Conditions, cyber-attacks , and equipment failures.

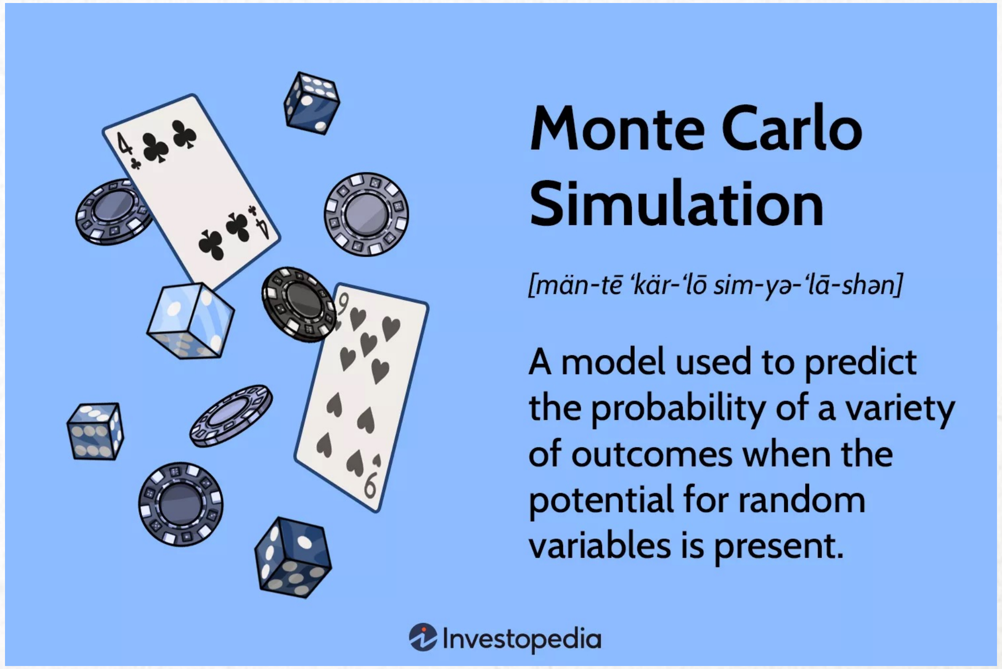
We are also considering sustainability aspects of smart grid systems, such as the integration of renewable energy sources, energy efficiency measures, and environmental impacts.

Here we will be using Monte Carlo Simulation within our project to analyze the resilience of smart grid systems.

WHAT IS MONTE CARLO SIMULATION?

The Monte Carlo simulation is a mathematical technique that predicts possible outcomes of an uncertain event.

It is called such because it depends on randomness to produce numerical results, which is why it shares its name with the famous Monte Carlo Casino in Monaco which has been popular for its games of chance and randomness.



HOW WILL MONTE CARLO SIMULATION HELP US?

- Monte Carlo Simulation will help us in assessing resilience of smart grid systems when faced with unexpected problems and outcomes.
- It will help incorporate stochastic model to represent factors such as component failures, irregular renewable energy generation, demand fluctuations and some more factors.
- By analyzing the simulation results statistically, we can gain valuable insights into the smart grid resilience, helping us to develop strategies to enhance system reliability, and ensure un-inturuppted enrgy supply to the consumers.

MONTE CARLO SIMULATION

- Modeling System Components:
  - power lines,
  - transformers,
  - renewable energy sources,
  - demand patterns

- Modeling Stochastic and. uncertain factors:
  - Component Failures
  - Renewable Energy Generation
  - Demand Fluctuations

CASE STUDY: TEXAS BLACKOUT 2021

The 2021 Texas Blackout was a complex event caused due to several factors:
1. Extreme Winter Storm: An unusual winter storm had hit Texas in February 2021 which resulted in Extremely low temperatures, ice and snow. This kind of weather conditions had overwhelmed the state's Power grid.

2. Frozen Power Plants: Most of the power needs of Texas rely on Natural gas. And these natural gas plants work on Vapours. Many of the pipelines, wells therefore had frozen during the outbreak resulting in limited supply of natural gas and electricilty demands.

3. No Interconnection of Grids: During early times when the grids of Entire American region were being built Texas Had at that time decided to opt out of it and build their separate grid to be independent of the federal and state Commissions of the other America. Because of which during the outbreak they were not able to reroute their supply Needs from rest of the America or neighbouring states.

This all happened because of the old Grid infrastructure and near to no advancement in the grid model of the Texas, if a Smart grid would have been incorporated then the scenarios would have been different.

CASE STUDY: TEXAS BLACKOUT 2021

HOW COULD SMART GRID HELPED IN PREVENTING THE BLACKOUT?

Early Warning and monitoring: Smart meters and sensors in the grid could have alerted the commissions about the Increasing demand and the decrease in production. This information could have alerted them to make useful requirements.

Demand Response Program: Smart grids can integrate with consumer devices and during high demand times and peak hours could have offered incentives to the customer for lowering their usage and also could have automatically adjusted thermostats or turned off the appliances

Automated Controls: Smart grids can react automatically to changing conditions. During the outbreak, the system could have:

- Adjusted power flows to prioritize institutions like hospitals.
- Activated backup energy sources like solar panels or local energy houses.
- Could have controlled or limited blackout to a shorter radius and a lower span of time.

ALGORITHM

1. Input Parameters:

•**N:** Number of Monte Carlo iterations

•**T:** Number of simulation time steps

•**Grid_Model:** Structure containing component states (string), failure rates (float), and resilience metric function pointer
•**System_Constraints:** Structure containing component state thresholds and imbalance

2. Output:

- **Resilience_Metrics:** List of resilience metric values for each iteration

3. Declaration Section:

- Δt: Time step duration (float)
- P_fail(i): failure probability for component i (Array of floats)
- D(n, t): Demand level at time step t in iteration n (float)
- G(n, t): Renewable energy generation at time step t in iteration n (float)
- Oi(n, t): Binary variable indicating outage state of component i (Array of lists of integers)
- Imbalance(n, t): Demand-supply imbalance at time step t in iteration n (Array of floats)
- Ci(n, t): State of component i at time step t in iteration n (Array of lists of strings)
- Rn: Resilience metric for iteration n (Array of floats)

ALGORITHM

a. Initialization (t = 0):

1. Δt = (Define time step duration)
2. For each component i in Grid_Model:
    - P_fail(i) = 1 - exp(-Grid_Model[i]["failure_rate"] * Δt)
3. For each iteration n (n = 1 to N):
    - $C_i(n, 0)$ = [component_state for component_state in Grid_Model.keys()] (Initialize all component states)
    - For each time step t (t = 1 to T):
        - D(n, t) = Demand_Model(t) (Sample demand from the model)
        - G(n, t) = Renewable_Gen_Model(t) (Sample generation from the model)
        - $O_i(n, t)$ = [0 for _ in Grid_Model.keys()] (Initialize outage states for all components)

b. State Update:

- For each component i:
- If $C_i(n, t-1)$ == "operational" and random number < P_fail(i):
    - $C_i(n, t)$ = "failed"
    - $O_i(n, t) = [1] + O_i(n, t-1)$ (Update outage state)
- Else:
    - $C_i(n, t) = C_i(n, t-1)$
    - $O_i(n, t) = [0] + O_i(n, t-1)$

c.Demand-Supply Check:

- Imbalance(n, t) = D(n, t) - G(n, t)
- If Imbalance(n, t) > System_Constraints["imbalance_threshold"]:
- Apply chosen resilience strategy using Resilience_Strategies (specific function call depends on chosen strategy)

d. Resilience Metric Calculation:

- Rn = Grid_Model"metric_function": $O_i(n, t, C_i(n, t))$

5. Result Section (Actual Outcome):

Resilience_Metrics = [Rn for Rn in Rn]

RESULT AND OUTPUT

```
(base) ritvikgupta1721@Ritviks-MacBook-Air MODELING CODE % ./final_code
Enter details for each component:
Enter the values of failure rate and rating for component 1
Enter failure rate: 0.05
Enter rating: 10
Enter the values of failure rate and rating for component 2
Enter failure rate: 0.02
Enter rating: 8
Enter the values of failure rate and rating for component 3
Enter failure rate: 0.07
Enter rating: 12
Enter the values of failure rate and rating for component 4
Enter failure rate: 0.03
Enter rating: 9
Enter the values of failure rate and rating for component 5
Enter failure rate: 0.01
Enter rating: 7
```

RESULT AND OUTPUT

```
Implementing demand response (shifting demand to match supply)
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Simulation Results:

Resilience Metric: 0.350000
(base) ritvikgupta1721@Ritviks-MacBook-Air MODELING CODE %
```

Resilience metric of 0.350000 indicates that over the simulated scenarios, on average, 35% of the total energy demand across all components could not be met due to failures in the grid.

RESILIENCE STRATEGIES USED

1. By activating a backup system: This resilience strategy simulates bringing an alternate backup energy system to work while the main system or source is damaged or not available. This alternate backup energy system may include energy stored in batteries from the renewable energy sources.

2. Load Shedding: This strategy involves reducing the load by disconnecting the electricity for some users i.e. for a shorter radius, avoiding total blackout in the entire city or state. This is done to match the supply in order to protect our devices from getting damaged.

3. Demand response (shifting demand to match supply): This strategy involves encouraging users to adjust their electricity consumption .It might involve offering incentives to consumers who reduce their demand during peak hours or use smart appliances that automatically adjust usage based on grid conditions.

THANK YOU!!