Power Adaptive Dynamic Compute Nodes

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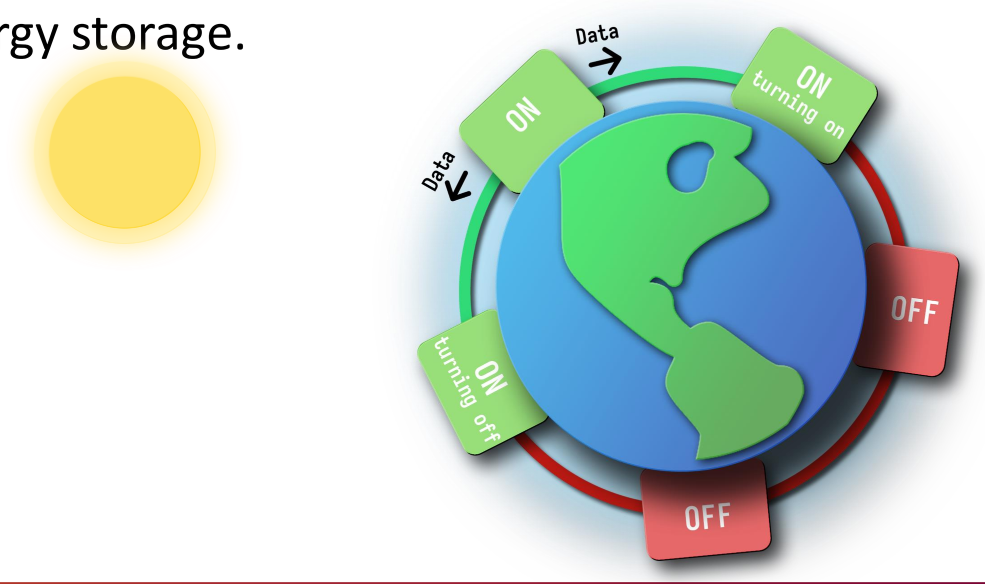
Problem

In the last 20 years, large data centers have sprouted across Northern Virginia, requiring significantly more power than what was intended for the region and drawing a constant load from the grid. Utilities, such as Dominion Energy, must build high voltage power lines, requiring large amounts of copper, which are expensive to construct and maintain, in order to provide sufficient power to these centers.

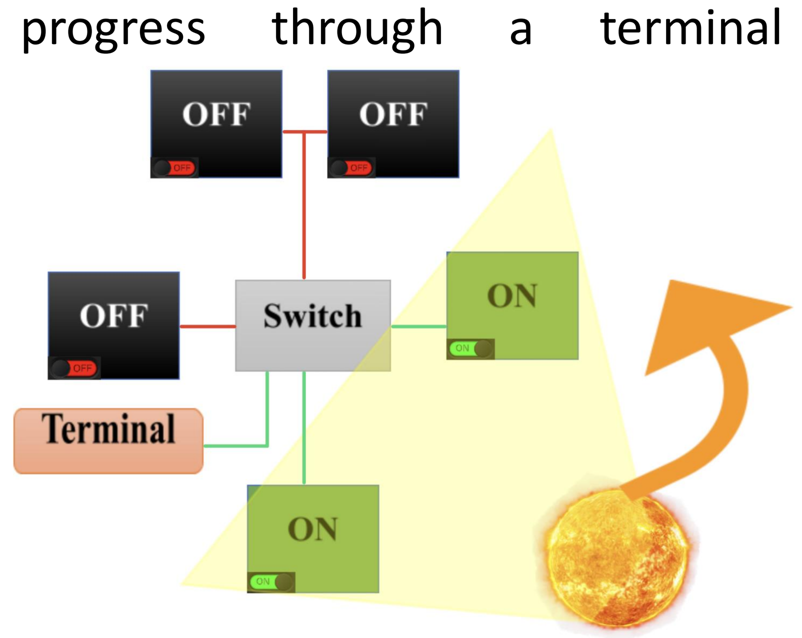
Objective

Create a collection of distributed solar powered computing nodes with a human machine interface to allow persistent operations regardless of the conditions at each node. The system should be fault tolerant on a dedicated wired network, with each node capable of energy storage.



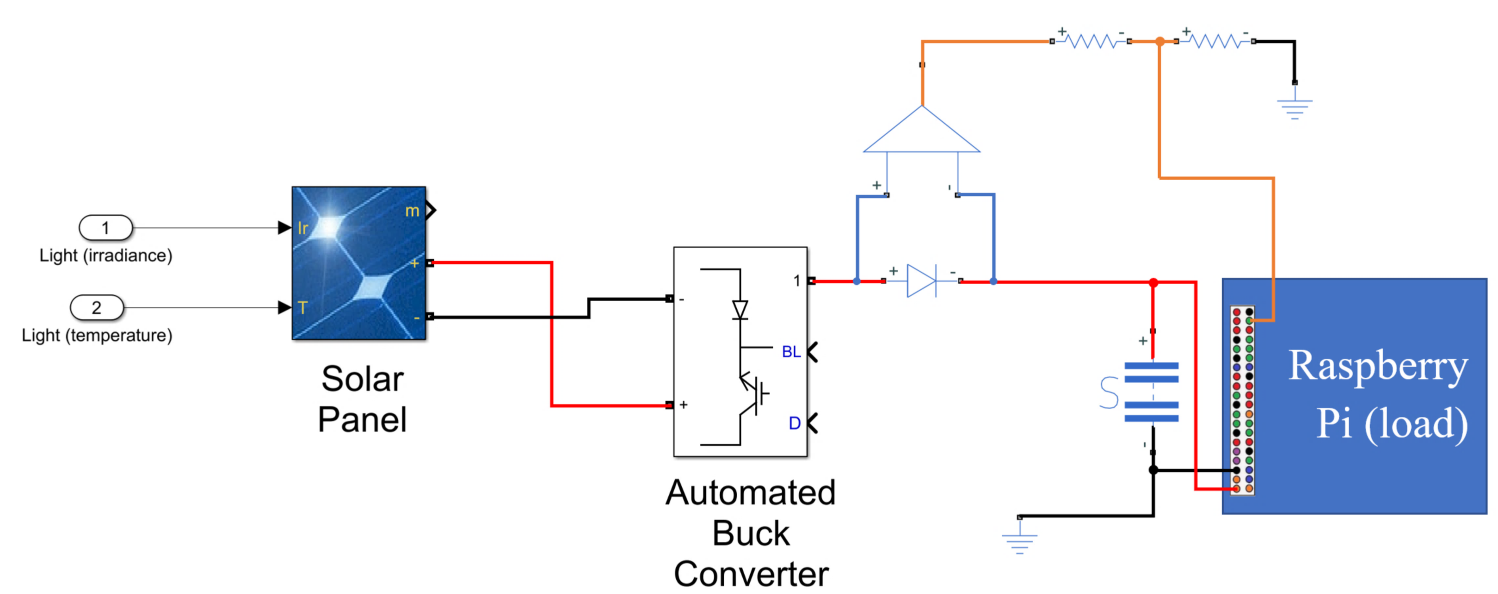
Approach

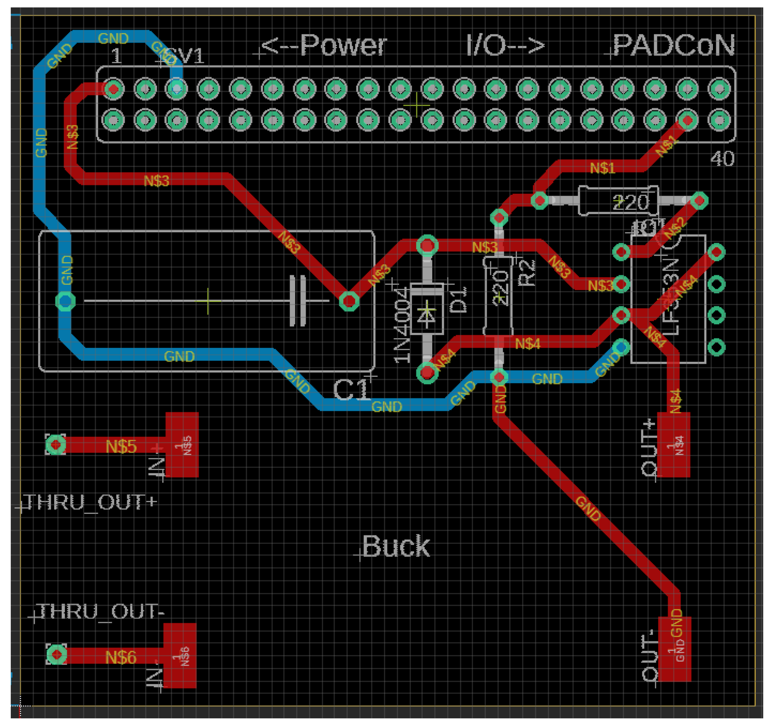
A model was designed and constructed to represent the system above as a proof of concept. Five nodes, each consisting of a Raspberry Pi and power supply circuit, represent data centers across the world. The power requirements for each node are met by a solar panel, converter and capacitor. In terms of software, a state machine was developed to handle communication, running a job, and monitoring progress through a terminal program.



Implementation - Hardware

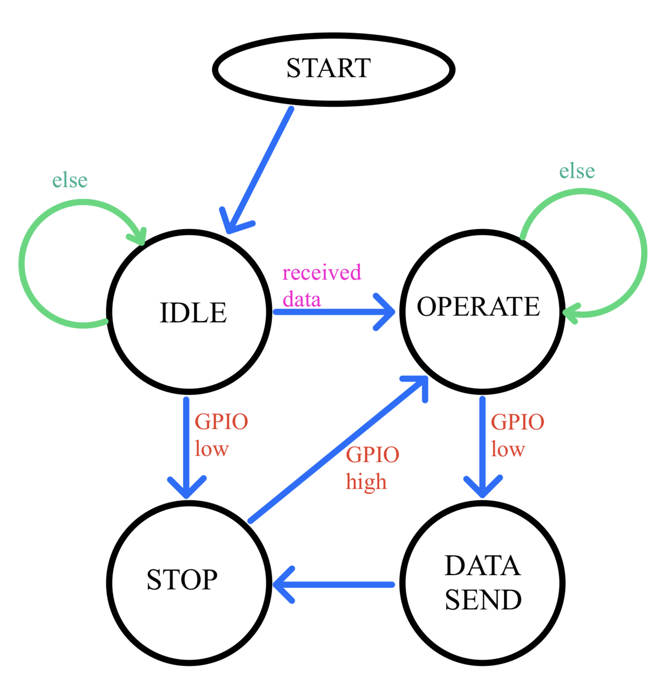
- Key components: solar panel (power supply), automated buck converter (power converter), comparator, and supercapacitor (energy storage)
- Solar panel must supply minimum 8.7V to account for 5V delivered to Raspberry Pi, plus voltage drop across buck converter and diode but can supply up to 20V during open circuit
  - Must be able to supply at least 2A of current to support Raspberry Pi start-up
    - Maximum current (short circuit current) 3.2A to allow for internal resistance and suboptimal weather
  - Additional capacity allows 8.7V to be delivered on a cloudy day/suboptimal conditions
- Buck converter needed to step down the voltage so the Raspberry Pi is not damaged by excess current and voltage
- Supercapacitor supplies power to Raspberry Pi during shutdown to mitigate packet loss when solar panel voltage drops below 8.7V instantaneously
- Op-amp used as a comparator to determine when buck converter output crashes and drops below 5V

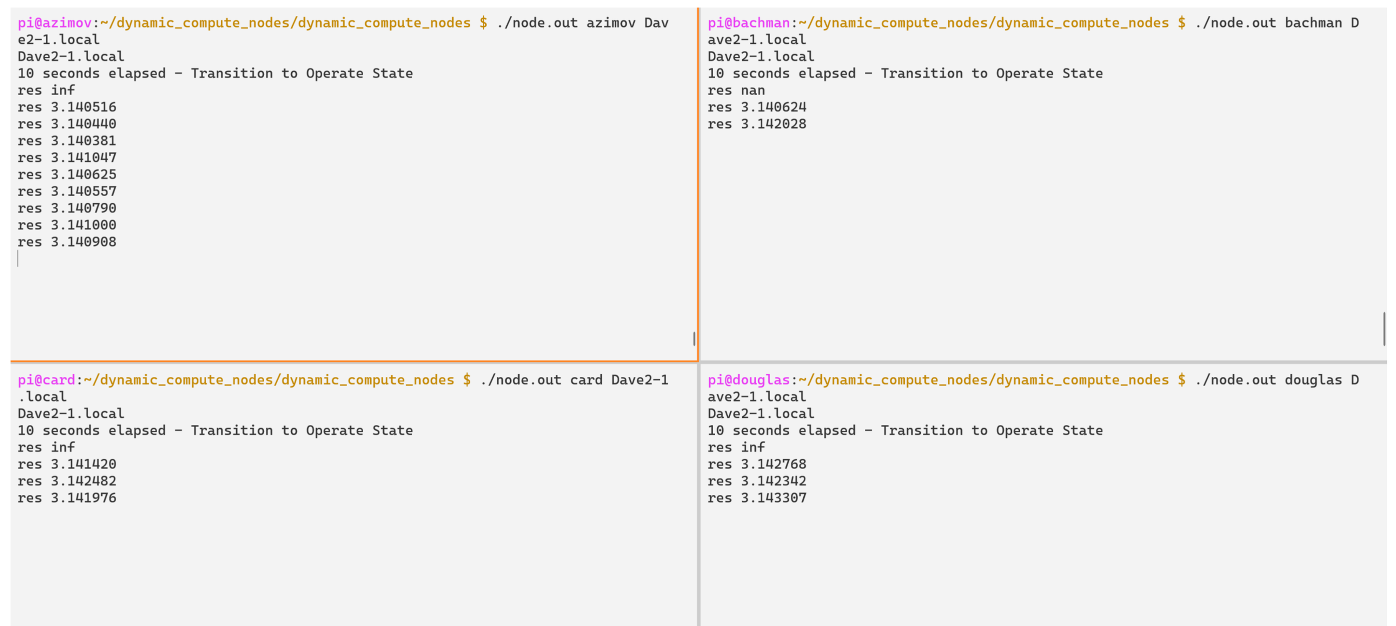




Implementation - Software

- Overarching node software is controlled by a state machine that changes state based on status of surrounding nodes or available power.
  - Transitions between states dependent on power availability and state of adjacent nodes
  - Four states (idle, operate, data send, and stop) allows the node to sufficiently accommodate most scenarios
- Each node connects to directly connects to adjacent nodes via TCP
- The job class defines an interface that can be used to instance other job types. This interface allows the state machine to easily collect, transmit, receive, and update a running predefined job.
  - Our initial job was designed to run algorithms that had many repeated tasks accumulated at the end.
  - The algorithm we used was the Monte Carlo algorithm for calculating pi.
- All software was written in C++ and compiled with g++ on Raspberry Pi OS. The only non-standard library used was WiringPI (Which only became unsupported in the middle of our project)





Video

Results & Conclusion

- Nodes are able to successfully operate on solar power
- ~30 seconds of recorded shutdown time sufficiently allows the node to transmit relevant job data to adjacent nodes
- Nodes are able to accumulate work done on a job and fold that into their own work
- Program can successfully operate on one node, and as many as 5 nodes, at any given time

Future Work

- Handle creation and transmission of generic process state.
- Incorporate higher capacity energy storage

Acknowledgements

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