Vertically Integrated Projects (VIP) Team Description: Gaming for Electric Power Grids

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Motivation

Resilience to extreme events such as hurricanes and wildfires has long been a focus for operators of electric power systems. The challenges facing early system operators as described by a publication in the International Electrical Conference of 1904 still hold true today: a skilled writer would tell

> *"...a tale of fights with the forces of nature in the great valleys and mountains of the West; fights against ice, snowslides, floods and rockfalls, brush-fires, windstorms and lightning, where time was always on the side of the enemy."* – R.F. Hayward, 1904 [1].

Today's power system operators must address rapidly increasing numbers of severe natural disasters driven by accelerating climate change [2]. As shown in Fig. 1, the cost of large-scale natural disasters in the United States has reached record levels. In 2020, there were 22 separate billion-dollar disasters, including a doubling of the previous maximum burned acreage from California wildfires [3].

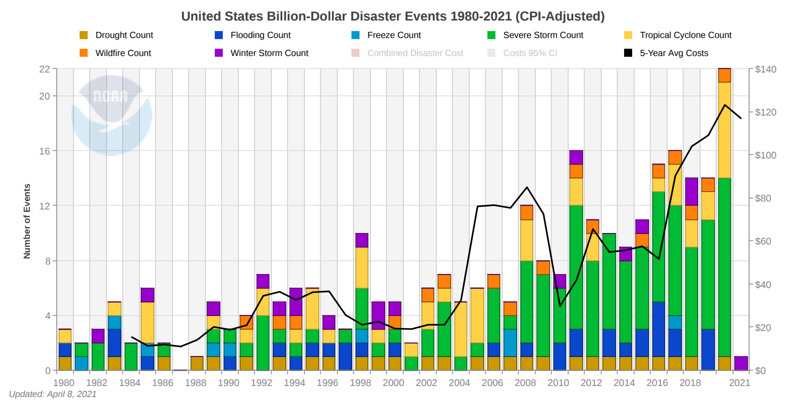

Fig. 1: Increase in billion-dollar disasters [3].

Due to these challenges, power system resiliency is widely recognized as a key national priority. For instance, the Biden administration's American Jobs Plan calls for a $100 billion investment to modernize and improve the resiliency of power system infrastructure [4].

Optimization provides essential tools for mitigating the impacts of extreme events. Dr. Molzahn's research efforts include efforts for using optimization to mitigate the risks of igniting wildfires [5,6], harden the system to avoid blackouts due to flooding [7], operate with reduced repair capabilities during pandemics [8], and manage evacuations of urban areas with high penetrations of electric vehicles [9].

Practical deployments of these techniques require outreach to build public acceptance of the associated disruptive actions (e.g., power loss during Public Safety Power Shutoffs for wildfire risk mitigation, proscribed electric vehicle charging schedules during evacuations, delayed service restorations during a pandemic, etc.) as well as the electricity rate increases and tax allocations needed to pay for infrastructure hardening. Additionally, the next generation of engineers must be educated to design and operate power systems during extreme events. Since resiliency is not included in many power engineering curricula, engineering students are underprepared for this increasingly important challenge facing future system operators. Moreover, the energy industry workforce is aging, with an average age eight years older than the economy as a whole [10]. Thus, quickly rectifying this gap in resiliency education is essential as new power engineers take the reins of the electric infrastructure [11].

Accordingly, this VIP team proposal aims to develop **video game style simulations of resiliency problems** to address both of these issues while simultaneously providing datasets to inform the machine learning algorithms used to advance the state-of-the-art in resiliency research. These simulations will be simplified versions of the optimization problems used in the aforementioned research efforts.

State of the art

Both the research community and the power industry have previously developed video game style simulations of power grid operations. Notable examples include the game "Griddle" intended for high school students [12], an "edu-tainment" course on control of power systems [13], and an educational simulation focusing on electric vehicle charging and renewable integration [14]. The Norwegian system operator Statnett also developed educational apps related to power system operations [15,16]. Additionally, players of the board game "Power Grid" [17] build and fuel generators to produce and sell electricity. None of these existing simulations focus on optimization for extreme events.

Prior work

Dr. Molzahn's prior educational efforts include the development of a Matlab simulation which places students in charge of operating, maintaining, and repairing a simplified model of the Georgia power system during a pandemic.[1] This simulation formed the basis of the course project for Dr. Molzahn's Fall 2020 and Fall 2021 senior-level power system operations classes (ECE 4320). In this project, students were tasked with providing a low-cost power supply by choosing the generator outputs and allocating crews to perform maintenance and repairs of the transmission lines. Sending crews out to maintain and repair transmission lines could result in them being quarantined after exposure to the pandemic disease, precluding their use from the remainder of the simulation. Students therefore had to balance the need to maintain low-cost and reliable power system operation against the health risk imposed on the repair and maintenance crews.

Goals

With the success of this prototype simulation, Dr. Molzahn is strongly motivated to drastically expand the existing pandemic simulation and develop new simulations for other resiliency problems. The ultimate goal is to develop video game style simulations with adjustable difficulty for each of Dr. Molzahn's resiliency projects (wildfires, floods, evacuations, and pandemics) as well as other related settings. The player's tasks during the simulation will be similar to the pandemic project, such as determining where to harden infrastructure, switch off lines, allocate repair crews, etc. as well as how to dispatch the generators. The simulations will be open-source and publicly available, accompanied by lesson plans for students at varying levels of maturity, and initially demonstrated via the Seth Bonder Summer Camps in Computational and Data Science,[2] run annually at Georgia Tech, along with other outreach efforts.

As an illustrative example, consider a simulation tasking the player with mitigating the risk of wildfire ignition while minimizing load shedding. The start of the simulation would give the player a budget to spend on installing batteries and renewable generators. Each period of the simulation would then allow the player to dispatch generators, shed load, and switch off lines. Using actual wildfire risk data, each period would determine whether any faults ignite wildfires in that period, run a power flow calculation, and return a score based on the generation cost, load shed, and wildfire damage.

Approach

Developing the video game simulations requires a diverse set of expertise, such as power engineering, optimization, software development, user interface design, digital media, etc. Successfully publicizing the video games and achieving the educational goals of this "citizen science" project will require expertise in topics such as public policy, business, media, communications, etc. Georgia Tech's "Vertically Integrated Projects" (VIP) program provides the ideal mechanism for bringing together this expertise. Through the VIP program, faculty lead a multi-semester project with groups of ten to twenty students, ranging from sophomore through senior undergraduates and graduate students. Students earn academic credit, and more senior students serve as leaders. The VIP program attracts students from majors across campus.

With mentoring from Dr. Molzahn, the VIP team will first design a common coding platform and "SimCity style" interface [18] suitable for various resiliency applications. Using Dr. Molzahn's implementation of the pandemic simulation as a prototype example, his graduate students will then guide the VIP team in translating the resiliency problems to a video game setting. This will involve explaining their problem and solution methodology to engineering undergraduates, who will then work with computer science undergraduates to integrate this application into the common platform. Students from other backgrounds (e.g., public policy, business, etc.) will work on outreach and deployment. The project implementation will

[1]Details regarding this simulation are available at `https://molzahn.github.io/matlab.html`.

[2]`https://sethbondercamp.isye.gatech.edu/`

use an online platform to enable widescale distribution and rapid updates, and the code will be made open source. The simulations will leverage the publicly available test cases and resiliency data [19–23] developed for Dr. Molzahn's research efforts and will thus be highly realistic while avoiding confidentiality concerns.

Audience

With varying difficulty levels, the simulations will be suitable for audiences from high school to graduate students as well as the general public. For instance, a low difficulty level for the wildfire simulation would only require the player to install batteries and renewables, with the simulation determining the remainder of the choices. Conversely, a high difficulty level would allow graduate students to write customized code (using, e.g., reinforcement learning) to automatically make all choices for the simulation.

Deployment plan

The simulations will first be deployed as projects in Dr. Molzahn's undergraduate and graduate power systems courses. Dr. Molzahn will then publicize the simulations beyond Georgia Tech via the IEEE Power and Energy Education Committee annual meeting [24] and the PowerGlobe listserv [25]. Additionally, Dr. Molzahn will submit a paper to the education track of the *North American Power Symposium*.

Along with undergraduate and graduate students, the project will reach out to high school students via the Seth Bonder Summer Camps in Computational and Data Science, organized at Georgia Tech by Dr. Molzahn's ISyE collaborator Dr. Van Hentenryck. Several week-long camps are run annually, targeted towards high school students interested in engineering who have no or minimal background in data science or programming. Certain iterations of these summer camps specifically recruit students from historically black high schools and thus have significant impacts on underrepresented students.

Successful outreach to high school students requires lesson plans complementing the simulations. To develop these lesson plans, Dr. Molzahn will leverage the Georgia Intern Fellowship for Teachers (GIFT) program at Georgia Tech. To recruit teachers from rural, socioeconomically disadvantaged communities for these fellowships, Dr. Molzahn's will work will Ms. Turcotte at the Center for Education Integrating Science, Mathematics, and Computing (CEISMC).

For outreach to the general public, the project will leverage Dr. Molzahn's role as a fellow of the Georgia Tech Strategic Energy Institute (SEI). In addition to using SEI's own outreach channels, Dr. Lieuwen, the Director of SEI, will connect Dr. Molzahn to the public relations groups in the energy industry to further disseminate the simulations.

Evaluation

To assess learning outcomes, the project will adopt similar techniques to those used in prior video game development efforts [12–14], including student feedback, pre/post surveys of self-assessed student knowledge, and the Knowledge Integration approach [26], where students' responses to open-ended prompts are scored using a rubric to assess the extent to which they incorporate factual knowledge from the simulations into their worldviews. The results of the evaluations will be published in a paper submitted to the education track of the *North American Power Symposium*.

Benefits for undergraduate and graduate students

The undergraduate VIP students who develop the video games will gain a number of benefits, with studies indicating that returning VIP students show improvements in technical skills, leadership capabilities, and ability to work in multidisciplinary teams with students from diverse backgrounds [27–29].

Other students will benefit from realistic and practically relevant projects in future offerings of the undergraduate- and graduate-level power systems engineering courses at Georgia Tech. Further, the deployment plan described above will translate the simulations to course projects at other universities.

Students in Dr. Molzahn's research group will learn to give simplified presentations of their research and practice mentoring teams of undergraduate students. This project will also broadly demonstrate and disseminate their research via simplified yet realistic simulations.

Benefits for the public

By giving players responsibility for managing power systems impacted by extreme events, this project will build public understanding of power system resiliency problems and the tradeoffs inherent to various mitigation strategies. An informed public is particularly important due to upcoming political decisions regarding massive infrastructure investments as well as the effectiveness of collective actions in mitigating extreme events (e.g., turning down the air conditioning during energy shortages). Educational research suggests that participants in citizen science projects like this one gain scientific knowledge, learn about the scientific process, and improve their social well-being [30].

Benefits for researchers

Researchers will benefit from the crowdsourced datasets informed by the players' solutions to the simulations. These datasets will be instrumental to training machine learning algorithms for power systems resiliency research, and Dr. Molzahn will make them publicly available. Dr. Molzahn's research group will apply *transfer learning*, which improves the performance of a machine learning algorithm on a particular problem by adapting knowledge learned from a different but related problem [31], to translate machine learning models trained using the simplified video game problems to actual research settings.

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