Testing Visualization Concepts for Power Systems Analysis

Effective XX/XX/2024

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Location of Study:	United States
Time Required to Complete:	6 months Anticipated start: February 28, 2024 Anticipated completion: August 15, 2024

Contents

Protocol Title

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IRB Review History

This is the first time this protocol has been submitted for review by any IRB.

Objectives

Understanding human perception is critical to the design of effective visualizations. The objective of this study is to gather user feedback on various visualization concepts for the analysis of power systems data. There is an open question to whether analysts are correctly interpreting power systems data using current visualization interfaces and as to which visualization systems they prefer. We hypothesize that current practice in visualization systems inappropriately aggregates geographically proximate data, and that our alternatives are more effective and accurate for several power systems analysis tasks. To test this hypothesis, we propose to gather feedback via survey and interview about users' ability to interpret a visualization as well as their preferences, asking energy professionals with power systems backgrounds to identify features using different visualization encodings.

Background

Visualization has become central to the analysis and understanding of large and complex data; however, it is critical to design visualization techniques for the data and the analysis at hand and validate the techniques through end-user feedback. With the proliferation of visualization libraries, data visualization is more accessible than ever before, but many of the techniques that industry is adopting for power systems analysis may not be actionable, or worse, maybe misleading. For example, consider the geographical contour map visualization of this synthetic power grid in San Francisco. On the left, we can see that there are several voltage violations in dark blue and dark red. However, these are obscured on the right contour map because of the spatial smoothing.

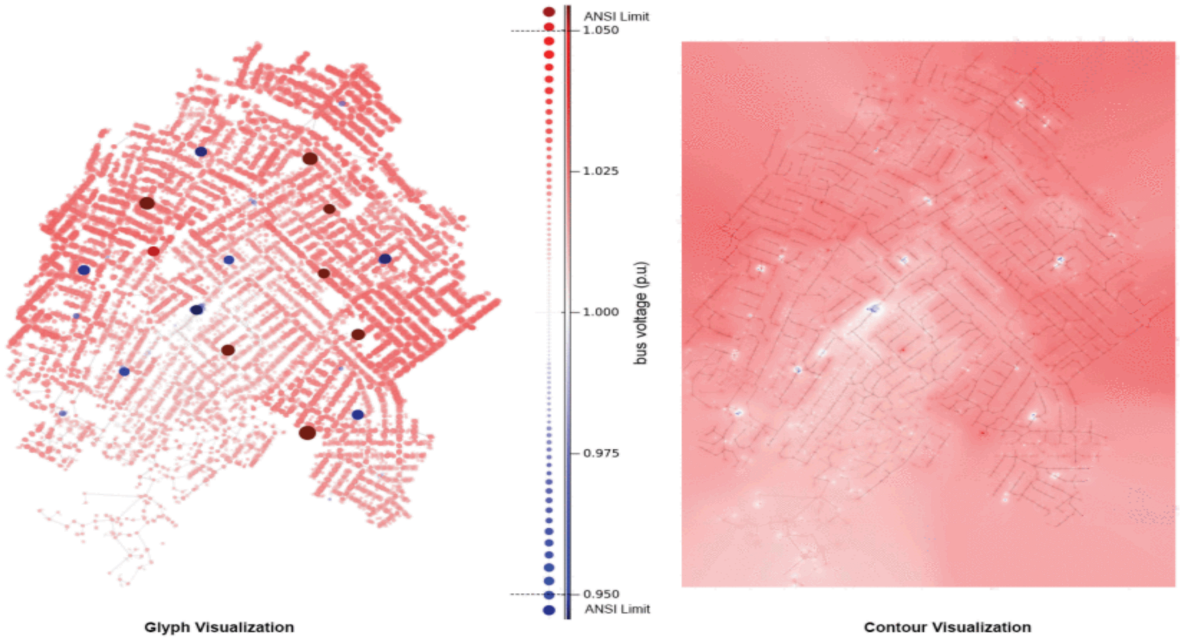

Figure 1: A glyph visualization and a heatmap visualization of voltage for a grid stability analysis [1]. The contour visualization on the right violates multiple visualization-science best practices, and maybe misinforming the analysis. We are proposing to evaluate the effectiveness of alternative visualizations such as glyphs, tile coverings, and topologically aware heatmaps.

We have developed 4 new visualization systems to represent such distribution grids aimed at more accurately representing the distribution of voltage values on the grid. We conducted a thorough statistical analysis comparing the visualizations and published our findings last year at IEEE Vis 2023 in the Energy Vis Workshop. Two such visualizations are pictured below. These new visualization concepts have yet to be evaluated by energy sector practitioners. We have deployed these visualizations in the Insight Center and would like to gather user feedback to further refine the techniques.

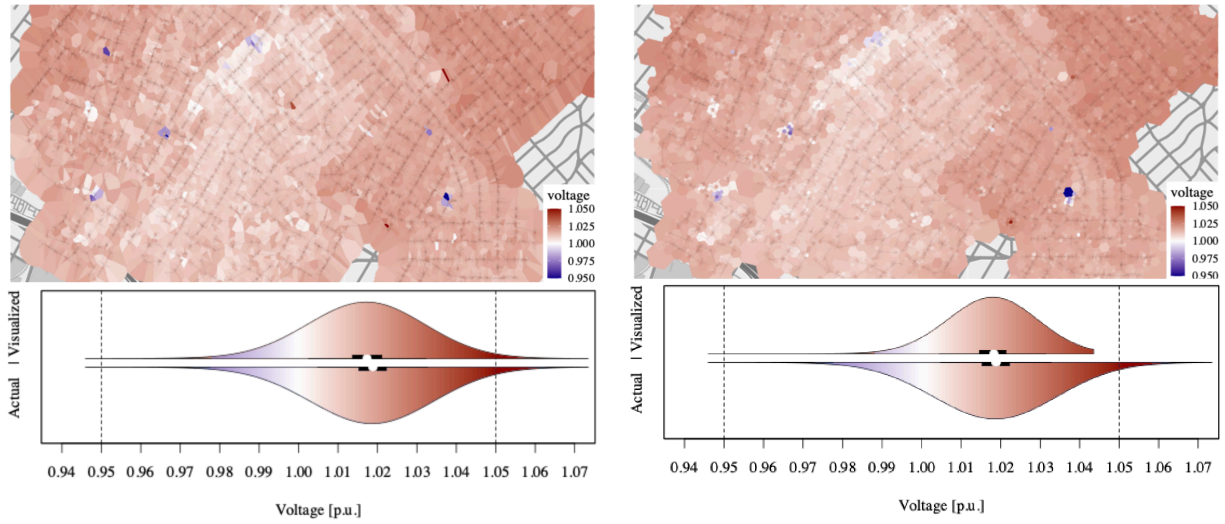

Figure 2: New visualization for energy grids depict the voltage for a grid stability analysis [2]. On the left is a Voronoi tessellation, while on the right is a hexagonal multi-layered tiling. These concepts have yet to be evaluated by energy sector practitioners.

Inclusion and Exclusion Criteria

Requirements for participants are at or over the age of 18, English proficiency, and normal vision. Prior exposure to power systems analysis concepts such as voltage and distribution grids is desired by not required.

Number of Subjects

We will run the study for long enough to receive feedback from 80-100 survey participants. We will interview 10-20 of these participants for more detailed, qualitative feedback.

Recruitment Methods

Participants will be recruited from our pool of visitors to the Insight Center at NREL. The vast majority of visitors at the Insight Center are energy professionals learning more about the ways that visualization tools can help the renewable energy transition. For example, at the end of February, we will host about 80 visitors for the EVs @ Scale Summit who will be engaging with power system visualizations already. Visitors will be verbally informed about the study and given the option to participate.

Study Timelines

The study will begin with the EVs @ Scale Summit on February 28 and continue for 3-6 months until we have reached our target number of user feedback surveys and interviews outlined in Study-Wide Number of Subjects.

Study Endpoints

The primary study endpoint is to determine which visualization concepts presented accurately depict the underlying data and helps them perform an analysis task effectively. The secondary endpoint is to determine what user preferences are between different types of visualizations. As there is no expected risk to participants, there are no safety endpoints.

Procedures Involved

Insight Center visitors will be invited to participate in the study and provided with an informed consent sheet, provided below. If the participant provides consent, the quantitative data collection will proceed. When time allows, the survey will be followed by a short qualitative interview.

We propose to collect quantitative user data including:

- Visualization interpretation responses
    - Perceived location of voltage values
    - Perceived spread of distribution data
    - Confidence in the response
- Subjective rating of each visual concept

A draft of this survey is attached in Appendix A.

When time allows, the following data will be collected in the form of verbal exit interview. The interviewer will type notes from the conversation to add on to the participant's survey response, but not their name or any identifying info. These questions are:

- How would you rate your familiarity with power systems?
- How would you rate your familiarity with visualization and perception?
- Did you find the exercise format easy to understand?
- Do you have any ideas for visualizations that were not presented here?
- Do you have any concluding remarks?

At no point will we collect any Personally Identifiable Information to minimize any risk to participants.

Data Banking

There will be no data banked for future use.

Data Management

They survey responses will be collected on paper and stored in a locked file cabinet in the Insight Center. All digital study data will be stored on secure, password-protected private devices at the National Renewable Energy Laboratory (NREL). At no point will the data leave secured NREL premises or devices. The data will only be accessed by members of the Data Analysis and Visualization group at NREL.

Survey results will be compiled manually into a spreadsheet for analysis. The spreadsheet will be exported as a Comma Separated Values (CSV) for further statistical analysis. The data will then be analyzed in R using ANOVA to determine if there is a statistically significant difference in the accuracy, confidence, and preferences of users for different visualization concepts.

Only aggregate findings and anonymized quotes from participants will be shared in publications resulting from this work.

Provisions to Monitor the Data to Ensure the Safety of Subjects

There is Minimal Risk associated with participating in this study.

Withdrawal of Subjects

If a subject is willing to participate in the survey, there are no anticipated circumstances under which the subjects will be withdraw from the research without their consent.

Risks to Subjects

There are no anticipated risks, discomforts, or hazards to participants. The expected inconvenience is for 10-15 minutes of their time during a regular work day.

Potential Benefits to Subjects

Participants will receive no direct benefit for participating in the study.

Vulnerable Populations

This research does not expect to reach any vulnerable populations.

Multi-Site Research

This research will be conducted on a single site.

Community-Based Participatory Research

This research does not employ Community-Based Participatory methods.

Sharing of Results with Subjects

We do not plan to share the results with subjects. This is because we will not collect any Personally Identifiable Information about the subjects, and so it will not be possible for us to contact them again.

Setting

The study will take place on campus at the National Renewable Energy Laboratory (NREL) in the Energy Systems Integration Facility (ESIF) within the Insight Center, a visualization lab with a multiple large, high-resolution displays. Managed by us, the Data Visualization team, this space sees many visitors every week coming to demonstrate or learn about energy systems through the power of data visualization.

Resources Available

This research will be carried out by the Visualization Research Team at NREL. The following members will be involved in the study:

- Kenny Gruchalla, PhD – Dr. Gruchalla is the lead researcher of the Visualization Team and has been doing research of this nature for over 20 years. He holds a doctorate in Computer Science from CU Boulder.
- Isaiah Lyons-Galante – Mr. Lyons-Galante is a graduate student at CU Boulder in Geography and an intern with the Visualization team. He is an expert in geographical data visualization and the lead author on the paper "Alternatives to Contours for Power Systems Visualization" that inspired this research.
- Samantha Molnar – Dr. Molnar is a senior member of the Visualization Team and an expert in visualizations for power systems. She holds a doctorate in Computer Science from the University of Colorado Boulder.
- Graham Johnson – Mr. Johnson is a senior member of the Visualization Team and an expert in web-based interactive visualization tools. He holds two Master's degrees in Mathematics and in Aeronautical & Astronautical Engineering from Purdue University.

All members of the research team have completed IRB training and are well-versed in the proper conduct of research and treatment of subjects.

As for the facility, the Visualization Research Team operates the Insight Center, a visualization lab with state-of-the-art equipment for 2D and 3D visualization. The Insight Center receives dozens of visitors every week learning about various energy systems research questions through interactive visualizations. A member of the Visualization Research Team is always present for

these demonstrations and will be able to administer the survey and interviews described above as time allows. Each study will add just 10-15 minutes of additional time to any given visit to the Insight Center.

Prior Approvals

There are no relevant prior approvals for this protocol. It is the first time it has been submitted for review.

Confidentiality

There will be no Personally Identifiable Information collected throughout the research. Although multiple participants may complete the survey in the room at the same time, we do not foresee any risk to an individual for being known to have participated in our study by their peers. Any data published will be in aggregate or anonymous.

Provisions to Protect the Privacy Interests of Subjects

Participants will fill out their survey responses privately on a sheet of paper so that other people may not know how they responded. Any interviews will take place between just the researcher and the subject with privacy from any other subjects.

Compensation for Research-Related Injury

There is no risk of injury for participating in this study.

Economic Burden to Subjects

There is no anticipated economic burden to subjects for participating in this study outside of 10-15 minutes of their time. No direct compensation will be provided for this.

Consent Process

Upon expressing interest, we will describe the study to the participants and provide them with the survey. At the top of the survey, there will an additional written description of the study to serve as informed consent. Because there are no anticipated risk to participants, we will not ask for a signature. Participants will be required to consent before formally participating. The informed consent information sheet is as follows:

Welcome, and thank you for your willingness to participate in energy visualization research!

Purpose: The purpose of this research is to understand how well different types of visual encodings affect the interpretability of power systems data. Your participation is purely voluntary!
Requirements: Must be at least 18 years old, fluent in English, and normal vision (with or without corrective lenses
Procedure: You will be shown various visualizations and asked a series of questions about them. The whole form should take less than 10 minutes to complete.
Benefits & Risks: There are no benefits nor foreseen risks of participating in this study.
Confidentiality: Your participation is anonymous. All records from this study will be kept confidential and we will not record any information that will make it possible to identify you.

Contact information: If you have any questions, concerns or complaints about this research, its procedures, risks, and benefits, contact the study's principal investigator, Kenny Gruchalla, at Kenny.Gruchalla@nrel.gov. If you have questions regarding your rights as a research subject or if problems arise which you do not feel you can discuss with the researcher, please contact the Alliance for Sustainable Energy Human Protections Administrator, Rick Press at rick.press@nrel.gov or 303.275.3229.

☐ I have read the information above and I consent to participating in this study.
☐ I would prefer to abstain from participating in this study.

Process to Document Consent in Writing

As shown in the consent form above, potential subjects will be asked to check a box to confirm that they have read the consent form and are willing to participate in the study.

Drugs or Devices

This research does not involve any drugs or devices.

References

[1] K. Gruchalla, S. Molnar and G. Johnson, "Reevaluating Contour Visualizations for Power Systems Data," in IEEE Transactions on Smart Grid, vol. 14, no. 6, pp. 4877-4887, Nov. 2023, doi: 10.1109/TSG.2023.3252468. https://ieeexplore.ieee.org/abstract/document/10058599

[2] I. Lyons-Galante, M. Karimzadeh, S. Molnar, G. Johnson and K. Gruchalla, "Alternatives to Contour Visualizations for Power Systems Data," in 2023 Workshop on Energy Data Visualization (EnergyVis), Melbourne, Australia, 2023 pp. 11-15. doi: 10.1109/EnergyVis60781.2023.00009. https://www.computer.org/csdl/proceedings-article/energyvis/2023/302800a011/1SQrf45KR6o

Appendix A: User Survey

NREL Energy Data Visualization Questionnaire

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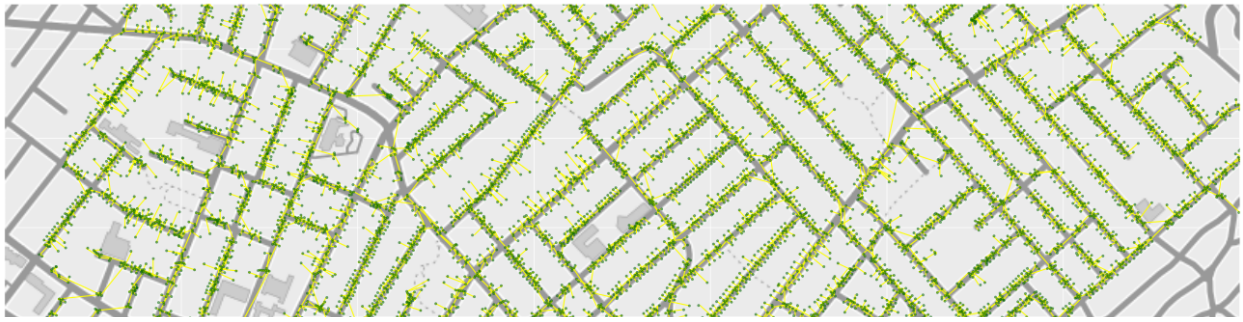
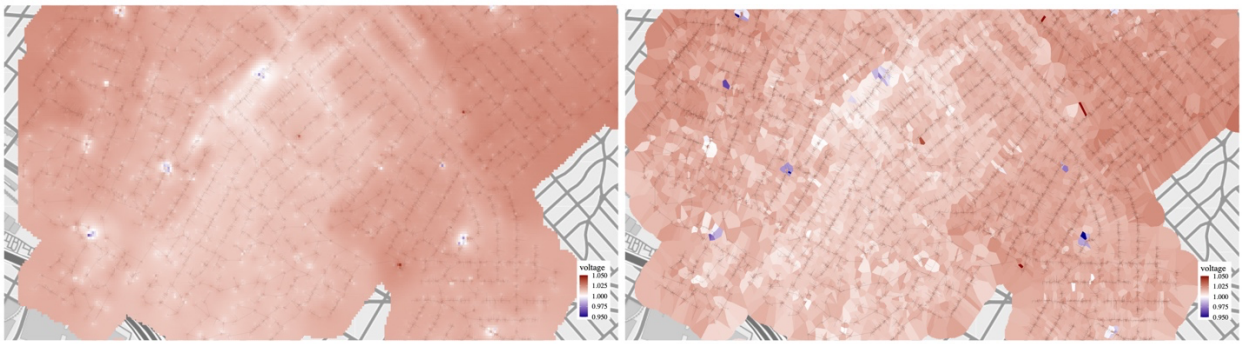
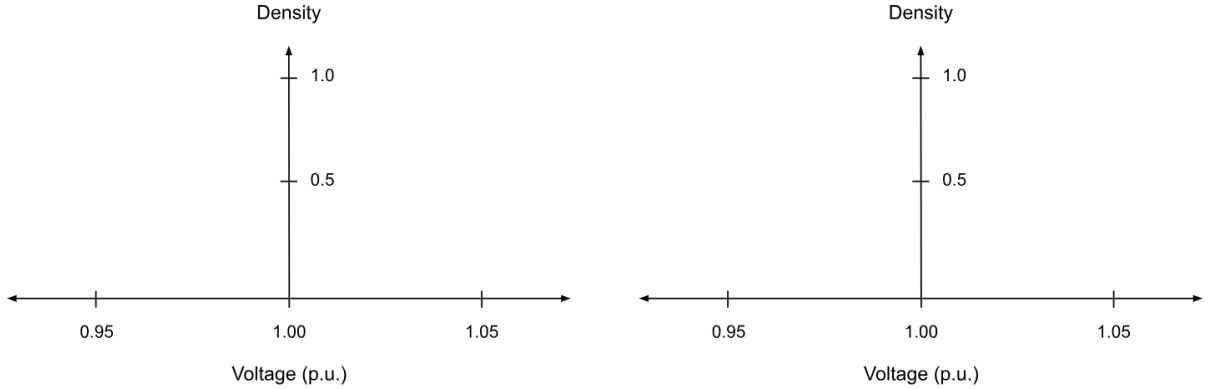
Background: The electricity distribution network below has over 20,000 buses in green and is interconnected by lines in yellow. Each bus in the network has an expected voltage of 1.00 +/- 0.05 p.u.



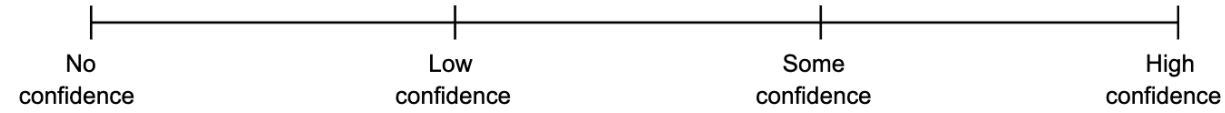
Question 1: Please circle any areas on the map where the voltage exceeds 1.05 or is below 0.95.


voltage
1.050
1.025
1.000
0.975
0.950
voltage
1.050
1.025
1.000
0.975
0.950

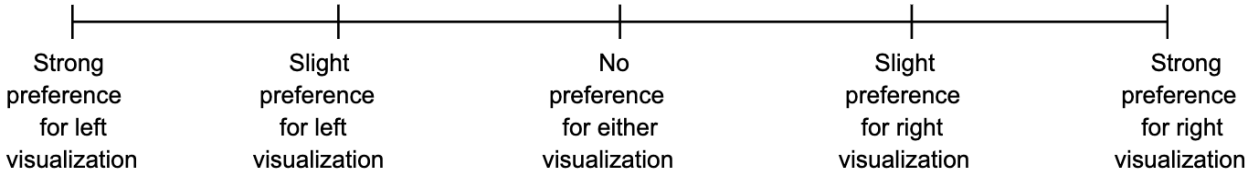
Question 2: Please draw your best guess of the statistical distribution of voltages across each of the diagrams above. A normal distribution is outlined for your reference.



Question 3: How confident are you in your responses? Circle your answer.

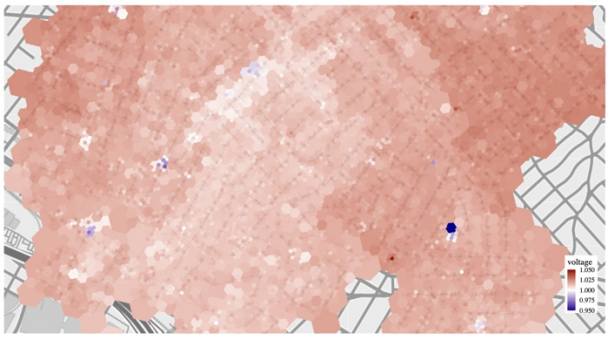


Question 4: Which visualization do you prefer?



Question 5: Do you have any feedback for the researchers?

Appendix B: Additional Visualizations




voltage
1.050
1.025
1.000
0.975
0.950
voltage
1.050
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1.000
0.975
0.950