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# STEPS: A Spatio-temporal Electric Power Systems Visualization

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**Abstract**

As the bulk electric grid becomes more complex, power system operators and engineers have more information to process and interpret than ever before. The information overload they experience can be mitigated by effective visualizations that facilitate rapid and intuitive assessment of the system state. With the introduction of non-dispatchable renewable energy, flexible loads, and energy storage, the ability to temporally explore system states becomes critical. This paper introduces STEPS, a new 3D Spatio-temporal Electric Power Systems visualization tool<sup>1</sup> suitable for steady-state operational applications.

**Author Keywords**

Power system visualization; spatio-temporal visualization.

**ACM Classification Keywords**

H.5.m. Information interfaces and presentation (e.g., HCI):

**Introduction**

The bulk electric grid is a very large and complex system composed of many elements, including hundreds of generators and thousands of buses and transmission lines. These elements are monitored by

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<sup>1</sup> Demo Videos: <https://goo.gl/qcmVd9>

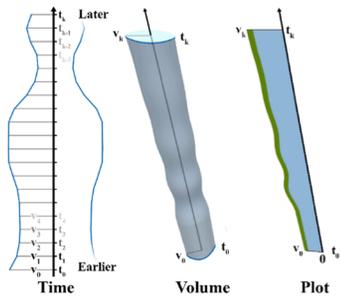


Figure 1: The *time volume* and *time plot* visualizations of a geospatial point (in this case, a bus). The values of the visualized attribute determine the radius of the volume and width of the plot, giving the user a quick summary of the bus behavior.

sensors connected to remote terminal units that periodically collect incoming streams of new information that power system operators must quickly analyze and understand in order to make effective control and operational decisions. The key to mitigating this information overload is to develop effective visualizations capable of swiftly transforming large datasets into representations that facilitate intuitive and rapid assessment of the overall system state [1].

Visualization has been used in power systems for over two decades with tools deployed in control centers around the world [2]. These tools typically utilize static large-scale 2D graphs and visualization techniques, including pie charts, animated arrows [3], and contouring [4]. As the electricity grid is populated with spatially distributed renewable energy, energy storage,

flexible loads, and smart power devices, new behaviors are emerging at shorter temporal scales that were previously not considered. This shift is driving the demand for new visualization approaches that can equip operators with the situational awareness they need in this dynamic environment [5].

A geographically based tool helps power system operators quickly pinpoint problem areas in the grid [2]. The ability to temporally explore system states could be used by operators to track the evolution of power system events as well as forecast upcoming changes. The large-scale 2D visualizations used in the past are appropriate for a more reactive operational setting; they cannot provide users with the necessary temporal reference. Animation also has its own limitations, requiring repeated re-watching to glean systemic behavior. The idea of using 3D to visualize power system data [7] is not a new one, but it has not extended to power system applications. Also, different methods of temporal navigation have been explored in other industries [8], [9]. However, most of the previous works in this area do not concurrently provide a geographic reference while addressing the issue of comparisons across time. The main contributions of this poster are 1) to present this new overview approach for visualizing time-varying power system information, 2) describe features implemented in STEPS, a prototype visualization tool, and 3) demonstrate the application of this visualization on a synthetic 37-bus test case.



Figure 2: STEPS's main view is composed of (A) the control panel and (B) the 3D network view. Here the 3D network view illustrates the changes of a desired variable, through time, for each bus. The control panel allows users to select the visualized attributes, visual bus and line characteristics (such as opacity or height), filter out values, adjust the cameras, and many other features.

### STEPS: Spatio-temporal Visualization

STEPS includes two distinct visualizations for time-varying, geospatial point data (such as bus/generator voltages or angles) and a single directional visualization for directed linear or path data (such as transmission

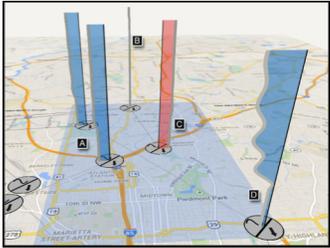


Figure 3: Time plot visualizations for several buses. Positive values are shown in blue, while negative values are red. The wavy bar (right) shows variable production while the red bar shows constant consumption (middle). Buses with near-zero values appear as an uncolored stalk.

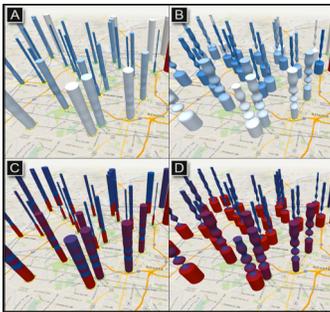


Figure 4: STEPS offers two methods for scaling volumes based on the underlying data: unscaled (A&C) or scaled by individual bus value (B&D). We also support color scheme by global value (A&B) or by individual bus (C & D).

line flows). The visualization is rendered over a map of the control area based on GIS data. For geospatial points like buses, we propose a *time volume* representation (Figure 1-middle) and a *time plot* representation (Figure 1-right). For both representations, the z-axis represents the time dimension. Earlier time steps are displayed toward the bottom (closer to the underlying map) while recent times are displayed toward the top.

The time volume representation leverages human depth perception and spatial sense to convey the evolutionary behavior of a single variable over time. The width of the volume is proportional to the rise and fall of a variable through time. The data points themselves form the radii for the lathe-like volumes and can be scaled to improve clarity. We offer local (for a single bus) and global (network wide) scaling. The more constant a variable, the more uniform its volume; a constant value will appear as a cylinder while oscillating values will appear vase-like or jagged (see Figure 4). Additional time steps can be visualized by increasing the height or by compressing the space between the radii of the tube. The time plot visualization (Figure 1-right and Figure 3) uses a vertical time-varying data plot. The color of the plot area denotes negative or positive values. Both approaches allow a user to compare the state of the system over many different time steps in order to understand the subtleties of complex system behavior. When viewed from above, only a single moment can be seen, summarizing the entire network with the more conventional 2D network-view that operators and engineers are used to seeing (Figure 5).

## User Interface

The STEPS user interface is comprised of two main sections (Figure 2). The control panel (A) provides the user with customization options for how their network data is visualized. The 3D network view (B) shows the time-varying volumes representing geospatially located buses or lines. We use synthetic GIS data to demonstrate the user interface and visualization techniques. The control panel allows the user to adjust the visualization:

### Bus (Generator), Line, and Camera Controls

The bus tab supports the customization of buses like: which variables should be visualized, whether to use time volumes or time plots, how to scale the volume based on that variable (Figure 4), how to color the volumes (Figure 4), the opacity of the time volumes or plots, filter by value for each, and manually adjust bus radius.

The line tab allows the customization of the line elements like: which variables should be visualized, the opacity of the line visualizations, and the filter level for when to show the line visualizations.

The camera menu facilitates the customization of the 3D views: the plot, volume, and line flow stack heights, hide shapes that are too close to the camera during exploration.

### Interaction Design

STEPS was designed to promote real-time user interaction. We support the conventional methods for exploring 3D environments: rotation, translation and zoom. These are more easily portrayed in video and can be seen in the supplementary demo footage. We

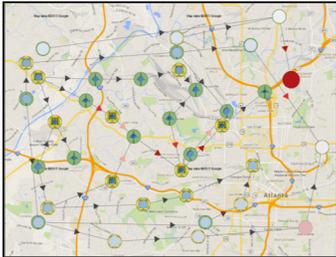


Figure 5: The top-down view in STEPS provides a conventional map-overlay network view, showing only a single measurement per node and line. The triangles show the direction of flow over lines while their color demonstrates the magnitude (high is darker red).



Figure 6: In order to show and hide the lines and buses, each selection plane can be interactively dragged.

allow flexible selection of buses and lines through a click and drag approach. The user can drag out selections over rectangular regions of the map to show just the lines and buses of interest. The selections, in blue, can be moved around the map in real time by dragging them with the mouse (Figure 6).

We developed our system using a client-server architecture with persistent data storage in SQLITE, so that the visualization needs only the visualized data and not the entire dataset at one time. STEPS uses state-of-the-art WebGL to render a time-varying network.

### Conclusion & Ongoing Work

By rendering each bus as a time volume or time plot, we offer users a quick and easy way to understand a power network's behavior through time. In our ongoing investigation, we are studying the usability of STEPS's features for summarizing and comparing power system network behavior through time. We plan to deploy STEPS on larger power systems to collect feedback from domain users (e.g., operators at control centers) on real-world tasks and how it may help with their day-to-day operations.

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