Introduction: Visualizing the Grid with HILLTOP+

Think of the utility grid like a highway system.

You've got the interstate (transmission lines), loops and exits (distribution feeders), and the main streets (local circuits) feeding homes and businesses. Hilltop+ builds a detailed model of this infrastructure—just like a GPS map of every road, intersection, and traffic light.
But the real value comes when we start simulating *traffic patterns*.

We throw in:

- Morning rush hour (peak load conditions)
- Late-night quiet (low demand scenarios)
- Accidents or flat tires (faults or outages)
- New traffic lights or detours (adding solar, batteries, EV chargers, etc.)
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With Hilltop+, utilities can see how the grid behaves, test out "what if" scenarios, and understand the impacts of new technologies or grid upgrades—*before* making major investments.

It's like running a full-scale traffic simulation to improve flow and reduce congestion—only for electrons instead of cars.

Executive Summary

"HILLTOP+: The Swiss Army Knife of Power Systems Modeling and Testing"

Developed by Tennessee Tech's Center for Rural Innovation (TCRI), HILLTOP+ is a power systems testbed designed for real-time simulation, analysis, and testing of power grid systems, distributed energy resources (DERs), and microgrid technologies.

By integrating cutting edge software and hardware-in-the-loop technology, HILLTOP+ equips utilities, energy providers, and independent contractors with the tools to tackle complex grid management and energy planning challenges, including:

- **Grid Planning & Optimization** – Simulate grid performance under extreme weather conditions, model outages and failure events, and develop data-driven response strategies to improve system resilience.
- **Renewable Integration & Regulatory Alignment** – Assess the impact of Distributed Energy Resources (DERs) on grid stability while ensuring compliance with evolving regulatory standards through data-driven insights.
- **Risk Mitigation** – Reduce financial and operational risks by leveraging real-time modeling for feasibility studies. Identify grid vulnerabilities, validate technology performance, and make informed, data-driven investment decisions.
- **Training, Engineering Support & Integration** – Gain access to comprehensive training materials, dedicated engineering support, and integration with industry-standard platforms such as Python, MATLAB, Typhoon HIL, and OpenDSS, empowering users to work independently with confidence.
- **RFP Data & Reporting** – Strengthen competitiveness in RFP processes with detailed technical reports based on real-time simulations, helping users refine proposals and demonstrate project feasibility.

Process Overview

HILLTOP+ follows a structured, three-phase engagement process designed to ensure accurate assessments, effective simulations, and high-quality final deliverables. Throughout this process, analysts, modelers, and technicians work collaboratively to execute each phase with precision and expertise.

Phase 1: Initial Consultation

We will schedule an initial consultation with our **HILLTOP+ Analyst** to:

- Assess your business or utility's current challenges in energy planning and grid management.
- Define clear objectives that HILLTOP+ can address through modeling and simulation.
- Outline expected deliverables and key project milestones.

If you decide to move forward with HILLTOP+, we will provide a Modeling Agreement, Non-Disclosure Agreement (NDA), and an intake form to gather details about the study scope, available data, and specific requirements.

Phase 2: Model Development & Support

Once we receive your information, a **HILLTOP+ Modeler** will:

- Translate your objectives into actionable simulations using HILLTOP+ software and real-time modeling tools.
- Guide you through the process of building, testing, and refining the model to meet your project goals.
- Connect you with **engineering and technical experts** for ongoing support, troubleshooting, and training to ensure seamless integration into your workflow.

Throughout this phase, we work closely with your team to ensure the models align with real-world scenarios, regulatory requirements, and industry best practices.

Phase 3: Project Completion & Final Deliverables

We believe a project is only complete when our client's objectives have been fully met. At this stage, our team will conduct a final review meeting to:

- Present key findings and simulation results.
- Ensure all deliverables are provided and meet expectations.
- Discuss the next steps for implementing the insights gained.

Upon completion, you will receive:

- **Comprehensive Technical Report** – A detailed document summarizing project findings, simulation results, system performance assessments, and actionable insights tailored to your objectives.
- **Project Simulation Files & Code** – Full access to the models, scripts, and datasets developed during the engagement, enabling further analysis, refinement, or integration into your systems.
- **HILLTOP+ Training Materials** – A repository of instructional content, including slides, video recordings, and documentation to support continued independent use of HILLTOP+.
- **Post-Project Support & Consultation** – A scheduled debrief session with our team to address any remaining questions, discuss long-term strategies, and explore opportunities for further collaboration

Frequently Asked Questions

Q: What information will I need to provide to the modeler?

A: After your initial engagement with the HILLTOP+ team, you will need to complete an intake form. This form includes general contact details, a project description, information about feeders at the specified substation, and your distribution grid model. If you do not have all the requested data, a HILLTOP+ analyst can work with you to find alternatives or develop solutions to accommodate missing information.

Q: Are there any limitations to the HILLTOP+ model?

A: Yes, the HILLTOP+ program is not intended for high-power circuit device testing or full-scale power hardware evaluations. Additionally, due to limitations of the Field Programmable Gate Array (FPGA), some problem complexity may need to be reduced to maintain real-time performance. However, our team will work closely with you to understand your specific project needs and address any limitations in a way that supports your goals.

Q: How does HILLTOP differ from tools like Milsoft or Cyme, and what advantages does it offer?

A: HILLTOP is built for real-time simulation and hardware-in-the-loop (HIL) testing, allowing you to test and validate actual grid components, controllers, and microgrid systems in a dynamic, controlled environment.

Unlike Milsoft or Cyme, which focus on static planning and load flow analysis, HILLTOP offers real-time, dynamic simulation of electrical systems with the ability to integrate real hardware—such as controllers, inverters, and RTACs—for hardware-in-the-loop (HIL) testing. It supports custom components and control development using Typhoon HIL and Python, and enables flexible modeling workflows through tools like OpenDSS, EnergyPlus, scripting and more.

In short, HILLTOP is a testbed, not just a planning tool—designed to help you move from models to real-world readiness.

Q: Are there any existing case studies demonstrating the efficacy of the HILLTOP program?

A: Yes, the outcomes of a recent study have demonstrated the effectiveness of the HILLTOP program in integrating distributed energy resources into a rural distribution grid:

- A 17 MWh energy storage system (ESS) with an 8.5 MW inverter successfully reduced peak demand during a 6-hour window, as confirmed by Typhoon HIL simulations.
- Up to 2.3 MW (8.44%) of solar PV could be integrated without requiring grid modifications.
- Combined PV and ESS deployment produced $706K in savings over 11 months, outperforming PV-only ($435K) and ESS-only ($152K) scenarios.
- All configurations maintained voltage and current within acceptable limits, with no negative impacts on grid stability.

Additional details can be provided upon request.

HILLTOP Program Specifications

Software Components

Core Simulation Software

- Typhoon HIL Control Center – Real-time digital simulator with a premium licensed toolbox for power grid modeling.
- EPRI OpenDSS – Distribution system simulation software for offline studies and power flow analysis.
- MATLAB/Python IDE – Used for scripting, automation, and data analysis within simulations.
- EnergyPlus – Building energy modeling software for load forecasting in different weather conditions.
- EPyQ Tool – Software for controlling EPC Power inverters.
- AcSELerator RTAC Software – Configures and programs SEL RTAC microgrid controllers.

Graphical & Programming Interfaces

- Typhoon HIL Schematic – Drag-and-drop interface for creating real-time simulations of distribution grids.
- Typhoon HIL SCADA – Supervisory Control and Data Acquisition (SCADA) interface for monitoring and control.
- Python for Typhoon – Enables customization of SCADA objects, simulation automation, and external device communication.
- Structured Text (ST) Programming – PLC-based language for programming microgrid controllers.

Custom Utility Programs

Python-based programs for:

- Large-scale OpenDSS study automation.
- Weather data acquisition for simulations.
- Custom Modbus utilities for communication studies.
- Scaling EnergyPlus models for more accurate customer load representation.

Hardware Components

Core Computational & Simulation Hardware

- Typhoon HIL 606 Devices (x2) – Real-time digital simulators with FPGA-based processing.
- PC Workstation – High-performance computing platform for running simulations and analysis.
- SEL RTAC 3530-4 Controllers (x2) – Real-time automation controllers for microgrid control applications.

Power Electronics & Control Devices

- EPC Power PV & BESS Controllers (x4) – Commercial inverter and battery energy storage system (BESS) controllers.
- Hil Connect Box – Signal amplification and interface for integrating hardware-in-the-loop (HIL) simulations.
- Smart Meters – Used for real-world measurement integration into simulations.

Networking & Communication

- Network Switch & Firewall (x2) – Secures and manages data communication within the HILLTOP+ system.
- DIGI AW08-G300 Remote USB Hub (x2) – Allows remote access to connected devices.

Communication Protocols

- Modbus & CAN – Standard protocols for communication between simulated and real hardware.
- IEC 61850 (Upcoming Expansion) – Future capability to integrate substation communication for extended hardware options.