Distribution Grid Analytics to Enhance Renewable Dominated Grid Reliability

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Background and Project Motivation

- Current electrical grids are centralized and powered mostly by fossil fuels
- Large push in recent years towards increased integration of distributed energy resources (DER), mainly PV in the Southwest US where conditions are ideal
- Integration of PV destabilizes the grid due to inherent variability so advanced modeling techniques and energy management systems are critical to advancing modern grid technology
- OpenDSS is a widely used software within the industry for performing time-series analysis on distribution systems, but it has critical drawbacks when it comes to ease of use and plotting capabilities
- The Phoenix Metro area has seen extensive development of utility scale PV and associated energy storage systems indicating significant investment in solar energy and battery storage tech

Project Scope and Goals

- Design a custom 13-bus, linear distribution grid using OpenDSS incorporating a utility scale PV system and battery storage to meet the load requirements within +5/-12%
- Incorporate real-world weather for accurate PV system modeling
- Create a testbench using Python to extract pertinent data from the OpenDSS simulation for enhanced analysis and visualization
- Emphasis placed on minimizing interaction with the OpenDSS software and maximizing integration with the Python script
- Goal of the Python integration was to create a testbench that was not project specific, but lays the groundwork for future development
- Script should be able to launch OpenDSS in the background, pull key data sets from simulation, and generate easy to read plots and visually appealing graphics

Initial Distribution System Design

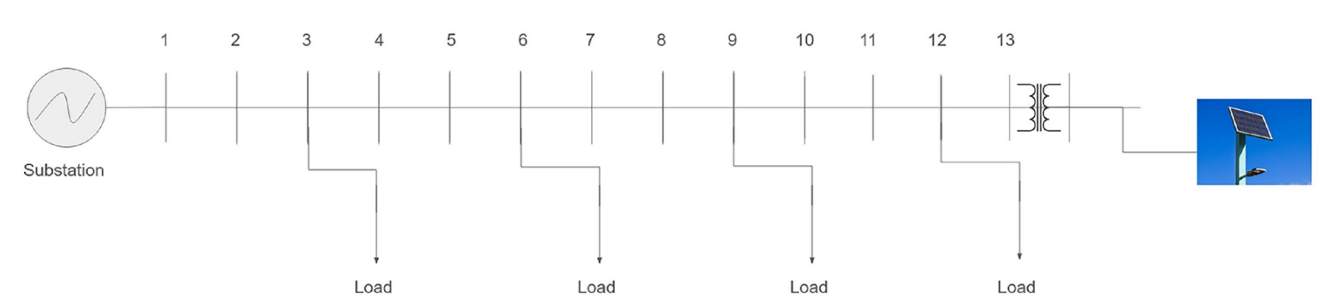

Figure 1. Diagram of the 13-bus distribution grid at 4.2 km in length

- Substation connection at Bus 1, nominal system voltage of 4.16 kV
- Load connected at Bus 3 = 150 kW, Bus 6 = 120 kW, 9 = 200 kW, Bus 12 = 180 kW, 650 kW total system demand
- 500 kW PV system at Bus 13 complete with isolation transformer for system protection. Transformer rated for 4.16 kV, 555 kVA
- 1 MWh, 200 kW battery storage bank connected at Bus 12 (not shown)

Design Considerations

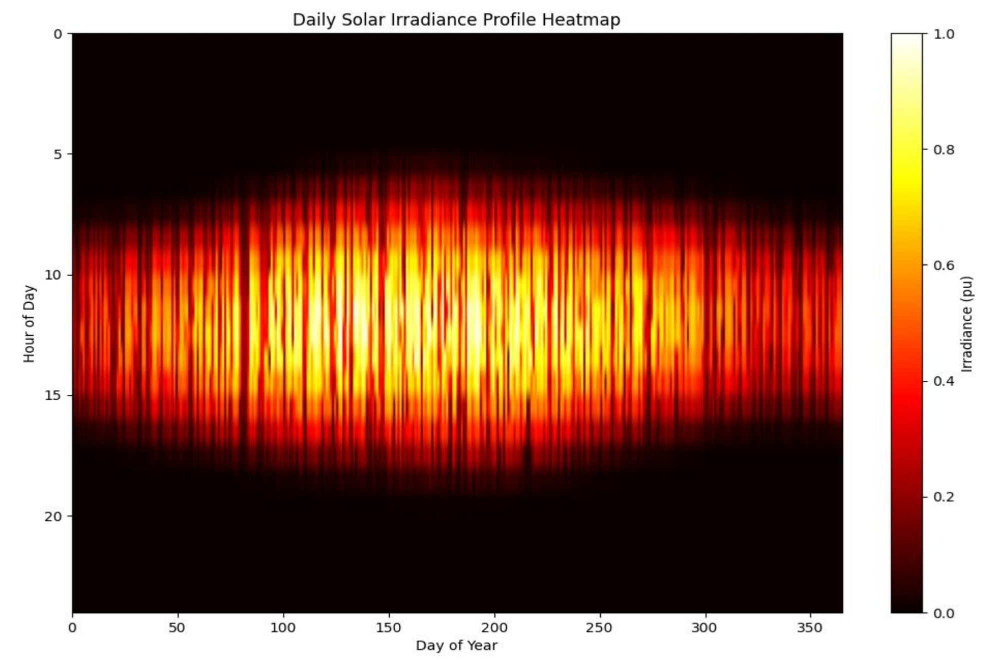

Figure 2. Daily solar irradiance heatmap for chosen location of Norfolk, Virginia

- Solar irradiance and temperature data pulled from TMY3 datasets
- Allows for the accurate modeling of PV system for all hours of the year by enabling development of Power vs. Temp and Irradiance curves

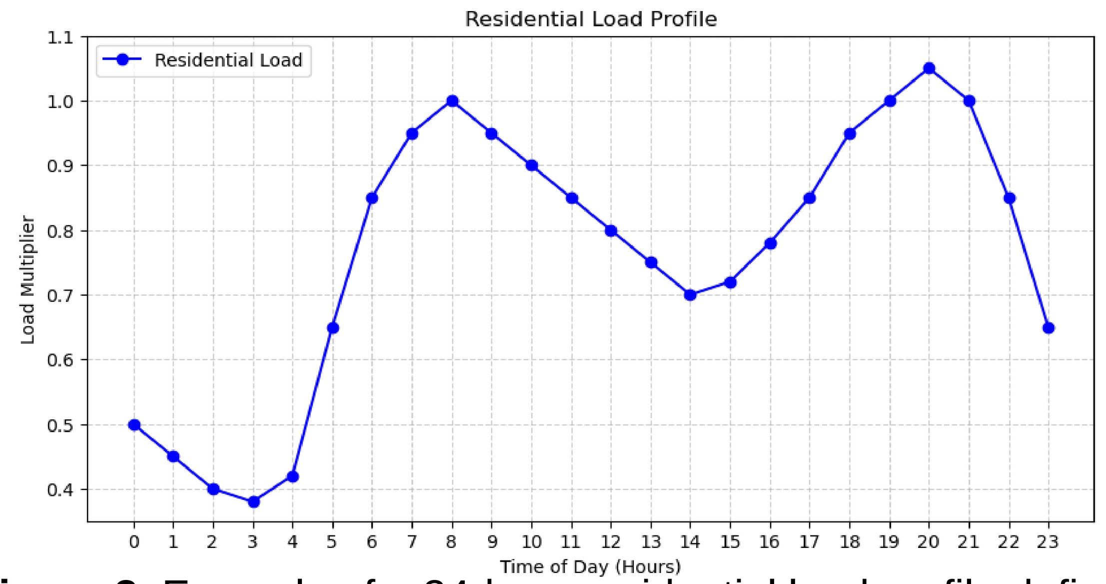

Figure 3. Example of a 24-hour residential load profile defined in the OpenDSS simulation

- Simulates a realistic residential load pattern with peak loads during morning and evening hours coinciding with normal occupancy of the home and operation of appliances

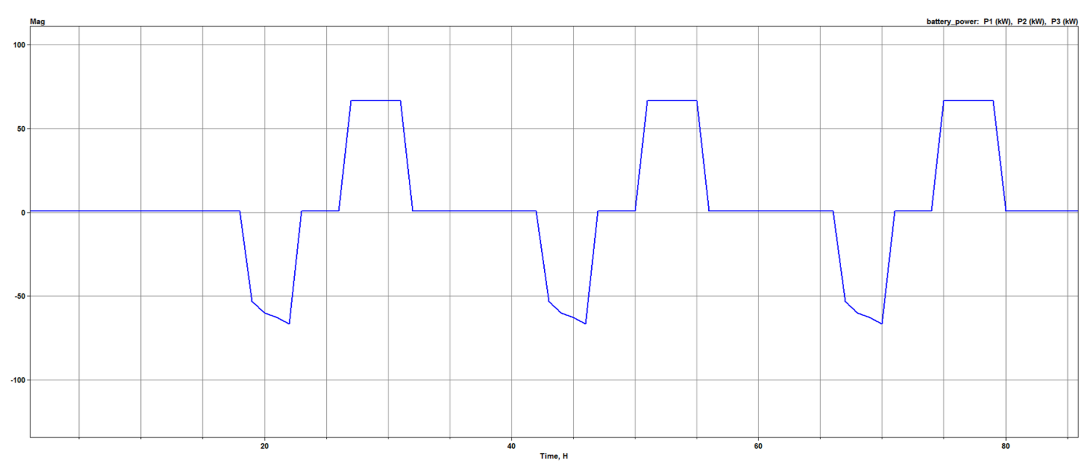

Figure 4. Battery storage cycle showing charge/discharge periods over a 48-hour period

- Battery storage set to charge between hours of 2AM-4PM
- Discharges power back to the grid during peak load hours of 7PM-11PM in a peak shaving measure

Technical Achievements and Critical Results

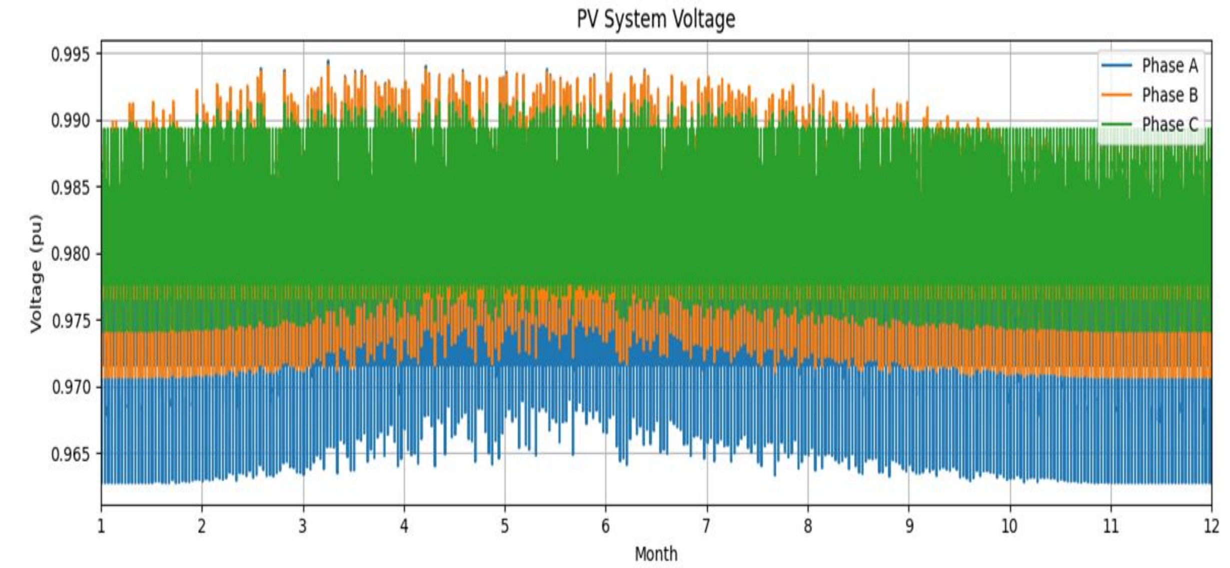

Figure 5. Three phase PV system generated voltage for all hours of the year

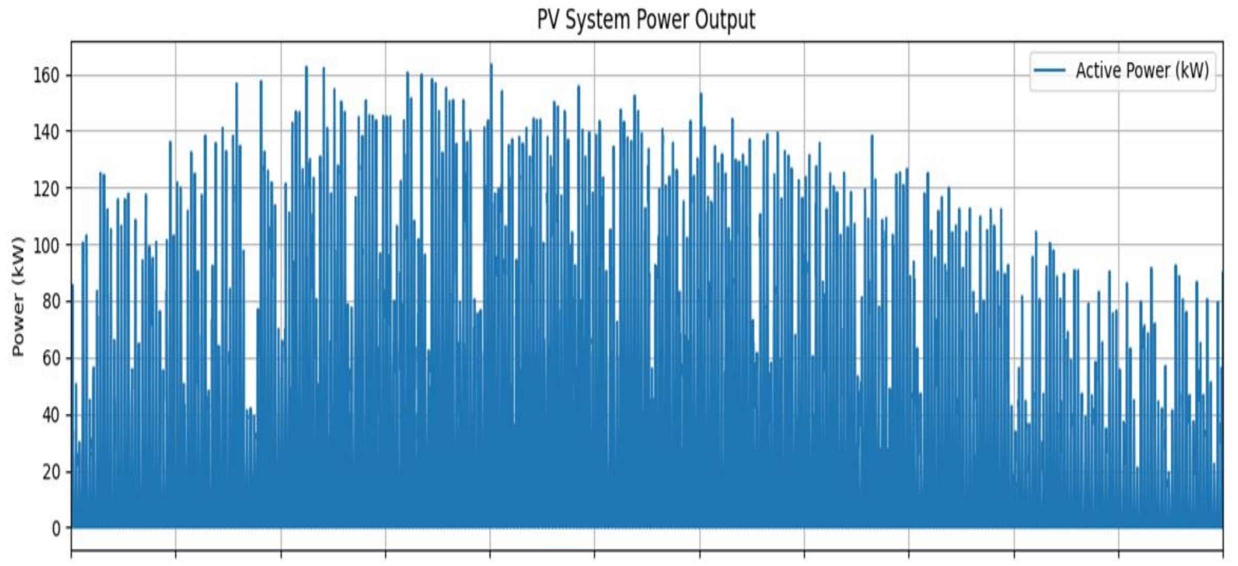

Figure 6. Active power output of the PV system over entire year

- Figure 5 and Figure 6 show examples of data that can be extracted from the OpenDSS simulation utilizing the Python testbench
- Through the openDSSdirect Python package, we can directly queue the simulation and extract data without direct interaction with the OpenDSS script itself

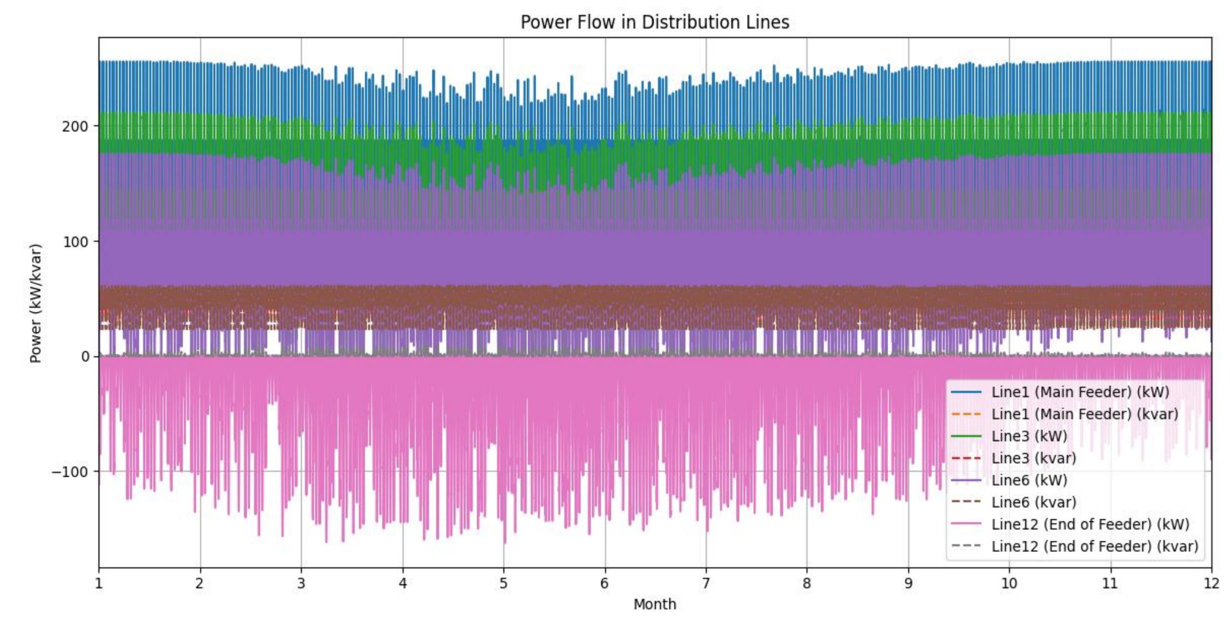

Figure 7. Power flow in lines 1, 6, and 12

- A second method of data extraction is through the use of line monitors and energy meters directly implemented in the OpenDSS script
- While tedious, these monitors export data into .CSV files which can be read into the Python script and used to generate visually appealing plots using the matplotlib library as shown in Figure 7

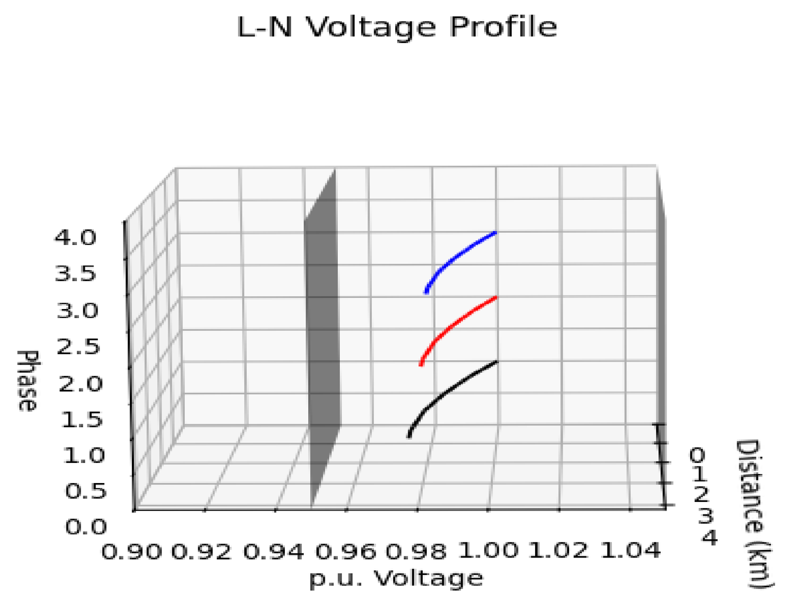

Figure 8. 3-dimensional load-to-neutral per unit voltage profile vs. distance for all three phases from OpenDSS

- Successfully defined and tested all parameters for the designed 13-bus distribution grid
- Active losses = 3.15 kW, Reactive losses = 9.05 kVAR. Losses are negligible compared to system size and indicate excellent system stability
- Max system voltage = 0.9999 p.u., Min System Voltage = 0.9779 p.u. (well within pre-defined voltage standards)
- Comprehensive Python integration with OpenDSS:
  - Ability to launch and run the OpenDSS simulation from Python with data extracted using two distinct methods
  - Functions designed for data visualization for a variety of variables
  - Modular design and functionality of Python script can be scaled for a larger subset of distribution systems and PV system locations

Conclusion and Opportunities for Future Development

- Team 40 successfully worked together to design and test the proposed 13-bus OpenDSS simulation that delivered power to all loads within +5/-12% levels
- Successfully designed a Python testbench for the OpenDSS simulation that minimized interaction with the software and integrated two distinct methods for data extraction and visualization
- Future developments and improvements to the project could include enhanced load modeling, a battery management system to control charge and discharge, and further refinement of the testbench for ease of use

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