Experimental Setup and Learning-Based AI Model for Developing Accurate PV Inverter Models

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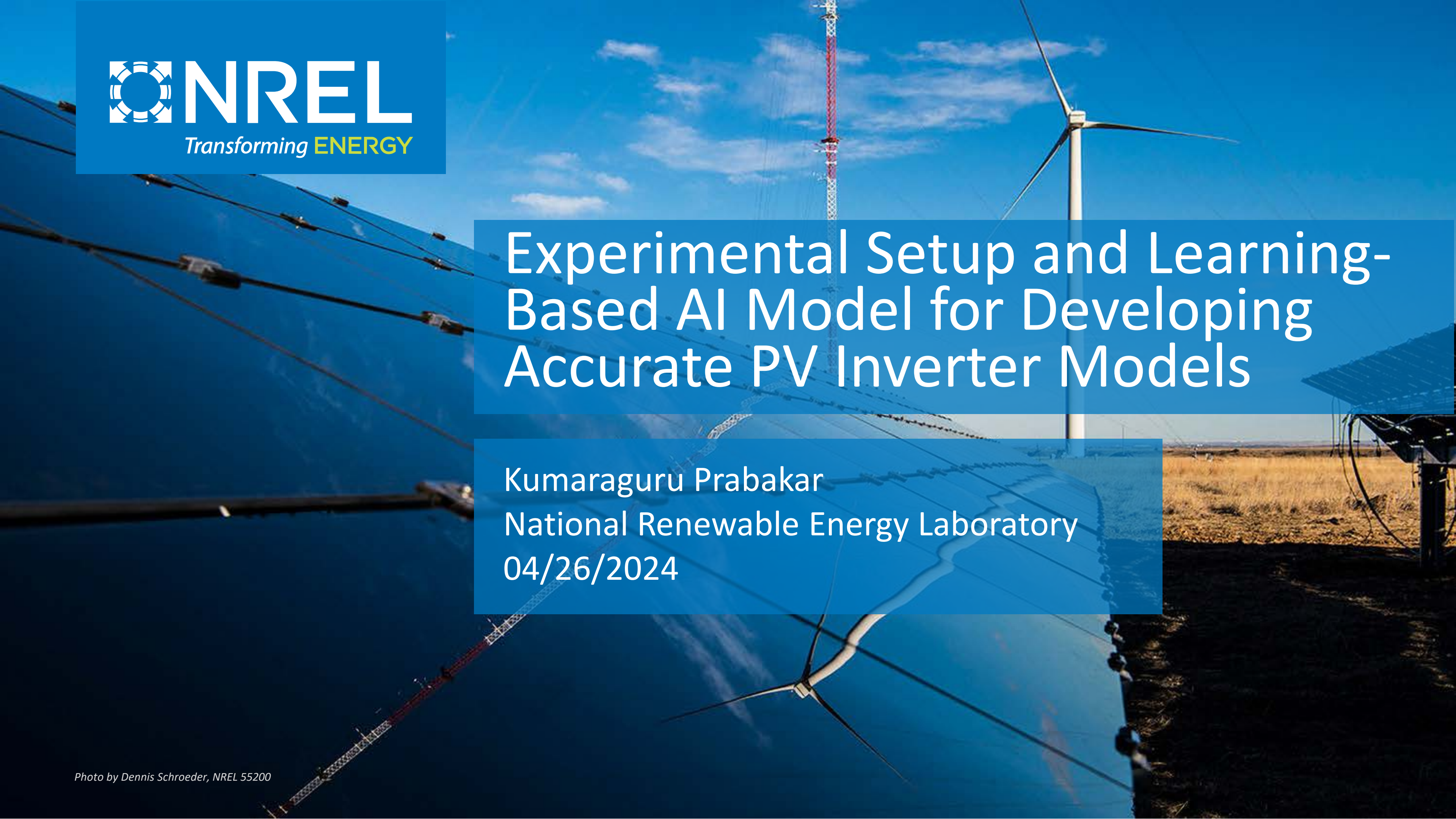


Photo by Dennis Schroeder, NREL 55200

Contents

Energy Systems Integration Facility

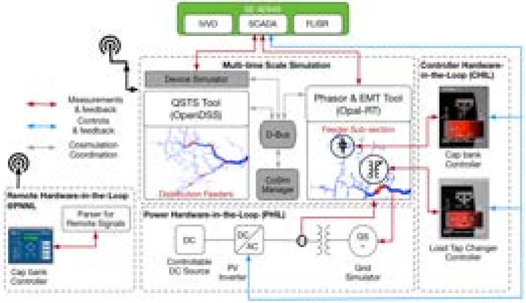
The Energy Systems Integration Facility (ESIF) is a national user facility located in Golden, Colorado, on the campus of the National Renewable Energy Laboratory (NREL).

http://www.nrel.gov/esif *Photo by NREL*

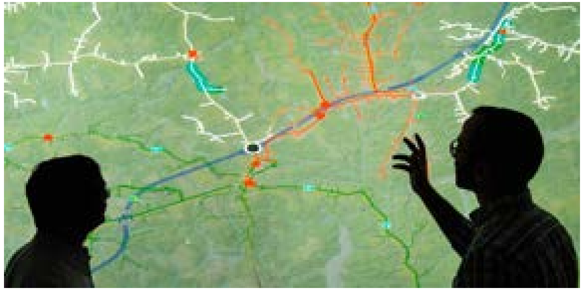
Controller- and Power-Hardware-in-the-Loop

NREL's megawatt-scale controller- and power-hardware-in-the-loop (CHIL/PHIL) capabilities allow researchers and manufacturers to test energy technologies at full power in real-time grid simulations to safely evaluate performance and reliability.

Microgrids



Cosimulation

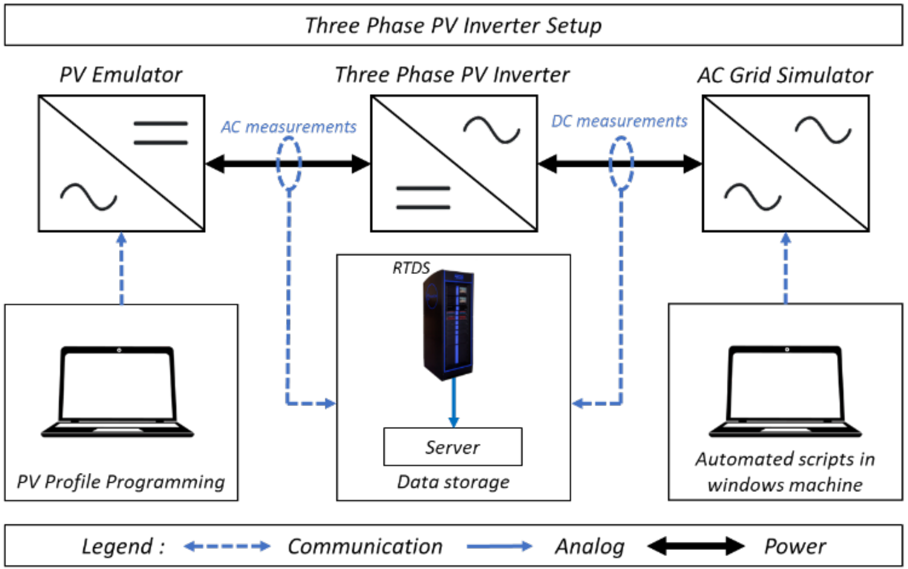


Photos by NREL

Power system studies

Experimental Setup

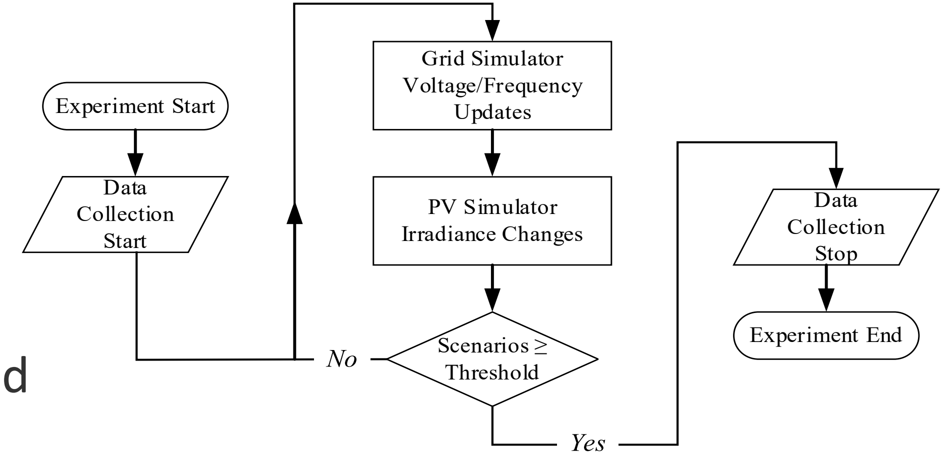
- Controllable AC supply.
- Controllable DC supply.
- High bandwidth measurements.
- High bandwidth, highly reliable, long duration data storage.
- Automated experimental setup.



Inverter under test experimental setup

Experimental Setup

- Three-phase PV inverter.
- Split-phase PV inverter.
- Battery inverter (not presented in the paper).
- Python script to synchronize the experimental setup.
- Experiments are usually completed in less than three hours.
- Data collected less than a few gigabytes.
- Voltage run and frequency run.

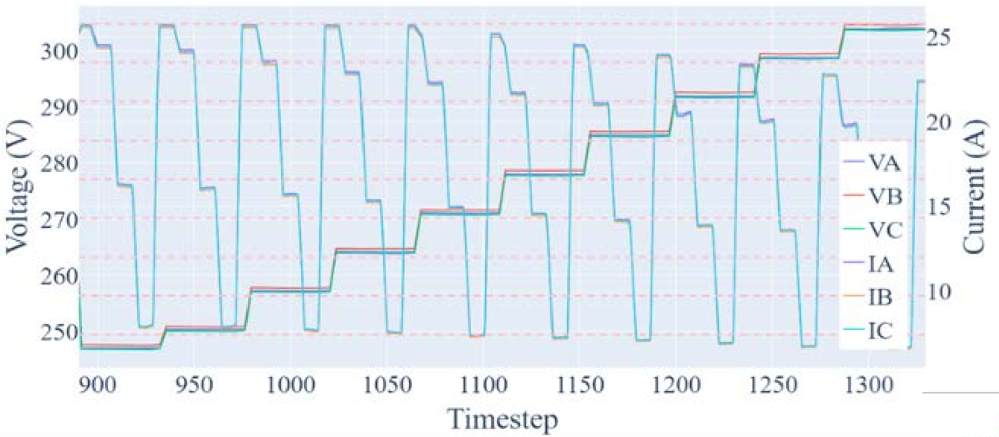


Experiment flowchart

Source: Prabakar et al. 2023

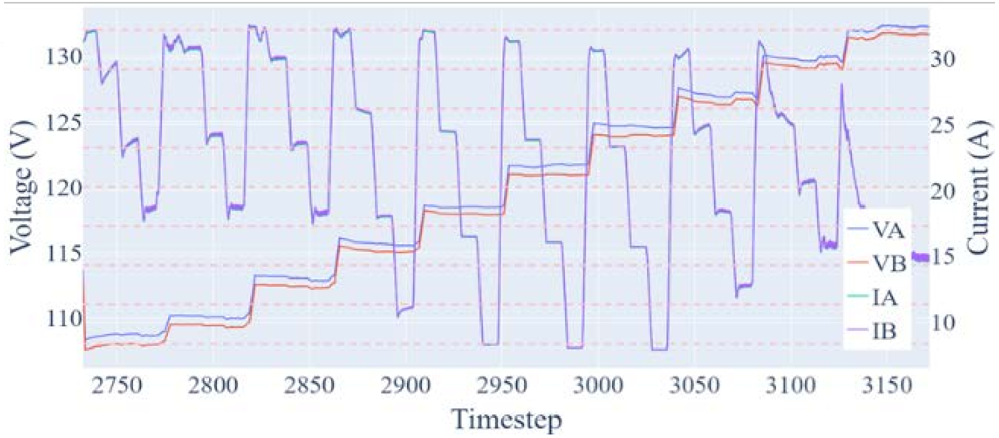
Background on datasets

(a) Three-phase PV inverter



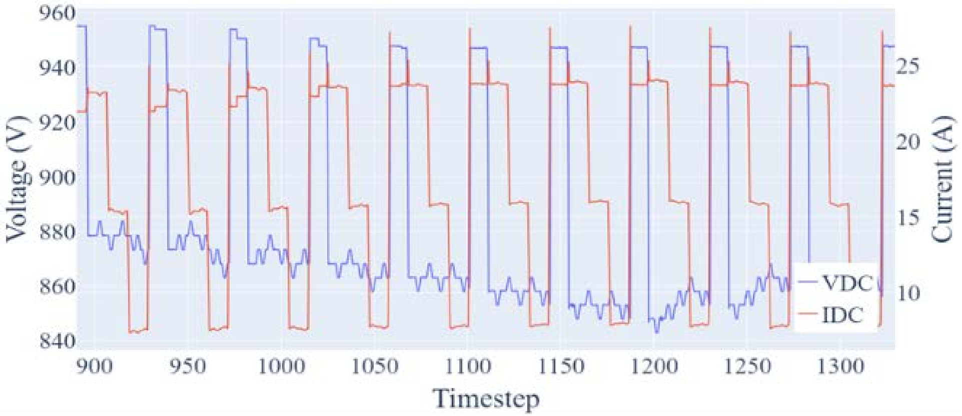
- Voltage magnitude run
  - RMS change
  - Irradiance change

(b) Split-phase PV inverter



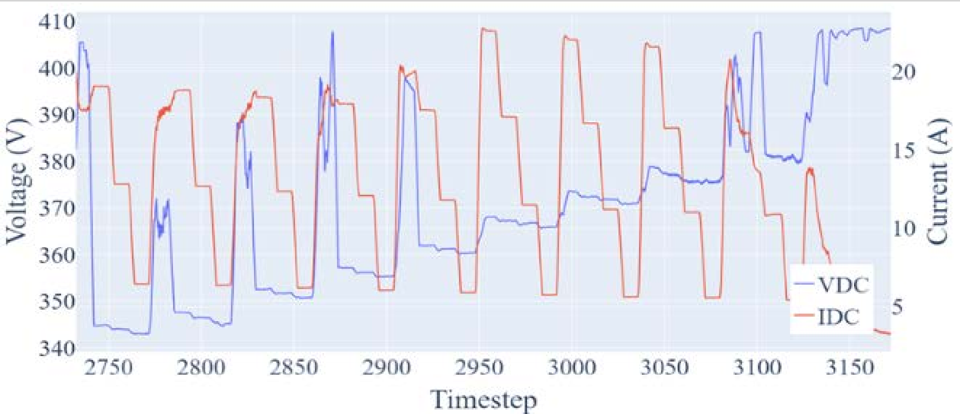
Background on datasets

(a) Three-phase PV inverter



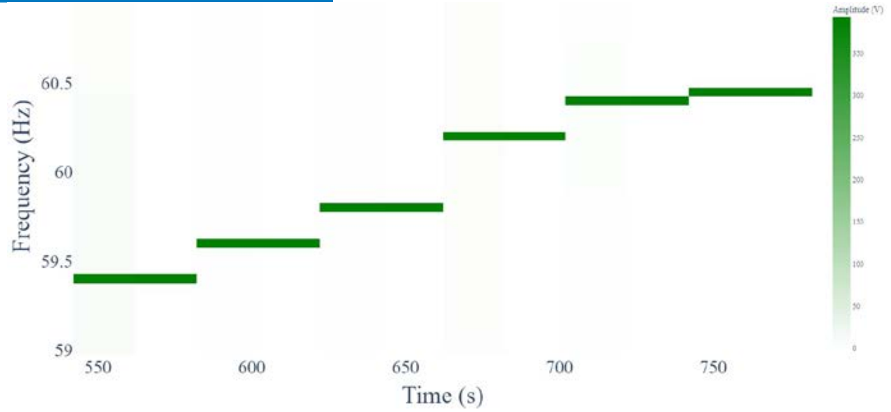
- Voltage magnitude run
  - RMS change
  - Irradiance change

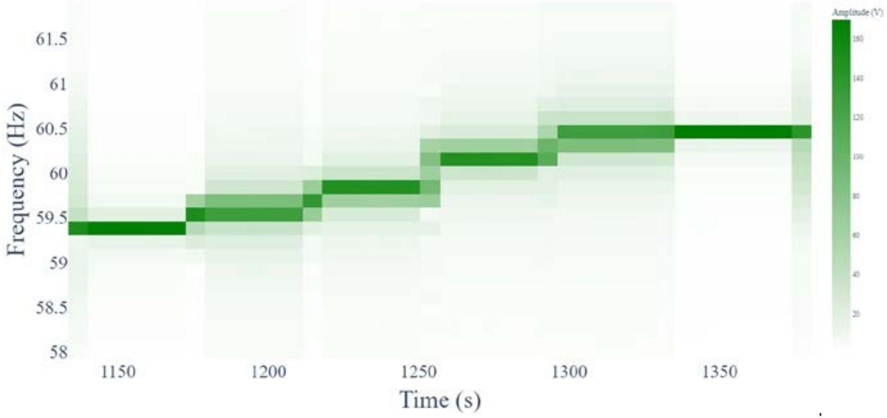
(b) Split-phase PV inverter



Background on datasets

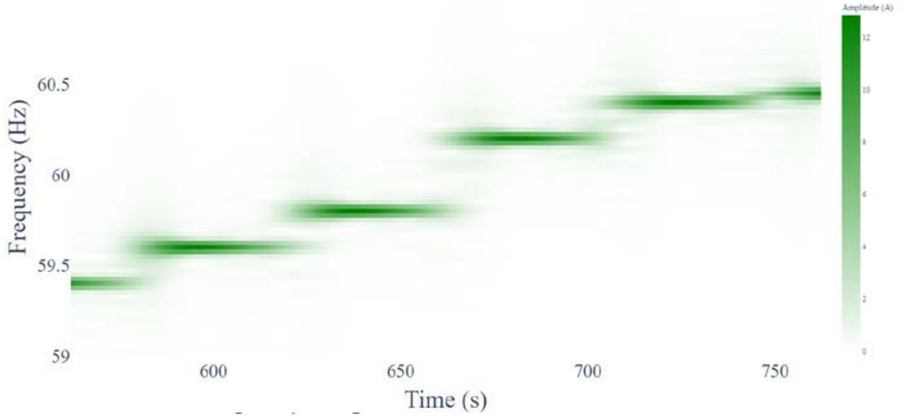
- Voltage frequency run
  - Frequency change
  - Irradiance change
  - Frequency measurement of voltage
  - Fourier transform time prioritized and amplitude prioritized

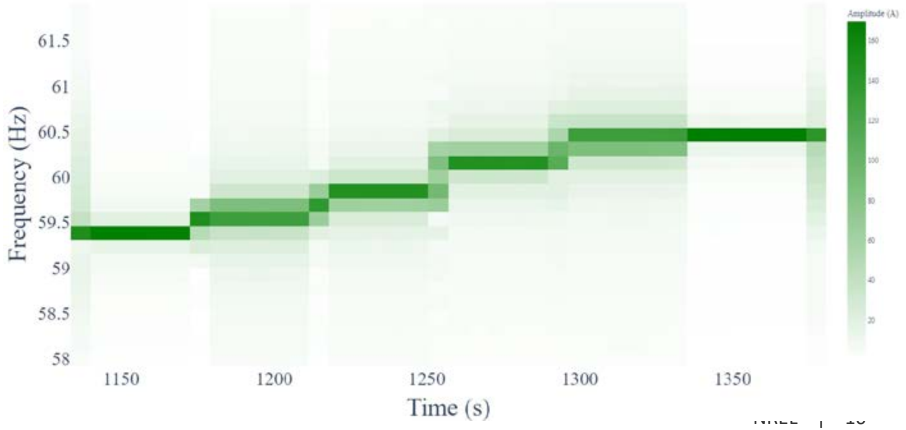




Background on datasets

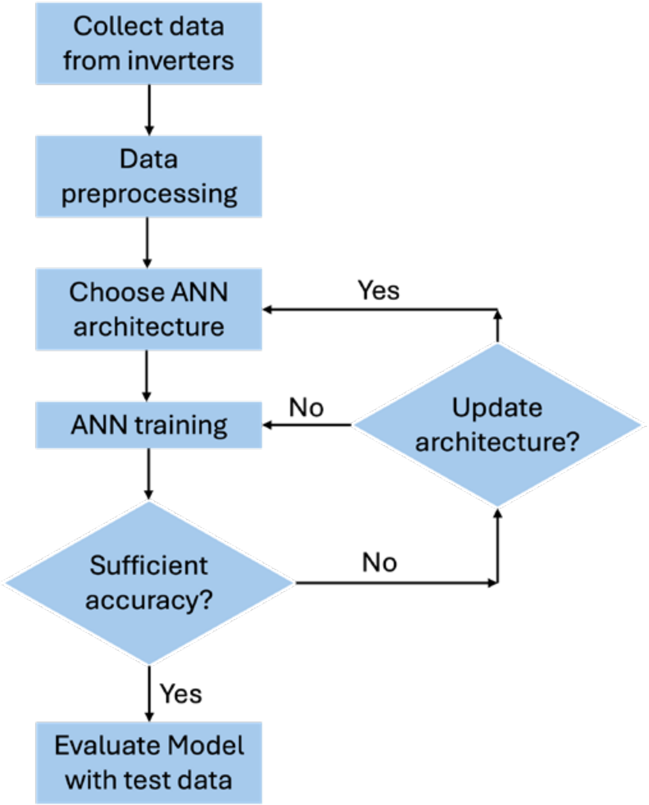
- Voltage frequency run
  - Frequency change
  - Irradiance change
  - Frequency measurement of current
  - Fourier transform time prioritized and amplitude prioritized



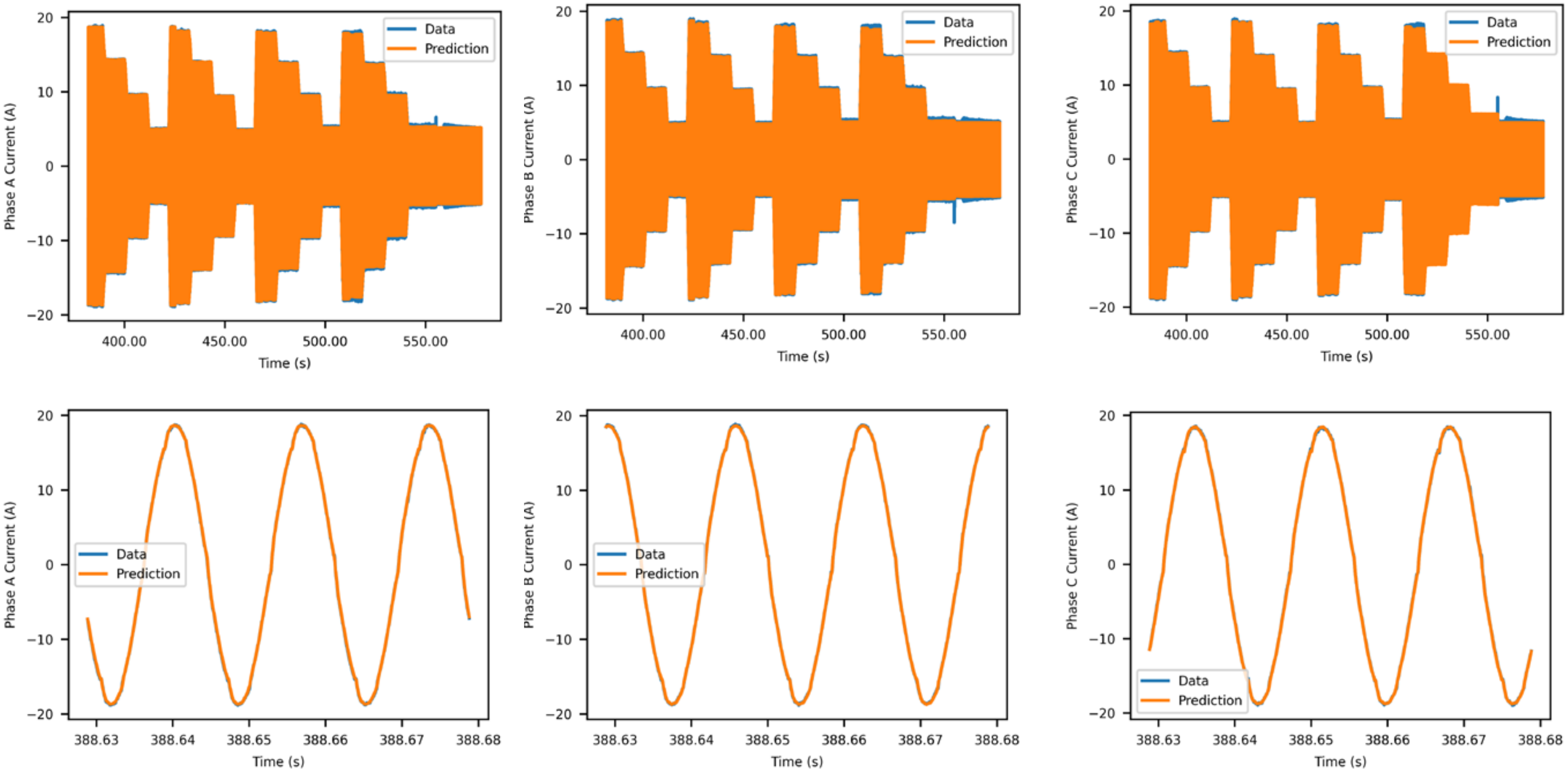


Machine Learning Model

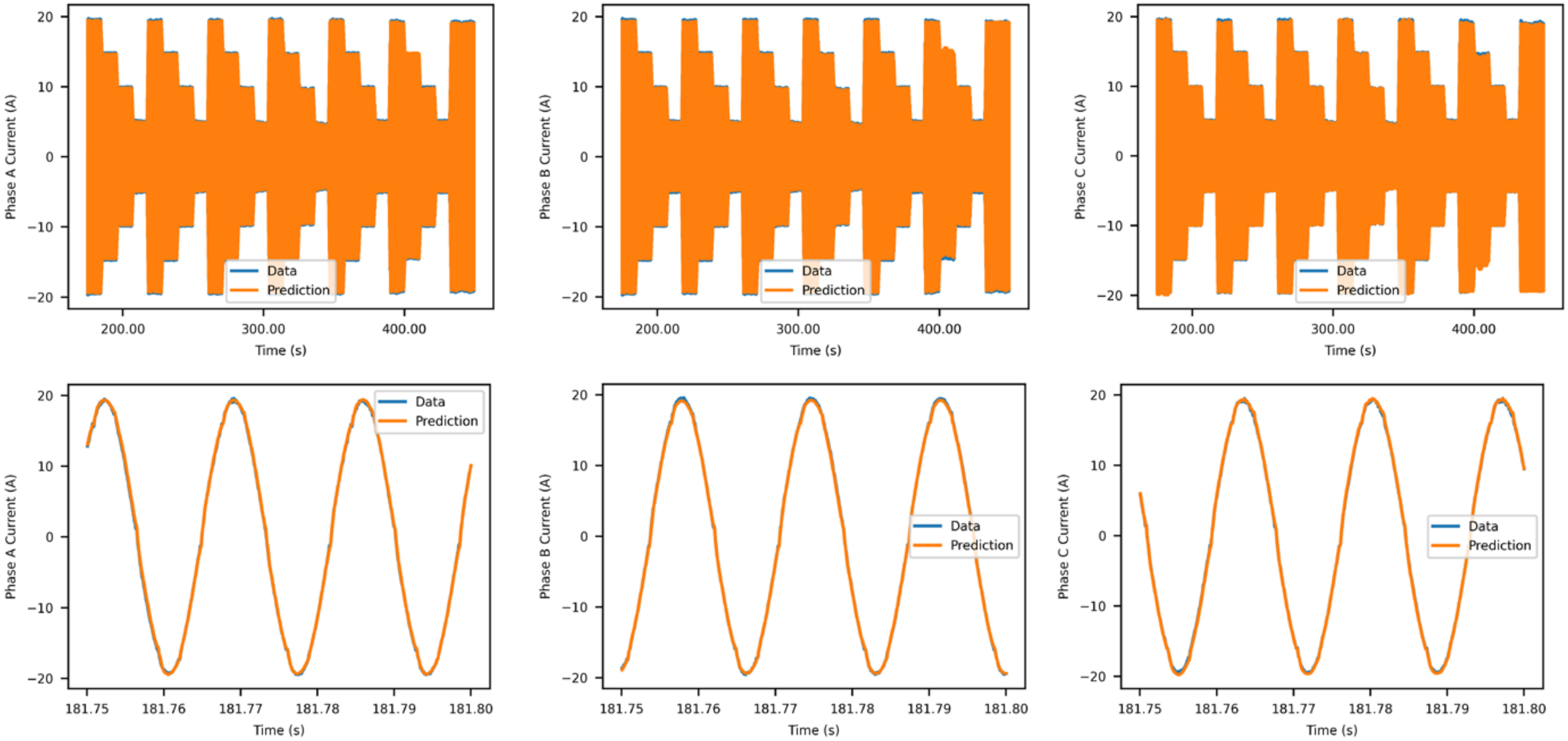
- Inputs: three-phase (a,b,c) voltage, DC current, DC Voltage
- Outputs: three-phase (a,b,c) current
- ANN topology: fully-connected with input/output layers and two 100-node hidden layers using ReLU activations
- Training: Adam optimizer, mse loss function, terminated training after 100 epochs



Voltage step experiments outputs



Frequency step experiments outputs



Future work: machine learning and data collection

- Experimental design: ensure sufficient frequency and voltage coverage in data to train ANN model representation of inverters
- Invest more time into the model, e.g., hyperparameter tuning, adding regularization, etc.
- Represent inverters using more advance ML models: given timeseries data, explore RNNs, Convolutional NNs, and SciML techniques such as:
  - Operator learning (DeepONets or Fouier Neural Operators)
  - Physics Informed Neural Networks (PINNs)

Takeaways and future directions

- Reduced inverter modeling time frame from 12-18 months to 3-6 months.
- Targeting to reduce this to days.
- Currently, experimental data is moved to computational setup after the experiments.
- Targeting to train models while the experiment is running.
- How to handle uncertainties?
- Use of design of experiments to determine the experimental sequence.

References

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Thank You

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