21PESGM2674
Panel Session “Dynamic Modeling in Distribution”
IEEE PES GM 2021
July 26, 2021

Reduced-Order DER Dynamic Models from Machine Learning

Qiuhua Huang, Tom McDermott, Yuan Liu
qiuhua.huang@pnnl.gov

Pacific Northwest National Laboratory

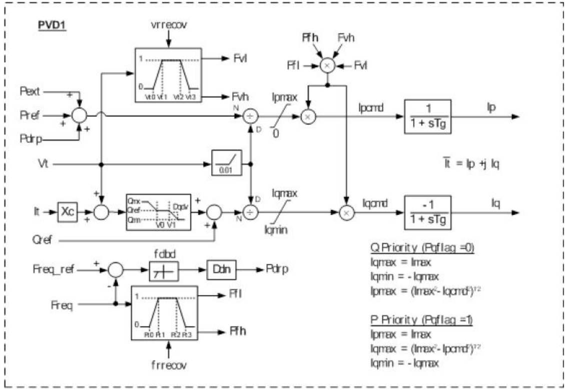
Pacific Northwest NATIONAL LABORATORY

IEEE PES Power & Energy Society®

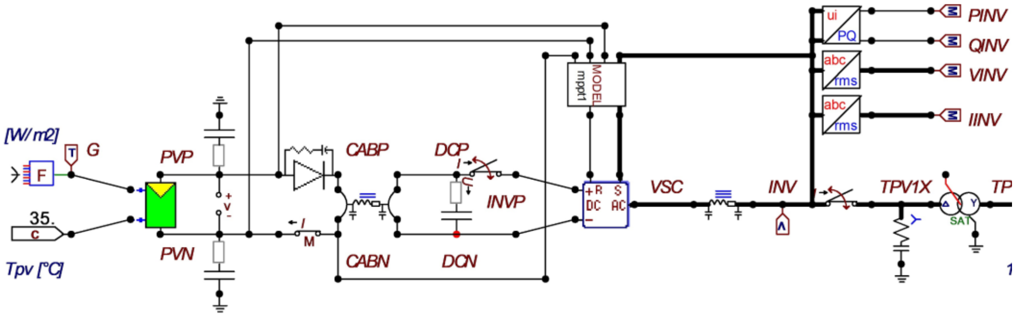
IEEE

DER Dynamic Modeling

- Two main types: 1)Phasor domain (PVD1, DER_A) and 2) EMT detailed modeling
- Control is part of the model (implicitly or explicitly)



PVD1



An EMT model of a PV system in ATP

Lack of DER models suitable for both control design and transient simulation

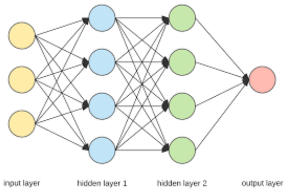
- Phasor models have to neglect some details and internal variables that are important for control design
- EMT type models tend to be computationally intensive and difficult to scale for system-level control design
- Need to develop separate models:
  - e.g., MATLAB/Simulink models for control design, ATP, PSCAD or EMTP models for transient simulation

Our objective is to develop DER dynamic models that are suitable for both control design and transient simulation.

Data-driven reduced-order modeling of DER

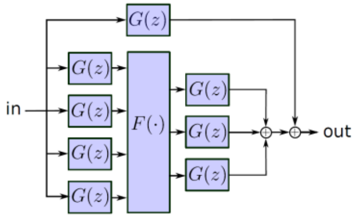
- Black-box, grey-box and white-box modeling

Input → **Black-box (developed with data)** → Output



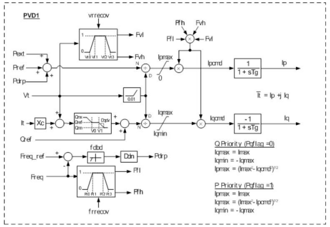
Neural network

Input → **Grey-box (Data + physical knowledge)** → Output



Block-oriented dynamic model (e.g., Hammerstein-Wiener model)

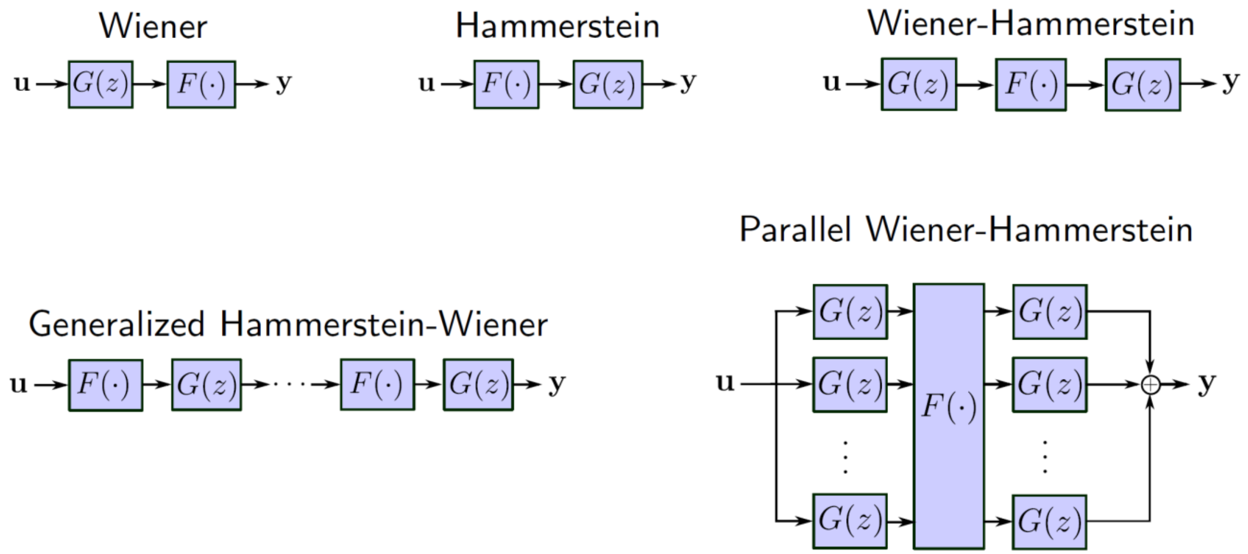
Input → **White-box (Equations based on physical knowledge)** → Output



Physics-based model

Hammerstein-Wiener (HW) models

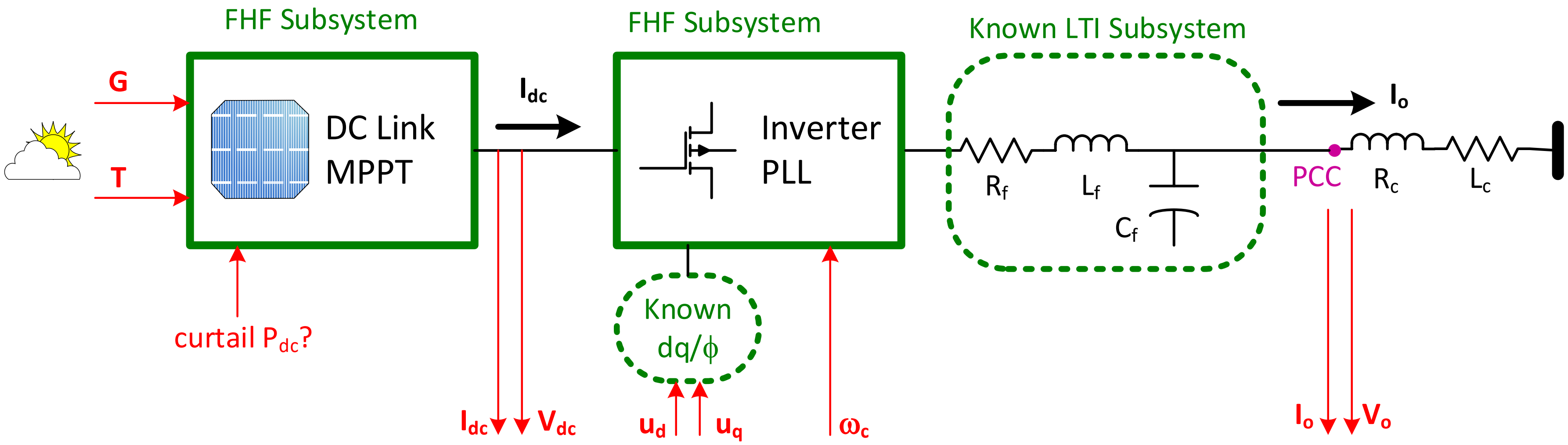
Block-oriented architectures consist in the interconnection of transfer functions *G*(*z*) and static non-linearities *F*(•)



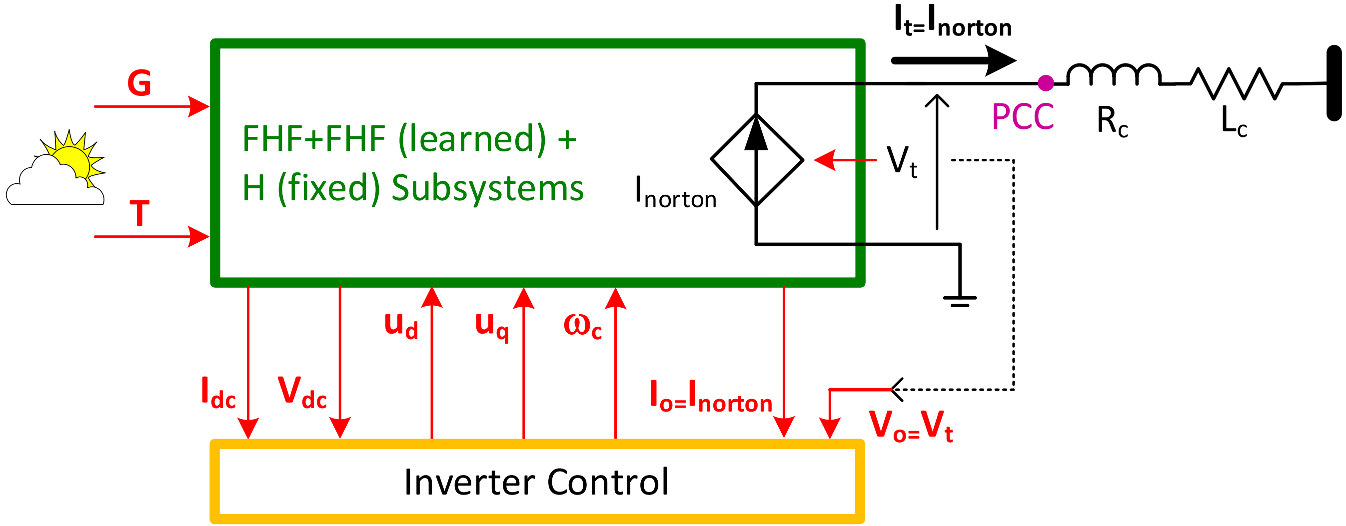
Credit: Marco Forgione, IDSIA, 2020

Our framework for training a PV solar model

Interface variables from **control viewpoint** shown in red. For training, V_o is an input.



Controlled current source interfaces HW model to the grid

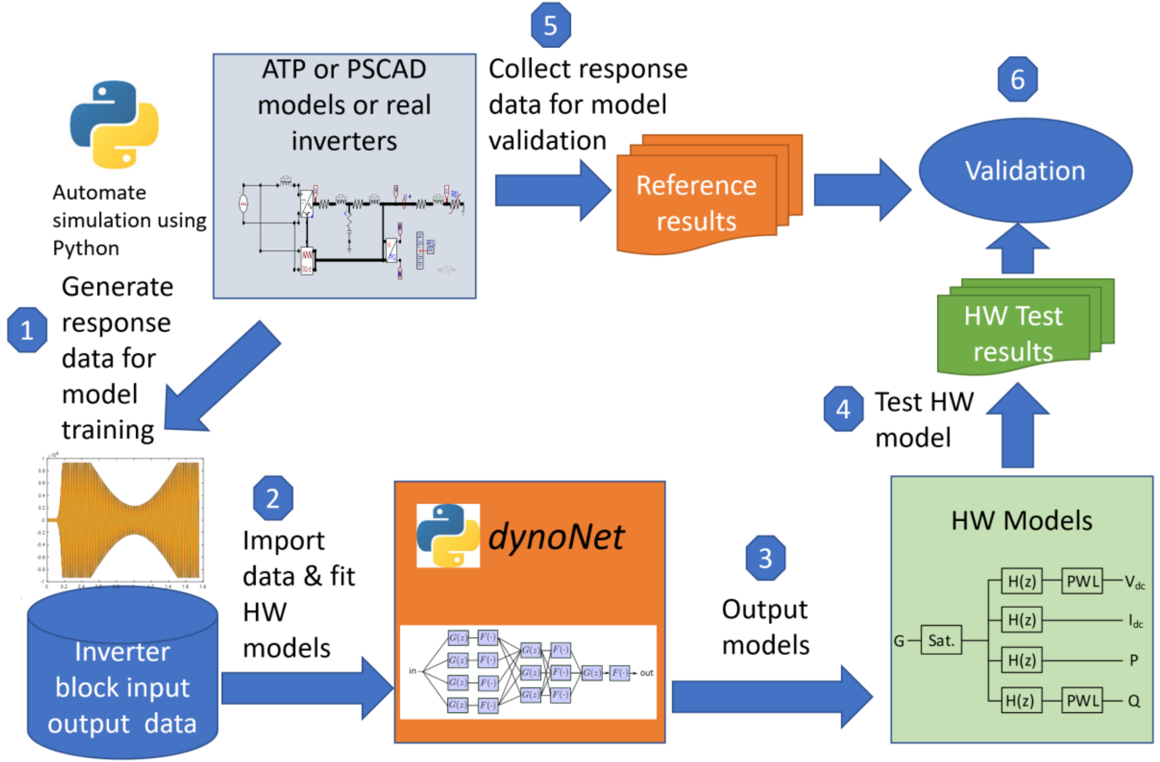


Code: https://github.com/pnnl/pecblocks
(Open-source license based on Berkeley Software Distribution [BSD-3])

dynoNet: A neural network architecture for learning dynamical systems

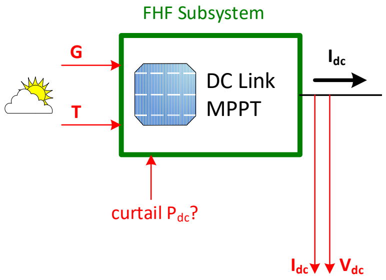
- An open-source python tool tailored for sequence modeling and dynamical system identification using a neural network architecture.
- HW models can be trained end-to-end by plain back-propagation.
- Support rich class of non-linear, causal dynamic relations (e.g., multi-input and multi-output with arbitrary block interconnections).
- Codes:
  - Original: https://github.com/forgi86/dynonet
  - Our work: https://github.com/pnnl/pecblocks

Workflow

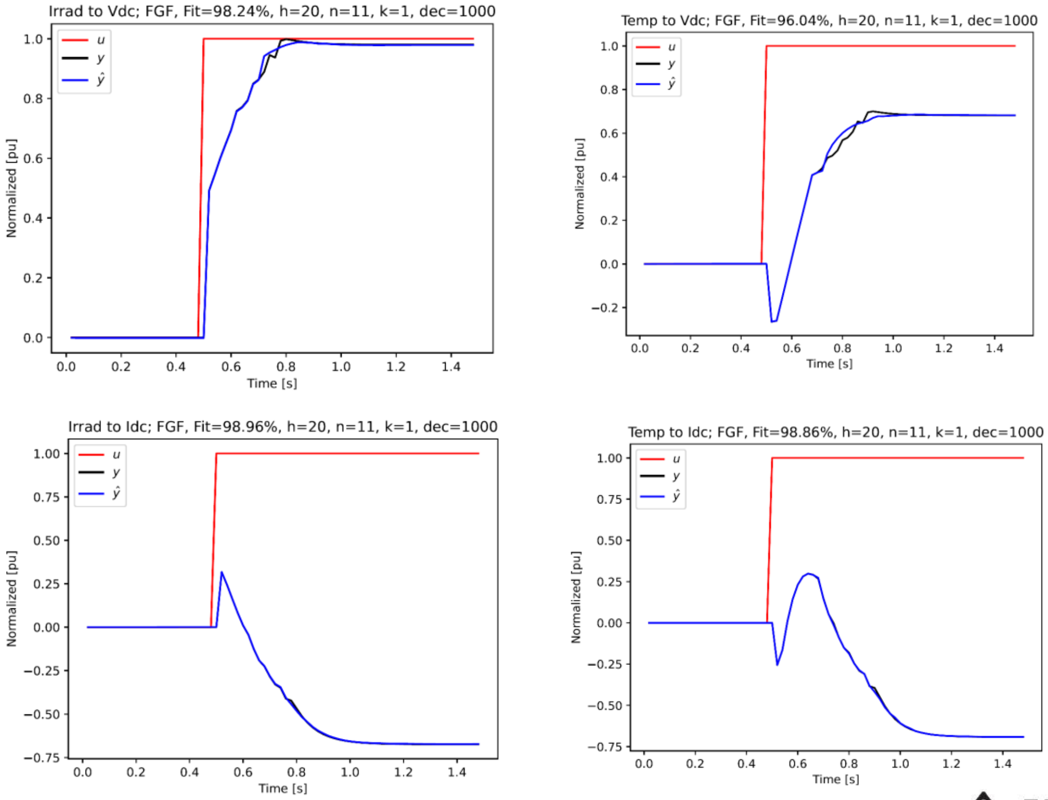


5
Collect response data for model validation
6
ATP or PSCAD models or real inverters
Automate simulation using Python
Reference results
Validation
1
Generate response data for model training
HW Test results
4
Test HW model
2
Import data & fit HW models
dynoNet
3
Output models
HW Models
Inverter block input output data
G
Sat.
H(z)
PWL
V_{dc}
I_{dc}
P
Q
in
out

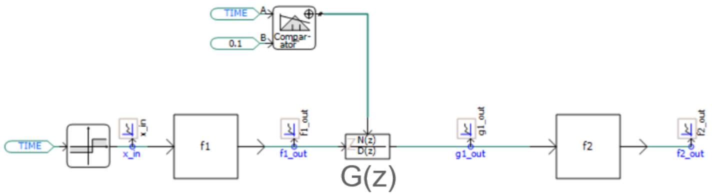
Test Results: G, T ➔ Vdc, Idc

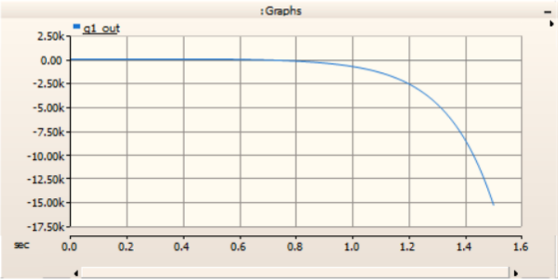


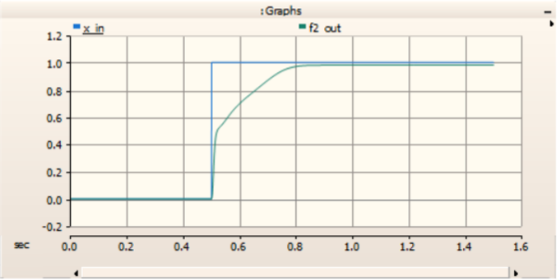
- Input *u* is normalized to its magnitude of change
- Outputs y also normalized to magnitude of change, i.e., (max-min)==1
- FGF denotes HW block cascade, 20 hidden nodes, 11th-order G, Dt=20ms for DC, 1-step delay on G

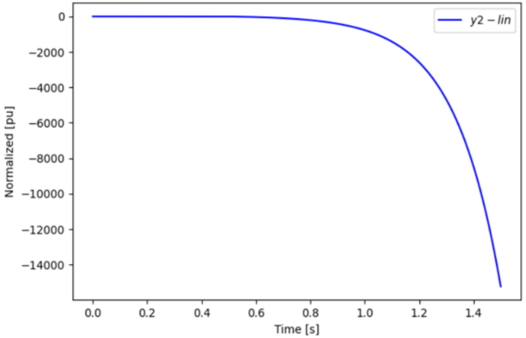


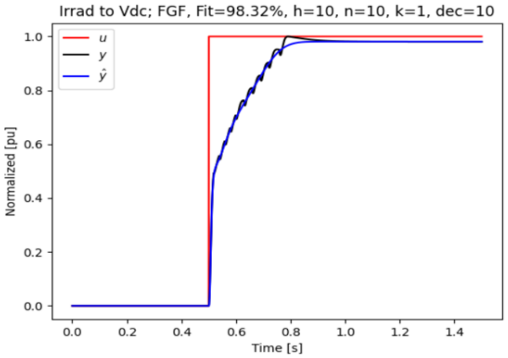
Comparison of PSCAD to dynoNet result











Summary

- Grey-box, block-oriented dynamic modeling of DERs can meet the needs of both control design and efficient transient simulation.
- We have developed a deep-learning based approach for deriving cascaded Hammerstein-Wiener models for a solar PV system and showed promising results.
- Our work is open-sourced on GitHub: https://github.com/pnnl/pecblocks

Acknowledgement

- This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Solar Energy Technologies Office Award Number DE-EE0009028. The views expressed herein do not necessarily represent the views of the U.S. Department of Energy or the United States Government."

IEEE PES Power & Energy Society®

IEEE

Thank You!

Qiuhua Huang

qiuhua.huang@pnnl.gov