Literature review: Smart-PGSim: Using Neural Network to Accelerate AC-OPF Power Grid Simulation

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Problem

Power-grid simulation, which is a complex nonlinear optimization problem
Optimal power flow (AC-OPF) simulation

- large problem size: the generator node scale can vary from 10^3 to 10^6
- high requirement on the simulation latency and frequent usage of the simulation

Existing work

Entirely replacing the simulation solver with an approximated NN model or facilitating existing solvers by identifying active constraints.
Question: NN may not provide the desired precision for the solution (infeasible solution), or provide a non-optimal solution (results in a large economic loss)

Motivation

Formulation

$$\min_X f(X) \tag{1}$$

$$s.t.\ G(X) = 0 \tag{2}$$

$$H(X) > 0 \tag{3}$$

$$X_{min} \leq X \leq X_{max} \tag{4}$$

$X = \{V_a; V_m; P_g; Q_g\}$

Lagrangian:
$L^{\gamma}(X, Z, \lambda, \mu) = f(X) + \lambda^T G(X) + \mu^T (H(X) + Z) - \lambda \sum_{m=1}^{n_i} \ln(Z_m)$
Matpower: Newton's method

Proposal

Idea

Employ NN to generate an initial solution and then inject it to the AC-OPF solver.
So it can run faster (or converge faster) without losing the solution optimality.

1. Generates an NN model that uses power grid components as inputs and variables critical for the simulation convergence as the model output. Use sensitivity study to choose a correct and efficient NN topology.
2. Multitask-learning NN model to accelerate the AC-OPF simulation.
3. Allows embedding physical constraints from the original formulation of the AC-OPF problem into the NN model, imposed on objective function / last layer of NN.

Proposal:Smart-PGsim

Offline phase: find the most crucial features to construct an efficient NN model for online acceleration.
Online phase: Generate a warm-start point for MIPS prediction.

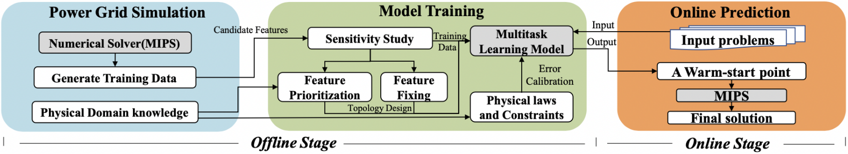


Fig. 1. Workflow of the proposed Smart-PGsim

I. SENSITIVITY STUDY

Analyse feature dependencies of X, λ, μ, Z: switch between impercise default data / precise simulation data and check the impact on success rate and speedup.

Inter-dependent result by observations

1. Using precise X leads to a 100% success rate
2. The contribution of Z to the success rate and speedup strongly depends on whether μ use precise data
3. The contribution of λ to the success rate and speedup is independent of whether the other features use precise data.
4. Implicit dependency.

Multi-task learning(MTL)

A MTL model is typically composed of shared layers and task-specific layers. Model inputs: power load.
Apply "detach()" operation for auxiliary tasks periodically.

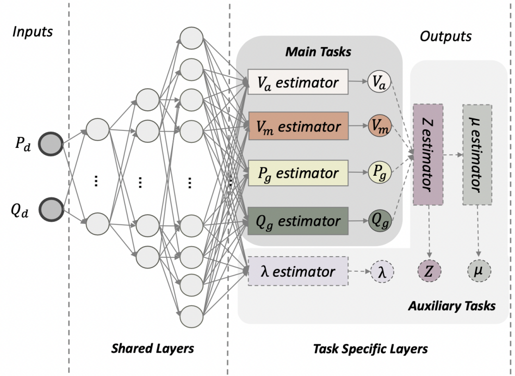


Fig. 2. Topology of the MTL.

Topology

Shared layers: five fully connected layers
Activation function: ReLU
Loss function: Charbonnier loss.
$L = \frac{1}{|\mathscr{V}|} \sum_{v \in \mathscr{V}} W_v \sqrt{(v - v_{gt})^2 + \varepsilon^2}$

III. PHYSICS-INFORMED LEARNING

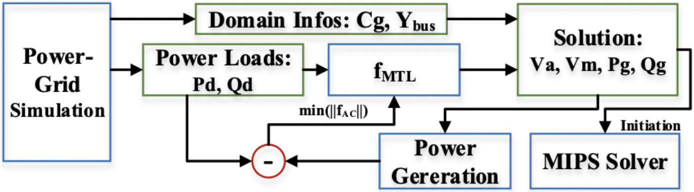


Fig. 3. Embedding AC physical laws in MTL training

1.data driven objective function f_{AC}

incorporate non-trivial data-augmentation;
efficiently perform transfer learning with fewer training data even if the typology of power network is modified.

2. Inequality Constraints $H(X) > 0$

Impose physics information, utilize exponential functions to punish the overflow error, add as loss function f_{ieq}

3. Optimization of Cost Function

$f_{f(X)} = |f(X) - f_0|$

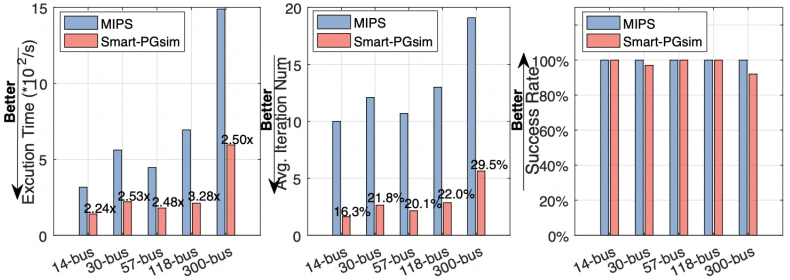
4. Implying Lagrangian Conservation

Reconstruct the inequality and equality constraints as soft constraints;
Use sigmoid as activation function to bound Z, μ

final loss $L_{total} = L + L_{AC} + L_{ieq} + L_{f(X)} + L_{lag}$

Evaluation

10,000 input problems for each test system, in which 8,000 of them are for training and 2,000 for validation.
All experiments on an NVIDIA DGX- 1 cluster with 16 nodes, and each node is equipped with two Intel Xeon E5-2698 v4 CPUs (40 cores running at 2.20GHz) and 8 NVIDIA TESLA V100 (Volta) GPUs.Use CUDA 10.1/cuDNN 7.0 to run NNs on NVIDIA GPUs.



(a) execution time comparison (b) iteration number comparison (c) success rate comparison

Fig. 4. Comparison of three aspects between MIPS and Smart-PGSim.