WASHINGTON STATE UNIVERSITY

Preliminary Exam Presentation

Scalable Multi-Period Optimal Power Flow for Active Distribution Systems

Aryan Ritwajeet Jha

Pursuing PhD (ECE) Power Systems

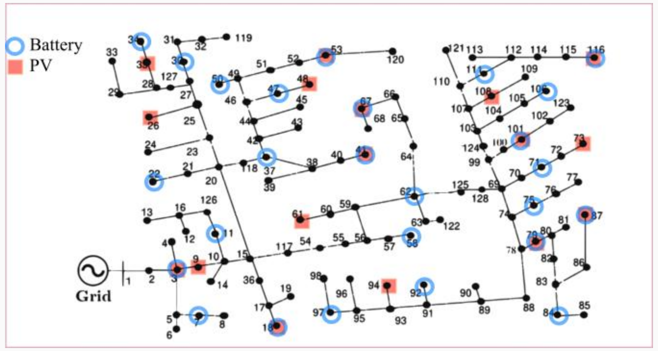
Introduction and Motivation

- What's MPOPF?
- Real-world benefit?
- Why a whole PhD on it?
- Intended Contributions of this PhD

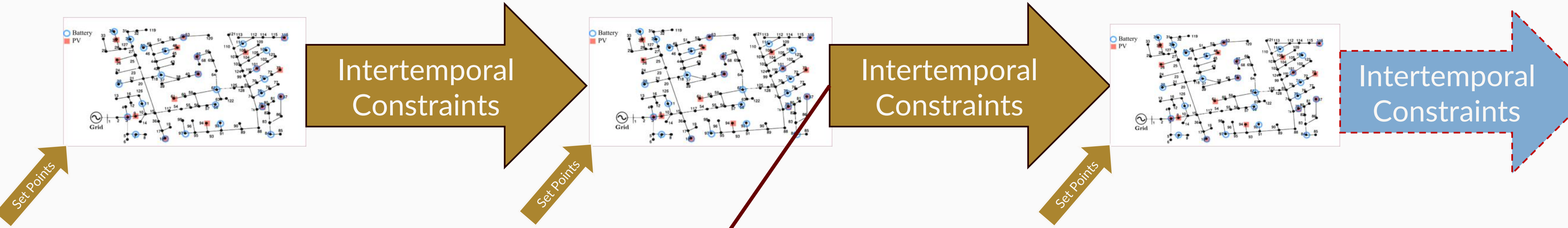
Introduction and Motivation

What's Multi-Period Optimal Power Flow (MPOPF)?

$min.$ Desired Objective Function
subject to
Network Constraints
Engineering Constraints
Component Constraints (DERs, Batteries)



Controllable Components: Grid Edge Devices (GEDs) like Batteries and PVs spread throughout whose real and reactive dispatch may be set every time-period



Battery SOC Equation

$$B_j^t = B_j^{t-1} + \Delta t \eta_c P_{c_j}^t - \Delta t \frac{1}{\eta_d} P_{d_j}^t$$

Due to these intertemporal constraints, the optimization problem size becomes T times larger, becoming more difficult to solve.

Introduction and Motivation

What Real-world benefit does research on MPOPF provide?

- The **MPOPF problem** is to be **solved routinely** (daily, hourly, 15-minutely) **by** Distribution System Operators (**DSOs**), Transmission System Operators (**TSOs**) to **schedule dispatch**
- While generally they may rely on approximated forms of the MPOPF problem, say Economic Dispatch or DC Power Flow, **increasing complexity and number of grid edge devices** can put
  1. obeyance of operational constraints at risk
  2. incur a lot of opportunity cost due to missed profits of operating at a suboptimal control point
- **Solving** the **true MP(AC-)OPF** problem – **if** possible **in** a **competitive time** would both be the **safest** and **most profitable** way to schedule dispatch for them

Introduction and Motivation

Is the MPOPF problem hard enough to warrant a PhD?

- Yes, the MP(AC-)OPF problem is inherently nonlinear and nonconvex – hard to solve for by optimization solvers unless the modeler can employ high quality approximation and/or relaxation techniques
- Still the MPOPF problem, as it expands in time-horizon T, can be very challenging to solve for due to its sheer size
- In such cases, **decomposition algorithms** may be employed exploit the weak coupling of individual time-step problems
- Putting out an algorithm isn't enough – engineers need strong convergence guarantees and competitive computational performance
- End-users need an easy-to-use framework to test the algorithm whose output in turn needs to be tested against trusted software

Introduction and Motivation

Intended Contributions of my PhD

- A framework for solving the MPOPF problem…
  - Which has a systematic procedure to model components of power distribution system in a manner faithful to their behaviour yet computationally efficient to solve for
  - That employs tailored algorithms which can exploit model's properties to come up with an even faster solution
  - Which has provision for comparison of output solution with those of trusted softwares, say OpenDSS
  - Whose procedure may be theoretically justified

An example
of

PhD Execution Pipeline at a Glance

- Courses (Program of Study)
- Current Publications and intended future publication
- High level timeline

PhD Execution Pipeline at a Glance

Courses (Program of Study)

Course Number and Name	Semester	Instructor	Grade
E_E 507 Random Processes in Engineering	Fall 2022	Prof. Sandip Roy	A
E_E 521 Analysis of Power Systems	Fall 2022	Prof. Noel Schulz	A
E_E 523 Power Systems Stability	Spring 2023	Prof. Mani V. Venkatasubramanian	A
MATH 564 Convex and Nonlinear Optimization	Fall 2023	Prof. Tom Asaki	A
MATH 565 Nonsmooth Analysis and Optimization	Spring 2024	Prof. Tom Asaki	A-
CPT_S 530 Numerical Analysis[1]	Fall 2025	Prof. Alexander Panchenko	
E_E 582 Electrical Systems Modelling and Simulation[1]	Fall 2025	Prof. Seyedmilad Ebrahimi	
E_E 595 Directed Studies in Electrical Engineering[1]	Fall 2025	Prof. Rahul K. Gupta	

[1] currently taking this semester

PhD Execution Pipeline at a Glance

Current Publications and intended future publication

1. **Jha, A. R.**, Paul, S., & Dubey, A. . Spatially Distributed Multi-Period Optimal Power Flow with Battery Energy Storage Systems. 2024 56th North American Power Symposium (NAPS). IEEE. doi: 10.1109/NAPS61145.2024.10741846 [1]

NAPS Paper

2. **Jha, A. R.**, Paul, S., & Dubey, A. . Analyzing the Performance of Linear and Nonlinear Multi -Period Optimal Power Flow Models for Active Distribution Networks. 2025 IEEE North-East India International Energy Conversion Conference and Exhibition (NE-IECCE). IEEE. doi: 10.1109/NE-IECCE64154.2025.11183479 [8]

IAS Paper which can be extended to an IAS journal

- Very recently I've been able to solve the MPOPF problem using one of my decomposition techniques which I'm aiming to submit as extension to the IAS paper by December 2025.

Task List

1. Foundational Studies
2. **Modelling** Tradeoff Analysis
3. **Spatial Decomposition** Algorithm
4. **Temporal Decomposition** Algorithms
5. Extension to Three-Phase
6. Multiple-Source Optimal Power Flow (MS-OPF) Exploration

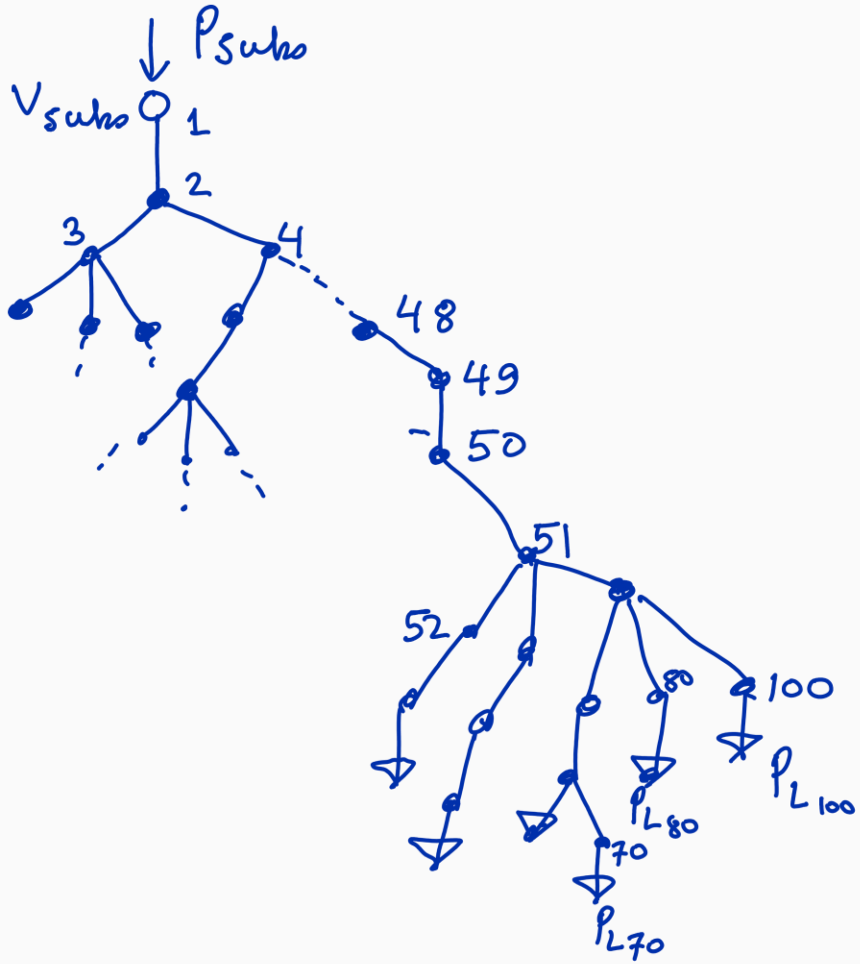
Modelling Tradeoff Analysis – Linear vs Nonlinear

MPDOPF - Spatial Decomposition of the MPOPF problem using ENApp

- Intuition for Algorithm
- Results

MPDOPF - Spatially Decomposition MPOPF

Intuition for Spatial Decomposition

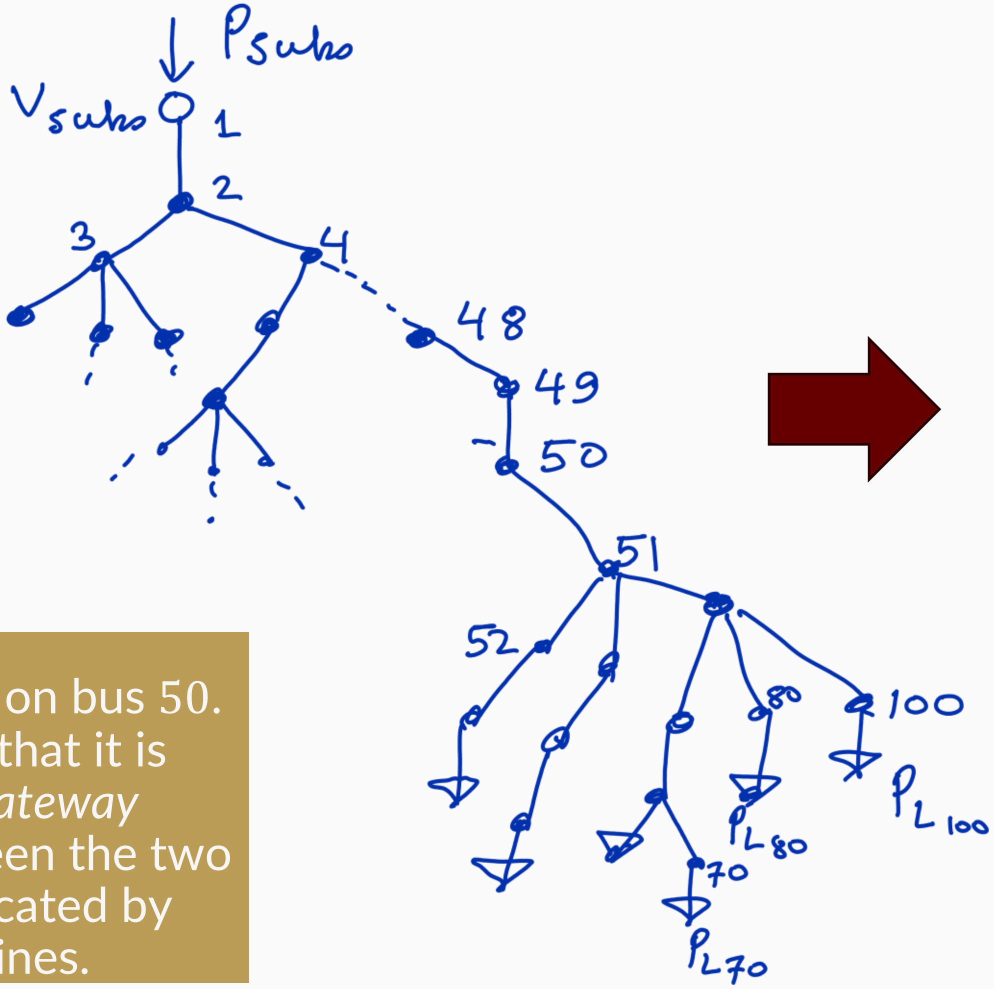


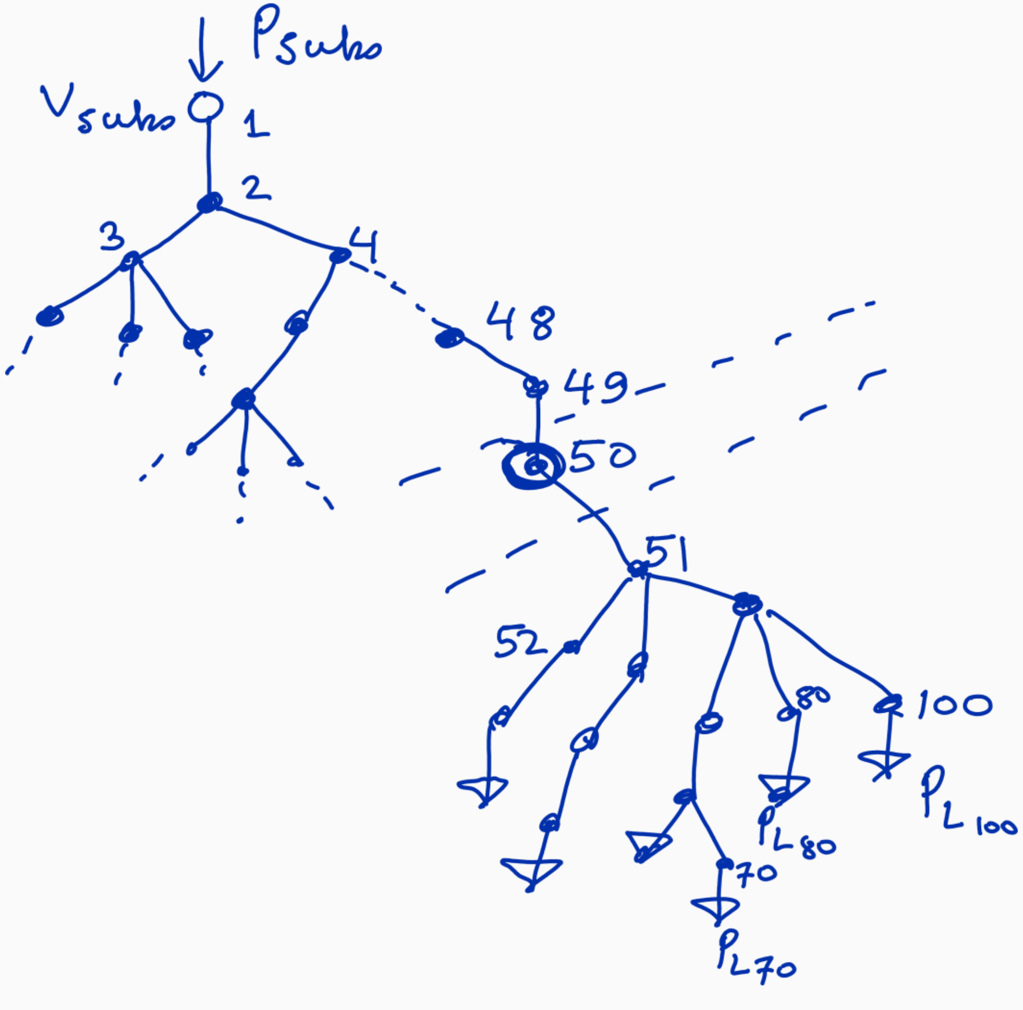
Imagine we have a 100 bus distribution system. Substation bus is 1. We wish to solve for its OPF, but would like to avoid solving the whole system in one go.

Let us focus on bus 50.

MPDOPF - Spatially Decomposition MPOPF

Intuition for Spatial Decomposition

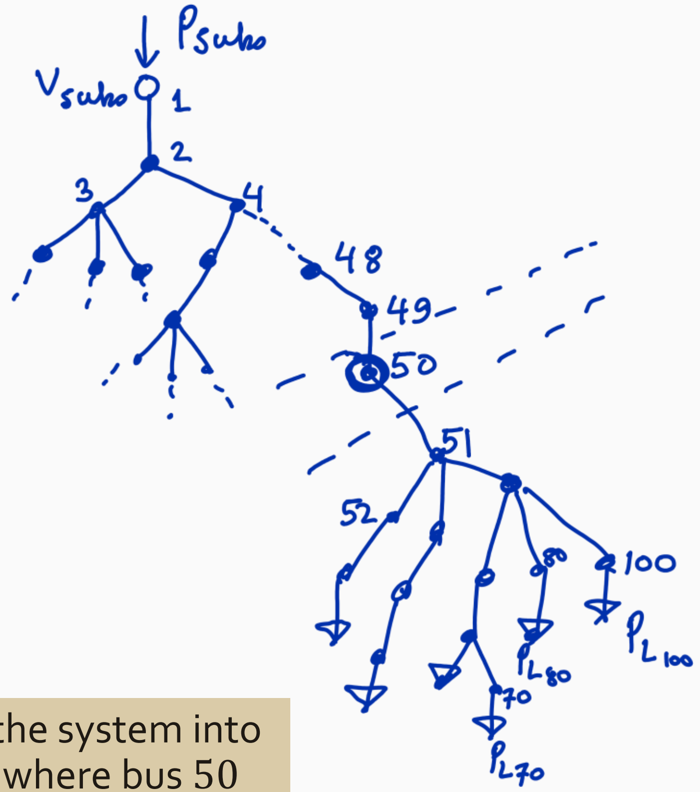




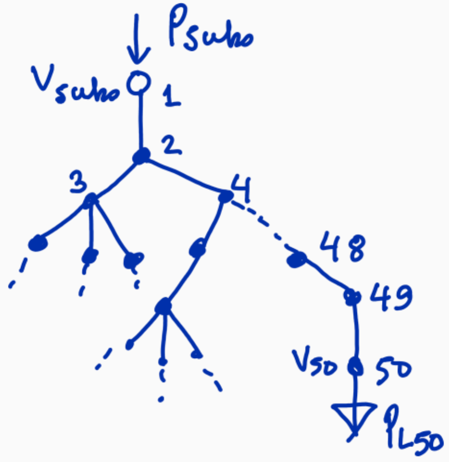
Let us focus on bus 50. We can see that it is one of the *gateway* buses between the two *areas* demarcated by the dashed lines.

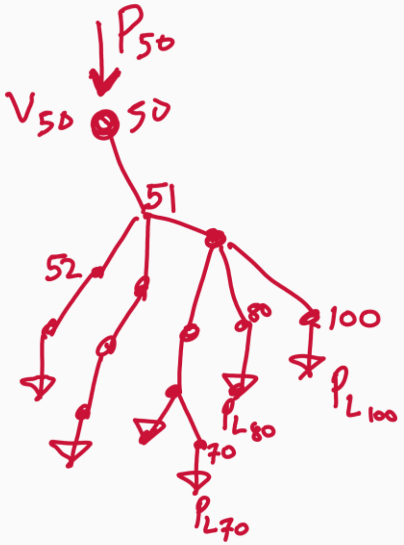
MPDOPF - Spatially Decomposition MPOPF

Intuition for Spatial Decomposition



We can divide the system into two *areas*, one where bus 50 behaves like a load node (whose load we don't know) and one where bus 50 behaves as a *substation* node (whose voltage we do don't know).





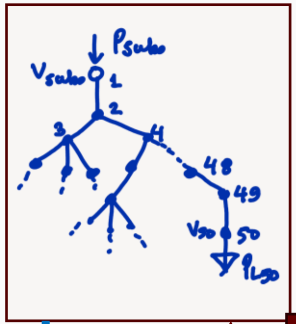
Now we have two OPF problems, each of half the size (and **less than half** the computation time) of the original problem

MPDOPF - Spatially Decomposition MPOPF

Intuition for Spatial Decomposition

Start

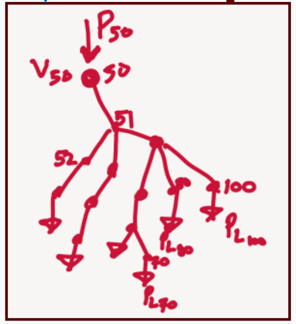
Each *macro-iteration* (k):



Area 1

Solve OPF to get for v_{50}
Set $v_{Subs} = v_{50}$

Solve OPF to get P_{50}
Set $P_{L_{50}} = P_{50}$



Area 2

Are boundary variables *converged*?

Yes

Stop

No

Exchange boundary variables, and continue.

$k{+}{+}$

Convergence means:

$$\left|v_{50}^{\{k+1\}} - v_{50}^{\{k\}}\right| < \epsilon$$

$$\left|S_{50}^{\{k+1\}} - S_{50}^{\{k\}}\right| < \epsilon$$

DDP – Differential Dynamic Programming

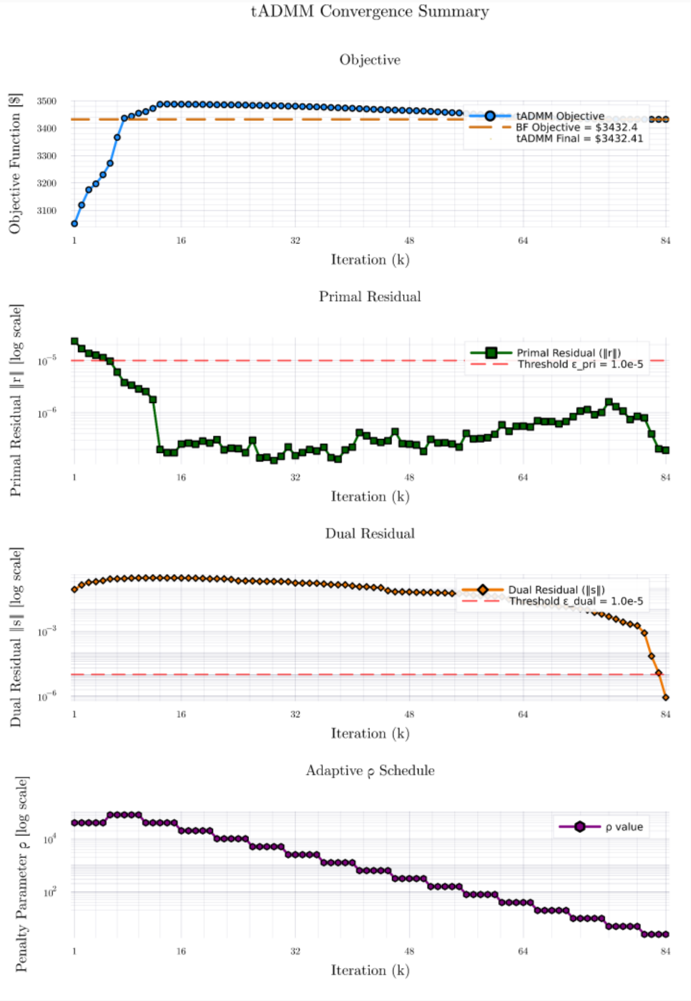
- Results

tADMM – temporal ADMM

- Results

tADMM – temporal ADMM

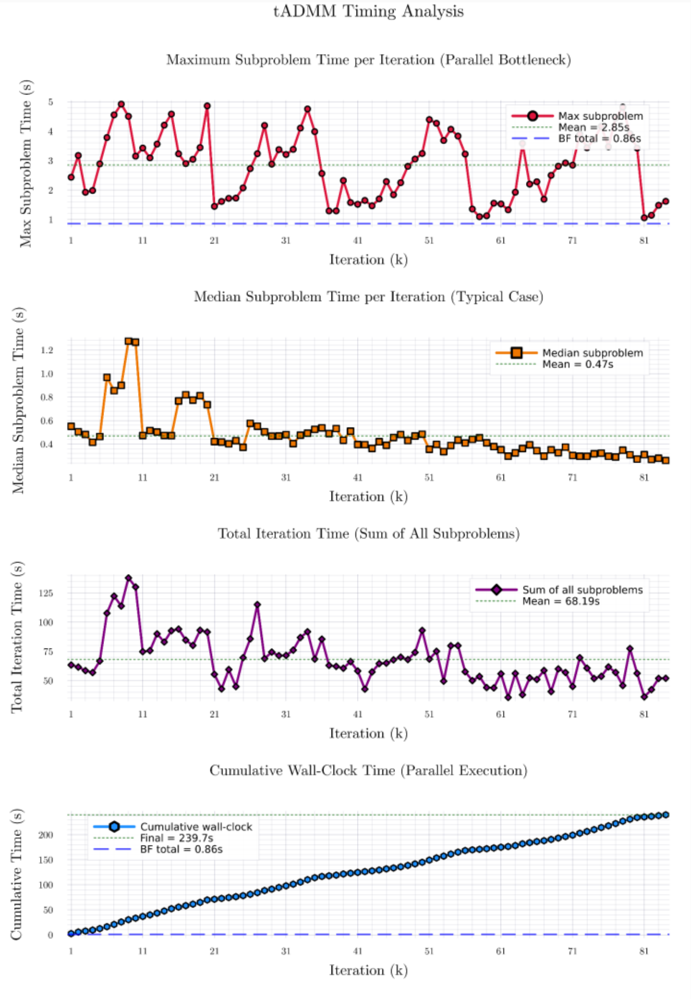
A temporal decomposition algorithm for MPOPF



IEEE 123 Balanced Three-Phase System with 17 PVs and 26 Batteries solved for $T = 96$ timesteps ($24h$ @ 15 minute time intervals)

tADMM – temporal ADMM

A temporal decomposition algorithm for MPOPF



IEEE 123 Balanced Three-Phase System with 17 PVs and 26 Batteries solved for $T = 96$ timesteps ($24h$ @ 15 minute time intervals)

Future Work

- Results