Semester Updates

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Goal of PhD Thesis

The current title of my PhD thesis is *Multi-Period Optimal Power Flow in Active Radial Distribution Systems*.

Multi Period Optimal Power Flow (MPOPF) in Active Radial Distribution Systems (RDS). MPOPF in Active RDS.

Chief outcomes of this thesis will be the algorithm(s) developed for MPOPF, along with detailed modelling insights exploring mathematical theory and implementational challenges.

Every system is a new problem statement, and ideally needs a tailor-made optimization model for the most efficient and effective optimization experience. Every RDS requires a desired level of modelling complexity (Linear/Nonlinear, Balanced/Unbalanced). Each RDS comes with its unique set and mixture of active components (Active Loads, PVs, Batteries) which themselves can have different models (reactive power control, load demand flexibility).

Similarly, the horizons for optimization, and the length of one time-period within that horizon, can often be pivotal in influencing the kind of optimization model required.

Questions I'll attempt to address using my thesis

1. Given a system's specifications and a desired optimization objective, what kind of model(s) would lead to the best optimization experience?
2. Why was that model chosen? How mathematically valid is it? Would a user have a productive experience when implementing and running it?
3. For a given model, are there any efficient algorithms which may be used to obtain a solution faster? Any scope for parallelization? How susceptible is the algorithm to a single point of failure?
4. Now that a model and an algorithm has been decided by a user, what should they do to solve for their own system? What software to install? Which repository to use? Which solver to use? Will it be free? Is a license required?

Key Dates

In chronological order

Start Date: 16 August 2022 (Fall 2022)

Qualifying Examination (QE): Passed

Expected Preliminary Examination (PE) Date: May 2025 (Spring 2025, after 6 semesters)

Expected Completion Date: December 2026 (Fall 2026, after 9 semesters)

Semesterly Progress

Starting Date: 16 August 2022 (Fall 2022). As of 18 December 2023, I've completed 3 semesters at WSU.

Fall 2022 (Sem I)

Task	Description	Completion Date	Remark
Completed* EE 521: Analysis of Power Systems	EE 521 is a core course	*18 December 2022	*Enough to get an initial grade. One project was completed next semester.
Completed EE 507: Random Processes	EE 507 is an elective	16 December 2022	
Literature Review: OPF	Read some standard OPF literature, including SH Low's Branch Flow Model papers, and OPF papers from our research group.		

Spring 2023 (Sem II)

Task	Description	Completion Date	Remark
Completed EE 523: Power System Stability and Control	EE 523 is a core course	08 May 2023	
Took my Qualifying Exam		17 April 2023	
Completed a remaining EE 521 project		03 April 2023	
Literature Review: PINN informed OPF study	Read Spyros's research on Physics Informed ML enabled OPF and presented it to the lab		
Modelling Batteries in an existing OPF MATLAB Model	I was handed a Distributed OPF (D-OPF) simulation on the 123 bus system, and asked to model batteries into them.		The semester was spent in converting the architecture of the codebase, which was originally a soup of fixed parts, into one which allows for different customizable moving parts, facilitating for any future additions.

Summer 2023 (between Sem II and III)

Task	Description	Completion Date	Remark
Performed studies on a Large-Scale Distribution Model	Performed studies on 1k/10k Distribution model	28 July 2023	Varied grid parameter values such as R, X, λ of the grid and observed the variation of state/output variables like $P_{Loss}, P_{Subs}, P_{12}, Q_{12}, v_1,$ etc.
Literature Review: MPOPF	Studied a couple of papers solving the MPOPF problem (Pileggi, Nazir), and presented it to Anamika, Subho. Also, used the literature to ascertain the set of equations to model batteries in my grid.		
Modelling Batteries in an existing OPF MATLAB Model	Batteries added to the model. Single-period Nonlinear Balanced OPF with Batteries was implemented.	30 July 2023	
Phase 1 of Development of PowerEdu.jl – Julia Package for Teaching Power System Analysis	Using the evaluation components of the two WSU core power system courses – EE 521 and EE 523: some projects for a Julia package named PowerEdu.jl were developed, with the objective of functioning as a modern, user-friendly, open-source package for facilitating teaching Power System courses.	08 September 2023	Two projects (Power flow and Sparse Power flow) were completed. Currently development has been postponed indefinitely, maybe can be resumed in time for PSCC 2026. Got a decent implementation experience for a larger project in JuliaLang.

Fall 2023 (Sem III)

Task	Description	Completion Date	Remark
Completed MATH 564: Convex and Nonlinear Optimization	A course for understanding numerical optimization solvers.	15 December 2023	MATH 564 is a very good course for people who use free/commercial solver to solve their optimization problems. In this course, I got to design and implement some of my own to solve a variety of problems.
Extending Single Period OPF simulation to an MPOPF simulation	Batteries added to the model. Single-period Nonlinear Balanced OPF with Batteries was implemented.	03 October 2023 (CMPOPF)	DMPOPF also implemented, but certain other issues came up postponing its development.
Features added to the MPOPF sim	Same sim can now perform CMPOPF and DMPOPF as specified by user. Batteries are now able to be switched-off the grid. Variable GED penetration New Objective Function – Cost of Substation Power		
Implementation of an initial validation script for checking OPF results		30 November 2023	Lack of an inbuilt mechanism for validation against OpenDSS has cost me a lot of development time due to incorrect results seeping into implementation. Starting with this task, I'll now be testing a variety of scenarios I've already implemented, before creating new features.

Plans for Next Semester

Spring 2024

My primary task for the upcoming semester is to work on tasks of immediate value to the CC project, mainly providing various working MPOPF simulations of varying complexities. Of course, working on this project also drives my own research, by giving me the implementation know how of applying my own algorithms when I devise them during my PhD.

As I understand, I should have a variety of MPOPF models to test the system on. For example, while I have been working on a Balanced Nonlinear Network, I will develop a Balanced Linear Model, an Unbalanced Linear Model, and an Unbalanced Nonlinear Model too. Thus, I'll mainly focus on implementing, verifying the models, and adding any new features.

Apart from that, I'll be studying literature and trying to design my own MPOPF algorithm.

Thirdly, I'll be taking the MATH 565 course, which I hope will help me come up with my own algorithm exploiting the weak temporal coupling in MPOPF problems and help me understand how solvers work for constrained problems.

CC Project (covers implementation for my own PhD too):

Verification of modelling of existing components + any development required to rectify errors detected.

Phase 1: Ensuring a Correct Balanced Nonlinear MPOPF model: (Target Date: Early February 2024)

- Verification of COPF on Base Model (completed)
- Verification of COPF on Base Model with Batteries
- Verification of MPCOPF on Base Model with Batteries
- Creation of OpenDSS files of various GED penetration schemes as specified by Anamika
- Implementation of the correct convergence scheme for DOPF
- Verification of DOPF
- Verification of MPDOPF

Phase 2: Implementation of Other MPOPF Models: (Target Date: End of April 2024)

- Can start with development of Unbalanced Linear Model
- Then implement Unbalanced Nonlinear Model

MPOPF Algorithm Development:

Target Date: Recurring throughout the semester.

Continue research into various schemes adopted by the power systems community to solve MPOPF problems. Current leads are:

- Using Linear Models for the whole horizon, and once set-points for active elements are obtained, solving for Nonlinear models for each time-step in parallel.
- Using an iterative Optimal Control like technique, such as Differential Dynamic Programming, involving solving for the current time-step using assumed future set-points, and updating the set-points after obtaining a solution for a future time-step.
- Some other references are also in my list, which I haven't been able to properly go through.

MATH 565: Nonsmooth Analysis and Optimization with Applications

Target Date: Recurring throughout the semester

This course will carry on from MATH 564, which I just completed, and help me in understanding implementation of solvers for solving for constrained optimization problems (In 564 we don't explicitly solve for constrained problems, but employ some workarounds). This course also talk about primal-dual decomposition methods such as ADMM, which I hope will help me get a working understanding for developing my own distributed algorithms.