SLURM-BASED COMPUTING CLUSTER FOR DECENTRALIZED DECISION-MAKING IN POWER SYSTEMS

JAIME E. LOPEZ-MOLINA
EDUARDO CASTILLO
YUANRUI SANG, PH.D.

AGENDA

- Introduction
- Study Objectives
- Literature Review
- Methodology
- Case Study
- Conclusion

INTRODUCTION

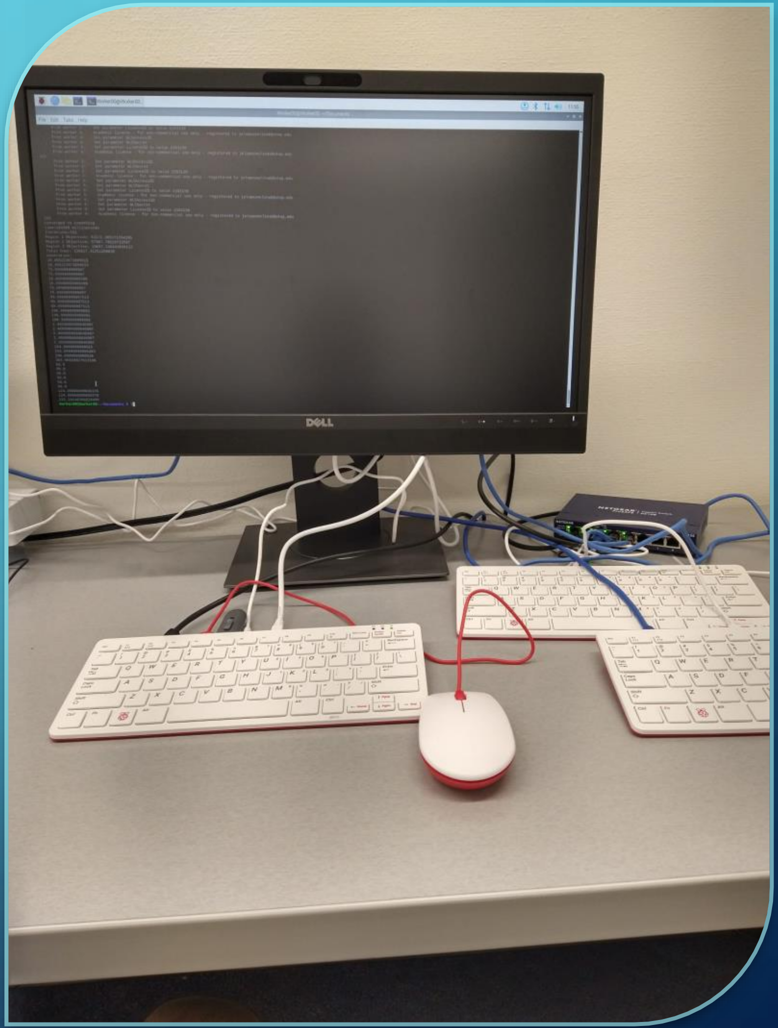
- Natural Disasters are a leading cause of economic losses
- Electricity companies are some of the most affected sectors as their infrastructure can be especially vulnerable
- Recent examples include hurricanes Harvey, Irma, and Maria, and winter storm Uri
- As grid resilience is challenged, new solutions are required to ensure grid operations

PROBLEM DESCRIPTION

- Transmission lines are some of the most affected infrastructure of a power system
- Most grids have centralized decision-making, where communication interruptions result in shutdowns in affected areas
- A decentralized approach can help ensure that the grid can maintain some operations in disconnected regions

STUDY OBJECTIVES

- Propose Decentralized model to solve a DCOPF problem using ADMM
- Test the efficiency of this algorithm compared to a centralized method
- Implement the algorithm in a SLURM-based Raspberry Pi cluster to simulate inter-region communications in a decentralized power system
- Analyze possible benefits in terms of load loss reductions



LITERATURE REVIEW – DECENTRALIZED POWER SYSTEMS

- The concept of decentralized power system control schemes has been around since at least the 1990s [1]
- There are two approaches: Distributed, where a central coordinator handles all communications, and decentralized, where communication is handled directly by each control entity [2]
- Algorithms for optimization include:
  - Analytical Target Cascading [3]
  - Alternating Direction Method of Multipliers (ADMM) [4]
  - Auxiliary Problem Principle [5]

LITERATURE REVIEW – DISTRIBUTED COMPUTING

- As more demand for distributed resources for power system applications arise, centralized frameworks pose concerns as for optimal communication and computation. [6]
- Each computer communicates with each other with the need of a centralized controller [7]
- The problem can be separated into separate several smaller subproblems that can be solved in parallel [8]
- Distributed computing algorithms may provide better data privacy given different ownerships. The communication only involves neighboring agents rather than centralized communication. [9]

MATHEMATICAL MODEL – CENTRALIZED PROBLEM

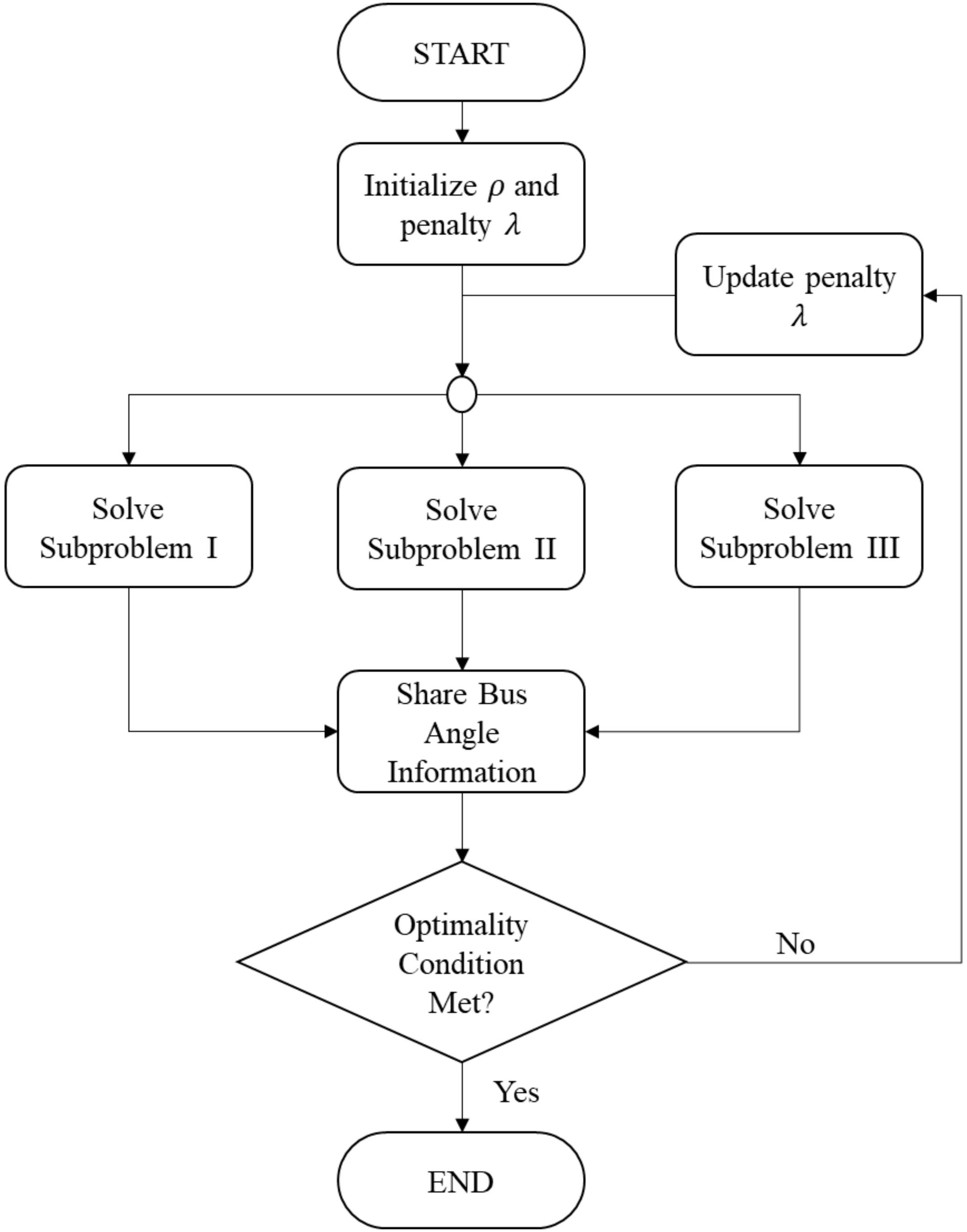
1. $OF = min\left\{\sum_{g=1}^{G_i} \sum_{seg=1}^{N} C_g^{seg} P_g^{seg} + \sum_{b=1}^{B_i} C_b^{LC} P_b^{LC}\right\}$
2. $\sum_{g\epsilon g_b} P_g + \sum_{l\epsilon\sigma_b^+} F_l - \sum_{l\epsilon\sigma_b^-} F_l = P_b^L - P_b^{LC}$
3. $P_g^{min} \leq P_g \leq P_g^{max}$
4. $0 \leq P_g^{seg} \leq P_{g,seg}^{max}$
5. $b_l\left(\theta_{to,l} - \theta_{fr,l}\right) = F_l$
6. $-F_l^{max} \leq F_l \leq F_l^{max}$
7. $0 \leq P_b^{LC} \leq P_b^L$
8. $\theta_l^{min} \leq \theta_{fr,l} - \theta_{to,l} \leq \theta_l^{max}$
9. $\theta_1 = 0$

MATHEMATICAL MODEL – DECENTRALIZED PROBLEM

1. $OF = \min_{p^{k+1},\theta^{k+1}} \left\{ \sum_{g=1}^{G_i} \sum_{seg=1}^{N} C_g^{seg} P_g^{seg} + \sum_{b=1}^{B_i} C^{LC} P^{LC} + \sum_{b \epsilon B^i} \left[\lambda_b^k (\theta_b - \bar{\theta}_b) + \frac{\rho}{2} \|\theta_b - \bar{\theta}_b\|_2^2 \right] \right\}$
2. $\sum_{g \epsilon g_b} P_g + \sum_{l \epsilon \sigma_b^+} F_l - \sum_{l \epsilon \sigma_b^-} F_l = P_b^L - P_b^{LC}$
3. $P_g^{min} \leq P_g \leq P_g^{max}$
4. $0 \leq P_g^{seg} \leq P_{g,seg}^{max}$
5. $b_l(\theta_{to,l} - \theta_{fr,l}) = F_l$
6. $-F_l^{max} \leq F_l \leq F_l^{max}$
7. $0 \leq P_b^{LC} \leq P_b^L$
8. $\theta_l^{min} \leq \theta_{fr,l} - \theta_{to,l} \leq \theta_l^{max}$
9. $\theta_3 = 0$
10. $\lambda_b^{k+1} = \lambda_b^k + \rho\left(\theta_b - \bar{\theta}_b\right)$

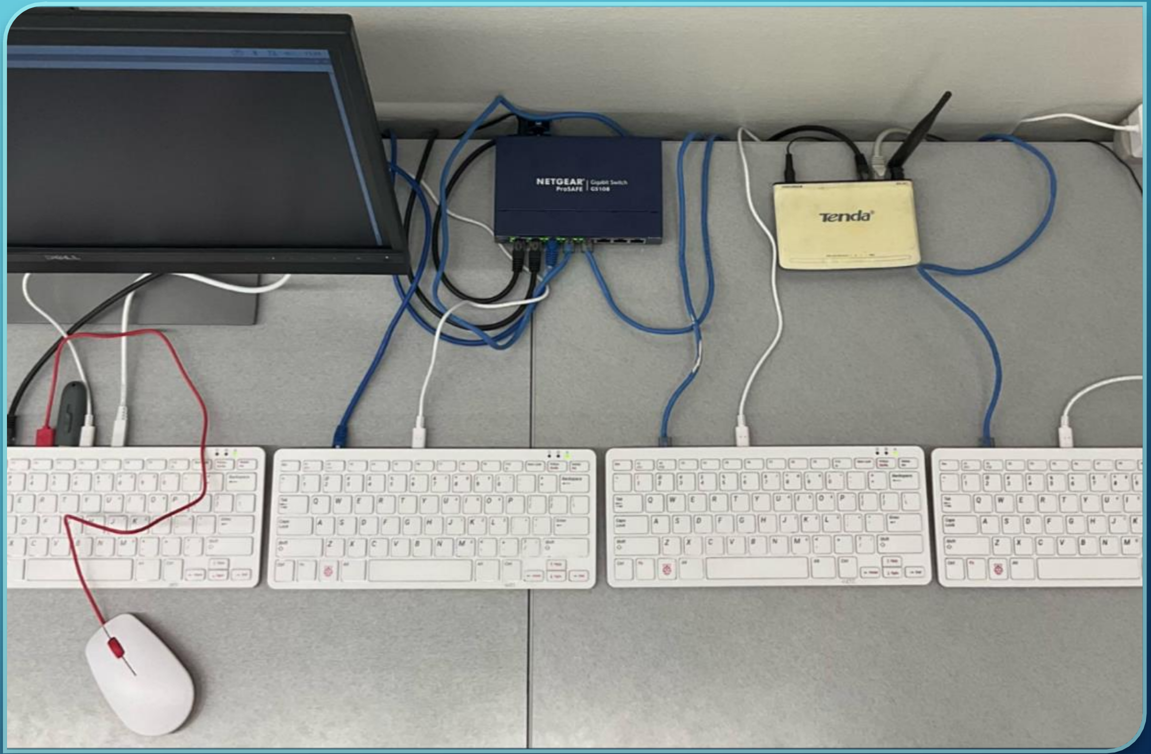
OPTIMIZATION METHOD

- ADMM Flowchart applied to a distributed Power System
- Each subproblem uses DCOPF formulation as described in previous slide
- Implemented in distributed optimization algorithm using Raspberry Pi Cluster and SLURM daemon controllers
- All regions must converge to a consensus value



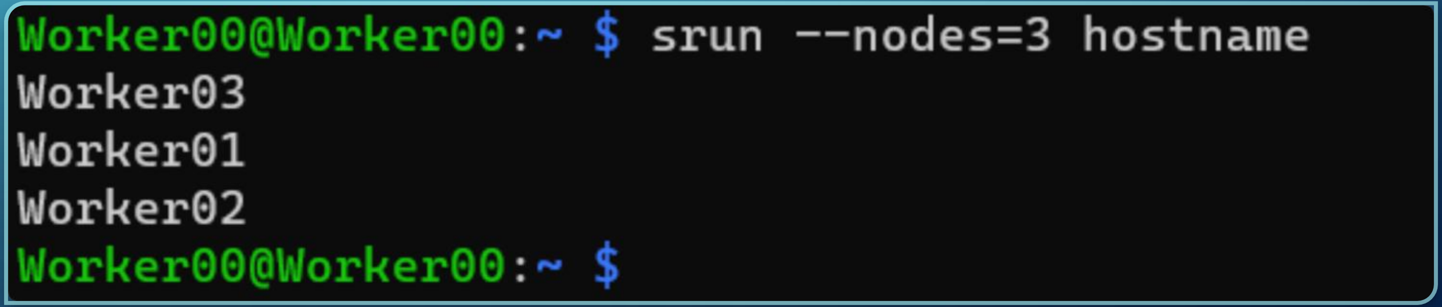
RASPBERRY PI 400 SLURM COMPUTER CLUSTER

- Consists of one head node and 3 computing nodes
- Head node will send out tasks to the computing nodes
- Computing nodes will receive and complete tasks as assigned as long as another task is not currently running
- NETGEAR Gigabit Switch connects devices via ethernet, and Tenda wireless router allows outside connection to manage the cluster and assign static IP address.



SLURM DAEMON CONTROLLER CONFIGURATION

- Raspberry Pis must have identical SLURM configurations and munge key file and directories, time and location settings, a shared storage device and active SLURM version installations for both head and compute nodes
- Created a default partition of the cluster and add the computing nodes with IP address
- Configured head node with worker hosting and copy files on shared storage drive for compute nodes
- Enabled and started SLURM controller and SLURM daemon services
- Tested head node to verify if each compute node's communication and functionality with respect to the head node:

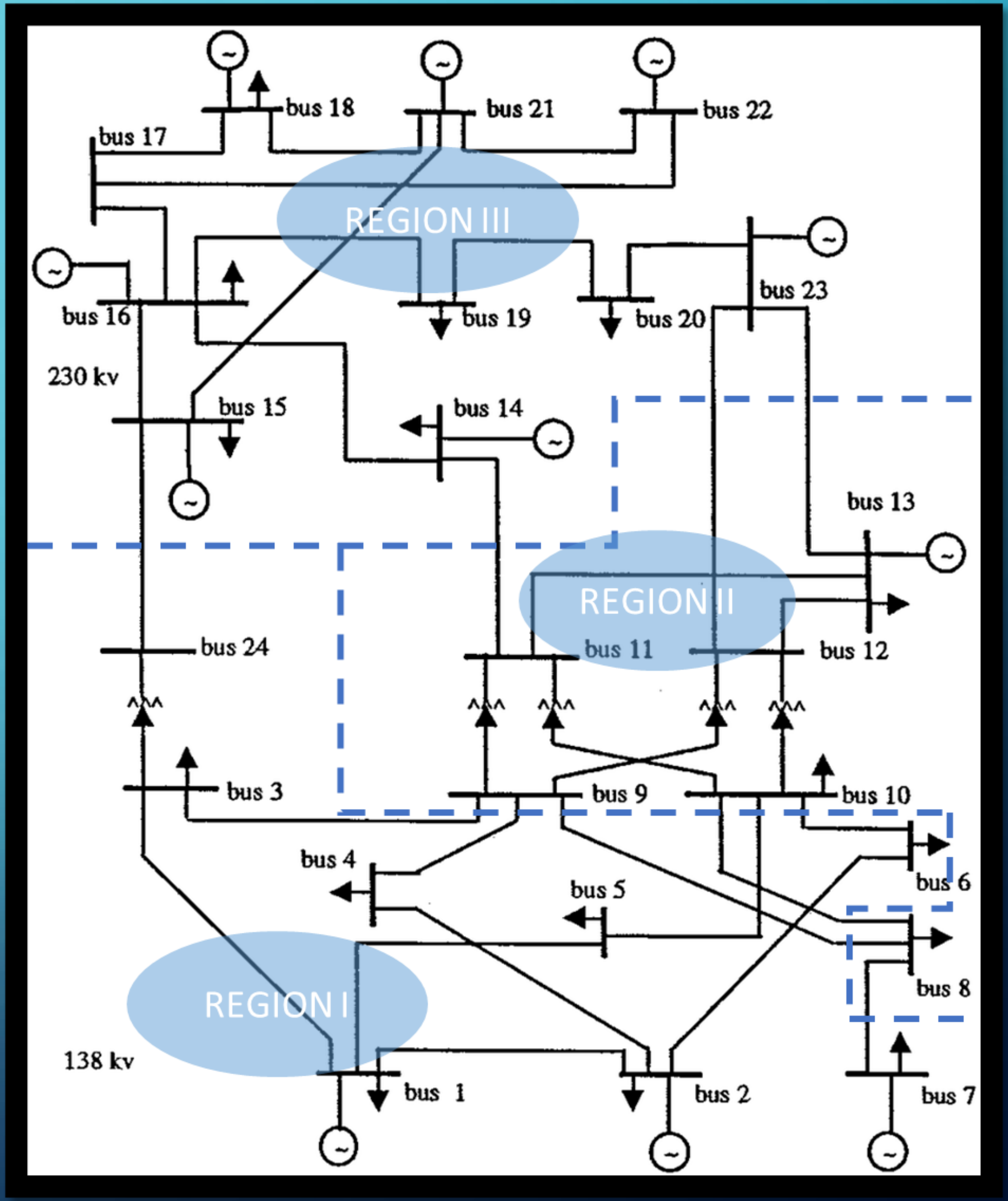


```
Worker00@Worker00:~ $ srun --nodes=3 hostname
Worker03
Worker01
Worker02
Worker00@Worker00:~ $
```

CASE STUDY

- Performed on the IEEE RTS-96
- System consists of 24 buses, 38 lines, and 32 generators
- Divided into regions as in [10]

	Buses	Generation Capacity (MW)	Load (MW)
Area I	1-7, 24	684	791
Area II	8-13	591	1286
Area III	14-23	2130	773



RESULTS

- Expected Costs
- Centralized:
  - 130,821.92$/hr
- Decentralized:
  - 130,827.41$/hr

- Computational Time
- Centralized:
  - 10.99 seconds
- Decentralized:
  - 181.69 seconds

LOAD LOSS COMPARISONS – REGION I ISLANDED

CENTRALIZED

	Load (MW)	**Generation (MW)**	**Load Loss (MW)**
Area I	791	684	107
Area II & III	2,059	0	2,059
Total	2,810	684	2,168

DECENTRALIZED

	Load (MW)	**Generation (MW)**	**Load Loss (MW)**
Area I	791	684	107
Area II & III	2,059	2,059	0
Total	2,810	2,743	107

LOAD LOSS COMPARISONS – REGION II ISLANDED

CENTRALIZED

	Load (MW)	**Generation (MW)**	**Load Loss (MW)**
Area II	1,286	0	1,286
Area I & III	1,564	1,564	0
Total	2,810	1,564	1,286

DECENTRALIZED

	Load (MW)	**Generation (MW)**	**Load Loss (MW)**
Area II	1,286	591	695
Area I & III	1,564	1,564	0
Total	2,810	2,155	695

LOAD LOSS COMPARISONS – REGION III ISLANDED

CENTRALIZED

	Load (MW)	**Generation (MW)**	**Load Loss (MW)**
Area I & II	2,077	1,275	802
Area III	773	0	773
Total	2,810	1,275	1,575

DECENTRALIZED

	Load (MW)	**Generation (MW)**	**Load Loss (MW)**
Area I & II	2,077	1,275	802
Area III	773	773	0
Total	2,810	2,048	802

CONCLUSION

- Presented a mathematical model for decision-making in decentralized power systems operations
- Created a SLURM-based computer cluster for decentralized computing
- Demonstrated implementation of ADMM-based optimization method in computer cluster
- Analyzed possible reduction of load loss in decentralized systems compared to centralized ones

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