New Mexico
SMART Grid Center webinar series

NM SMART Grid Center Research Overview

Presenters: Olga Lavrova (NMSU), David Mitchell (NMSU), Manel Martínez-Ramón (UNM), Ali Bidram (UNM), Anne Jakle (NM EPSCoR)

New Mexico
EPSCoR

New Mexico
SMART Grid Center webinar series

Next Webinar

Save the Date: October 25 @ Noon

Networked DC Microgrids

Presenter: Gary Oppedahl, Emera Technologies

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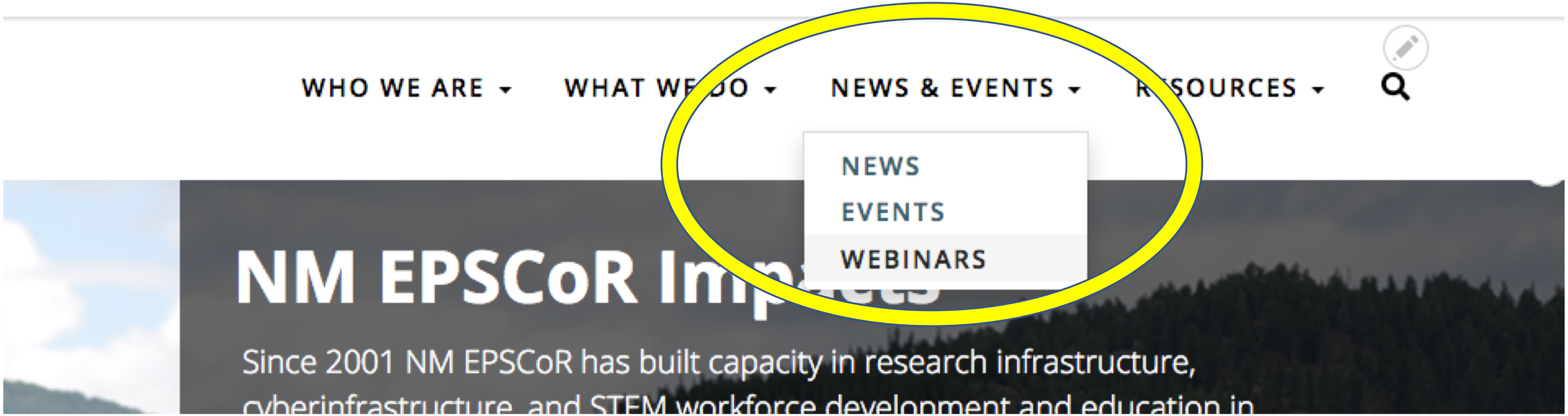
Upcoming NM SMART Grid Center Dates

- **October 5:** Jack Davis (former AZ Public Service CEO) Webcast
- **October 17:** Sandia National Lab Grid Resilience Forum
- **November 1:** Graduate Student Training Day
- **November 2:** NM Academy of Science Research Symposium (abstracts due October 6)
- **November 15:** Spring 2020 Graduate Student Externship best consideration date

www.nmepscor.org



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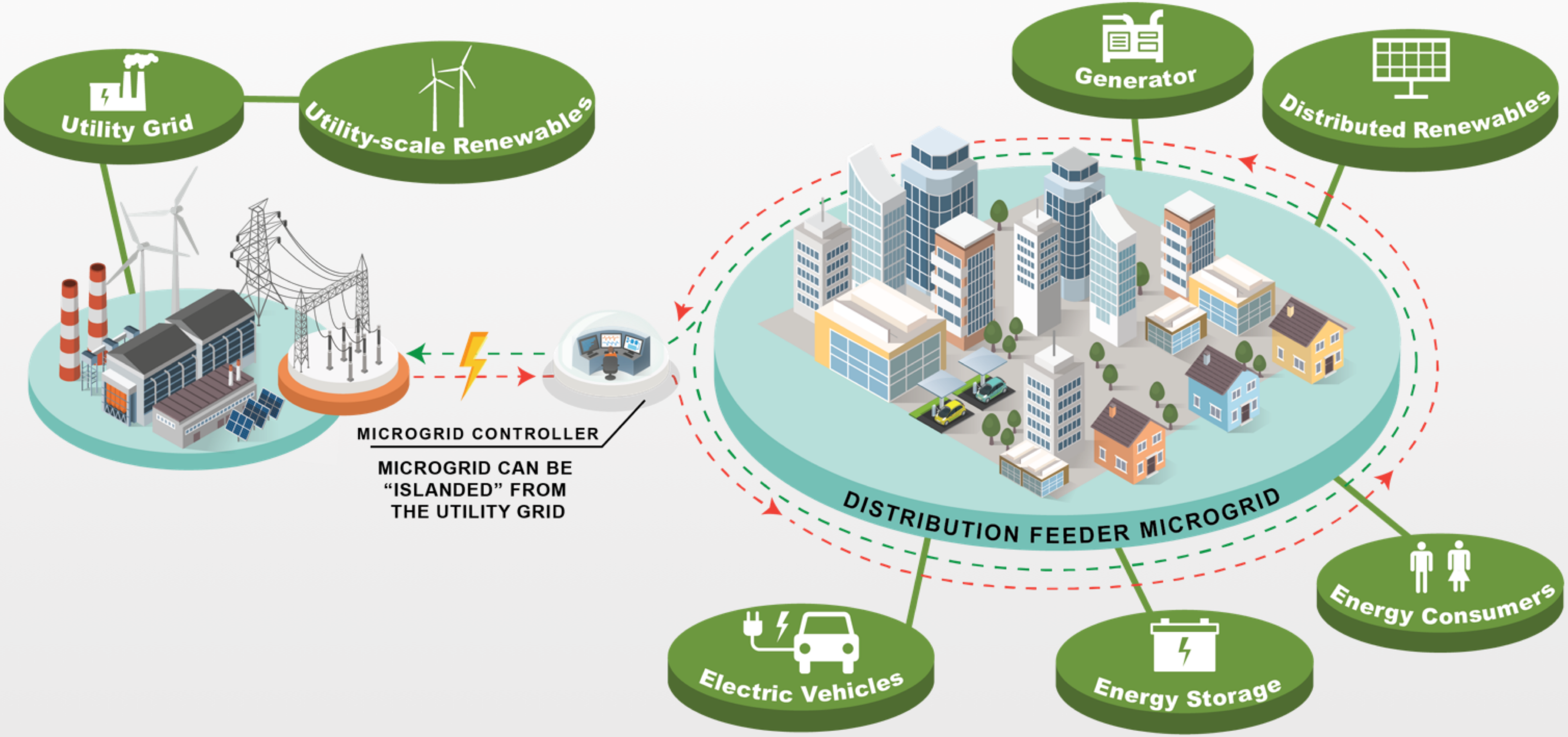
NM SMART Grid Center Overview

Presenter: Anne Jakle, NM EPSCoR

New Mexico EPSCoR

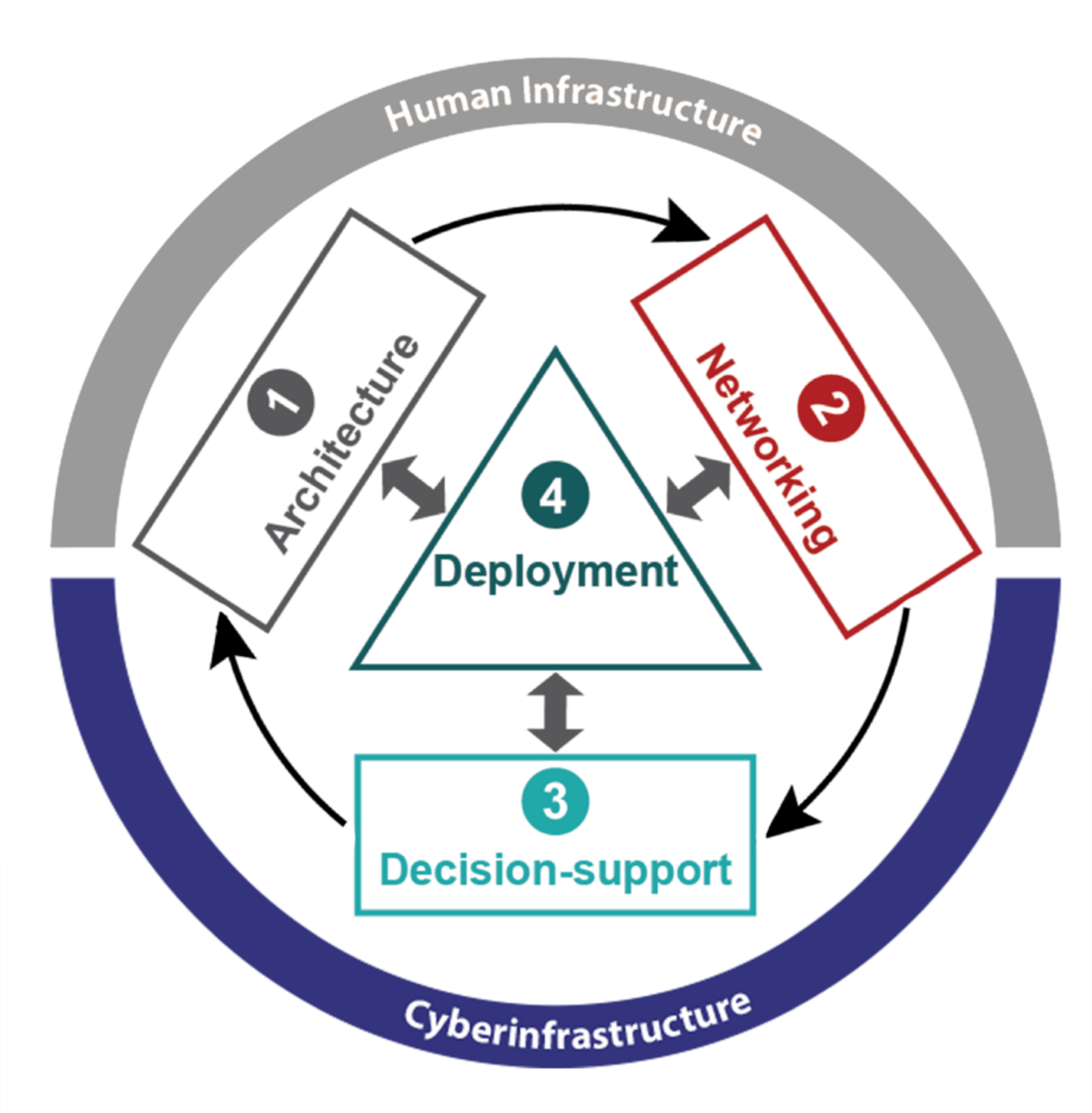
The NM SMART Grid Center

Sustainable, Modular, Adaptive, Resilient, Transactive



Why Distribution Feeder Microgrids (DFMs)?

NM SMART Grid Center Research Areas



New Mexico SMART Grid Center

Workforce Development, Outreach & Education

Participating Institutions

- 3 research universities
- 1 community college
- 2 national laboratories
- 1 museum
- 1 non-profit
- Industry partners

PNM

The Electric Company
El Paso Electric

ORACLE

SIEMENS

New Mexico CONSORTIUM

NREL | 40
NATIONAL RENEWABLE ENERGY LABORATORY
1977 - 2017

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Research Goal 1: Architecture

Presenter: Olga Lavrova, NMSU

Team members:

Olga Lavrova (NMSU ECE),
Satish Ranade (NMSU ECE),
Jay Misra (NMSU CS),
Students: Shubha Pati (PhD),
Chris Carr (MS),
Tochi Nwachuku (PhD),
James Pleasant (MS),
Josh Tellez (UG)

Ali Bidram (UNM ECE),
Jane Lehr (UNM ECE),
Janie Chermak (UNM Econ),
Benjamin Jones (UNM Econ)
Meeko Oishi (UNM ECE),
Svetlana Poroseva (UNM ME),
Students: Binod Poudel (PhD),
Jee Won Choi (PhD),
Jesse Kazmarski (PhD),
Joseph Ulibarri (PhD)

Industry partners:
PNM, EPE, LADPU, EMERA, Siemens, EPRI, SNL

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RG1 Architecture

RESEARCH OBJECTIVES AND ACTIVITIES

- **Motivation:** High penetration of renewable energy sources, coupled with emerging storage deployments and electrification of transportation, lead to new patterns and challenges in balancing of generation and demand.
- **Objective**: Create a comprehensive framework for distribution feeders to evolve into managed microgrids.

Key questions are:

1) What generation and storage resources should be deployed, where should they be sited, based on local generation and demand patterns?
2) How should distribution topology and sectionalizing be organized to enable reconfiguration and resilience?
3) How to develop local energy markets?, i.e. how can transmission and distribution system operators source grid flexibility services directly from end users, including residential customers?
4) What tariff designs could be used to engage and benefit participants
5) How to ensure traditional reliability, resiliency and quality of service of the electric grid, given new grid services model ?
6) What services are considered critical, and how can these services be guaranteed?
7) How do we develop adequate protection schemes for the new grid with high renewables penetration?
8) What are the additional sensing needs for the new SMART grids and what new types of sensors are needed ?
9) How can we source Restoration and Black start services from distribution feeders?

The Distribution Feeder Microgrid (DFM) is a SMART evolution of conventional feeder design

Secure
Modular
Adaptive
Resilient
Transactive

NM STATE UNIVERSITY

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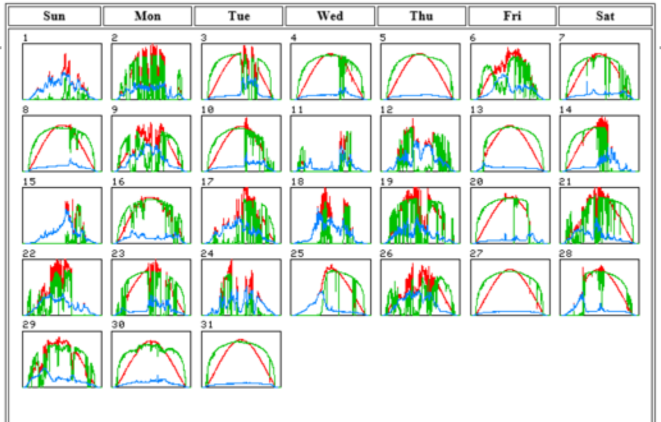
RG1 Architecture - Accomplishments

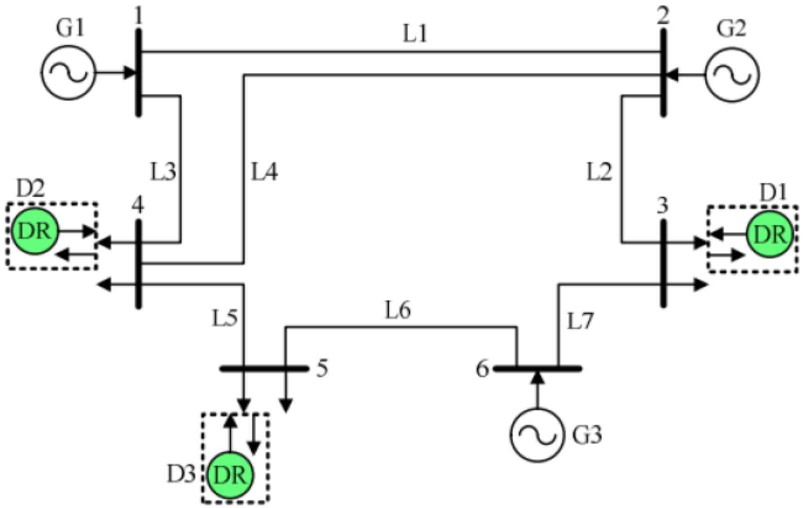
ACCOMPLISHMENTS(NMSU):

- Decentralized Robust Optimization for Transactive Scheduling of Distributed Resources
  - Jose Tabarez Ph.D. Dissertation, graduated April 2019

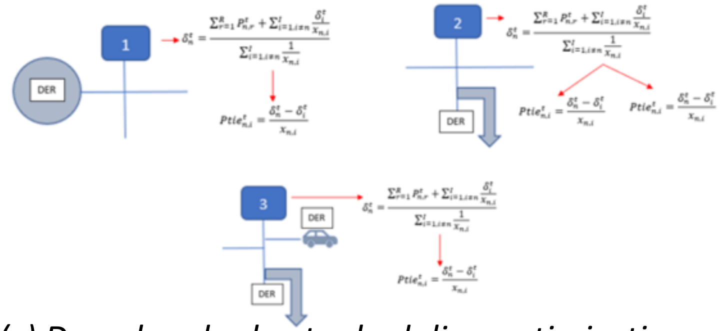
Given uncertain distributed solar resource (a) and demand, distributed agents in a six bus system (b) develop day-ahead robust resource schedules (c) via neighbor-neighbor communication (d).



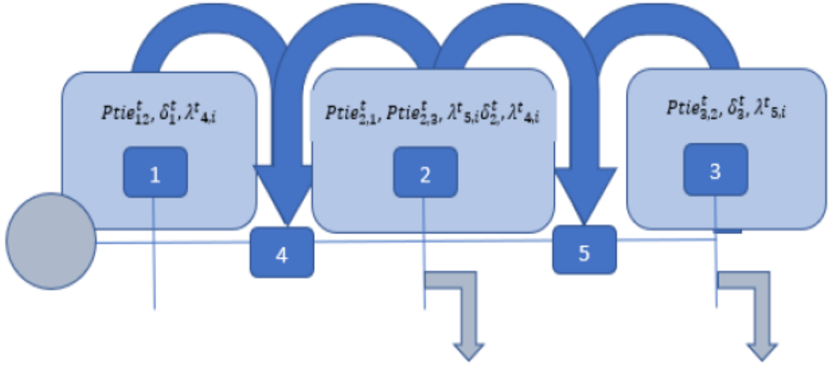
(a) Typical solar generation profiles



(b) 6 bus test system



(c) Day-ahead robust scheduling optimization

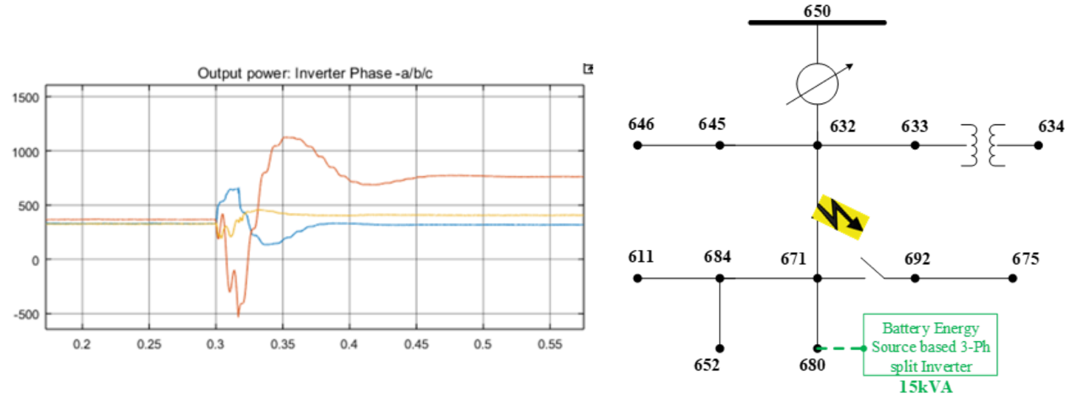


(d) Bus agents transmitting data to Branch Agents

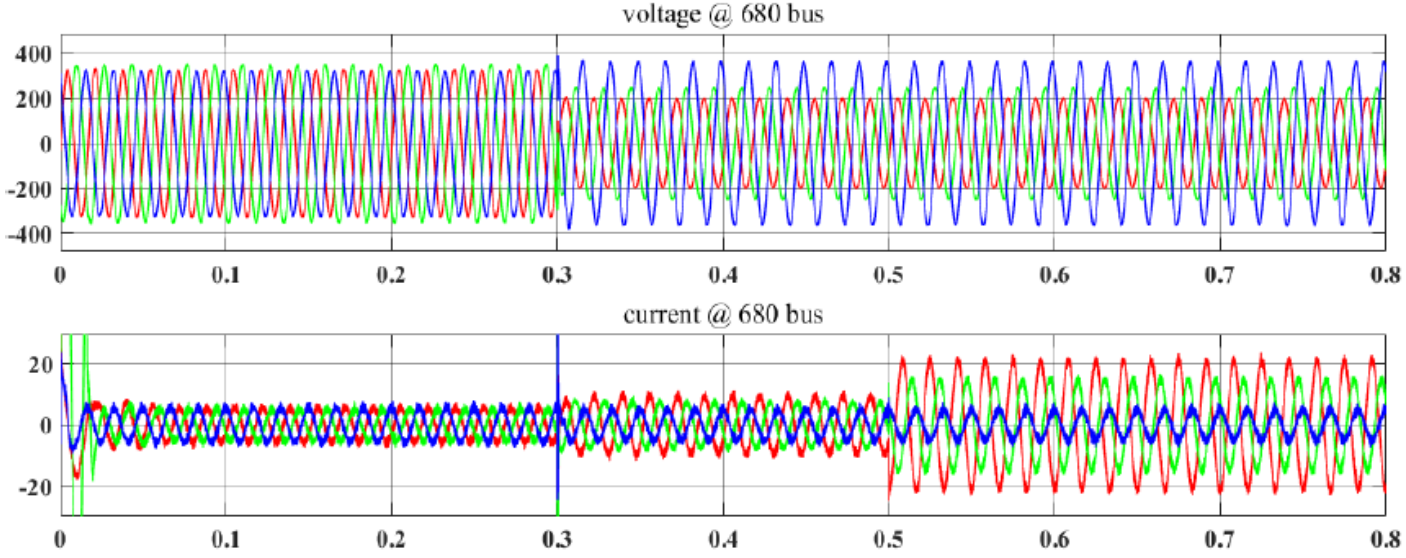
RG1 Architecture - Accomplishments

ACCOMPLISHMENTS(NMSU):

- Developed RT-HIL - ready model for IEEE 13-bus distribution system Modeling advanced inverter functions under different transient conditions.
- Developed plan for Power + Communication RT-HIL Co-simulation and prepared procurement



Reactive power support for an unbalanced fault in the IEEE 13 bus system



Voltages and currents for an unbalanced fault in the IEEE 13 bus system (Low Voltage Ride Through)

RG1 Architecture - Accomplishments

ACCOMPLISHMENTS(NMSU):

- Developed plan for Power+Communication RT-HIL Co-simulation and prepared procurement
- Developed RT-HIL - ready model for IEEE 13-bus distribution system
- Publications:
  - *“Exploring Multi-Objective Transmission Planning for Investment-Constrained Power Systems”, Tochi Nwachuku, O. Lavrova, S. Ranade, submitted to “Power Africa 2019” conference*
  - *“Robust Optimization for Distributed Energy Resource Scheduling”, Jose Tabarez, S. Ranade, to be submitted*
  - *“Exploring the Leakage Inductance of Transformers Used in Dual Active Bridge”, Denisse Alejandra Meza Soria, S. Ranade, to be submitted*

Exploring Multi-Objective Transmission Planning for Investment-Constrained Power Systems

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***Abstract*—In power systems comprised of a small number of generators and lines, additional investment significantly affects reliability, debt burden, and operating costs. Wise selection of candidate investments balancing multiple objectives is crucial, especially in developing countries where load shedding may already be in effect. In this work, a static transmission expansion methodology is presented using a multi-objective optimization framework, where investment cost, operating cost, and load shedding cost are combined. Pareto fronts are computed and examined to demonstrate trade-offs and sensitivities evident in the 6-bus Garver model, showing the applicability of the proposed approach. Practical observations and indications for future work are then demonstrated for a reduced model of the Nigerian grid.**

***Index Terms*—transmission planning, load shedding**

I. Introduction

In developing countries, power system planning activities often contend with networks whose design has become sub-optimal due to unplanned load growth, generator aging, or grid extension motivated by political goals. Investment capital is constrained, and load shedding or rotation may already be in effect, raising the debate whether serving more load may be more important than maintaining reserve margins or building additional transmission lines. Optimization of investment is needed to balance competing demands on financial resources, and utilities need to maintain adequate cash flow to expand electricity service for economic growth and poverty reduction.

The transmission planning problem, though dynamic in nature, is often simplified as a static optimization model, minimizing the total investment of network expansion for a single future scenario, subject to a number of constraints [1]. In most of the literature, the static transmission network expansion planning model is typically formulated to minimize the sum of investment cost and the load curtailments caused by lack of transmission capacity, subject to DC or AC load flow constraints [2], [3].

Maintaining the security of large, mature power systems is often translated into satisfying a deterministic approach such as the N-1 or even N-2 criteria [4], [5]. Although the contingencies included may be seen as worst case scenarios, a meshed system with interconnections and a large number of generating units can require relatively less investment to keep secure than a small system.

A probabilistic approach [6] may be better for a small system, because it allows the selection of a given risk level. While there is not an absolute meaning and guidance for metrics such as loss of load probability (LOLP), loss of load frequency (LOLF), and expected energy not-supplied (EENS), past performance is typically used as a relative measure. However, the application of these indices may be of limited validity if particular outage information is not available, and even historical information may not be relevant to a fast growing system. [7]

In real systems, this criterion is guaranteed only in meshed network areas and interconnections. A huge amount of money would be needed if the whole system had to ensure the N-1 security criterion including sub-transmission areas. After the optimization process, a probabilistic approach could be used to evaluate the best sequences considering interruption costs and an hourly load model.

In the literature, different TEP objective function are usually a combination of cost such as:minimization of

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RG1 Architecture - Deployment

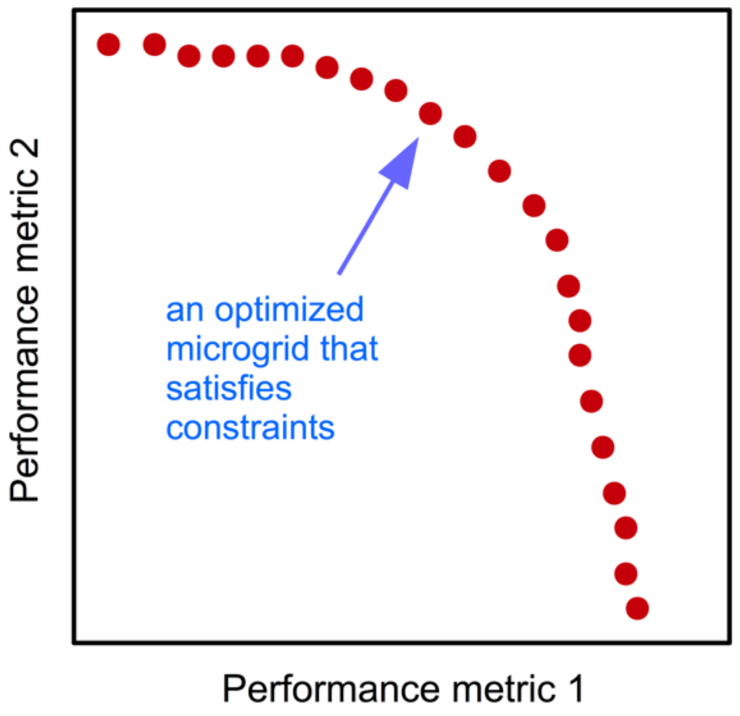
INFRASTRUCTURE IMPROVEMENTS: NMSU

- Infrastructure improvements:
- Developed data acquisition system for solar microinverters and energy storage system
  - Currently can monitoring electrical performance and power quality data from most NMSU electrical buildings panels
- 4 PV+Battery systems installed on Thomas and Brown roof
- Implemented HIL-RT simulation Capability
  - Will support laboratory-scale validation of 5-node DFM
- El Paso Electric Power Laboratory has six Labvolt test benches which can be configured using motor-generator sets as generating sources or loads.
- Each bench is tied to its substation and interconnected via transmission lines as a complete power system

RG1 Architecture - Accomplishments

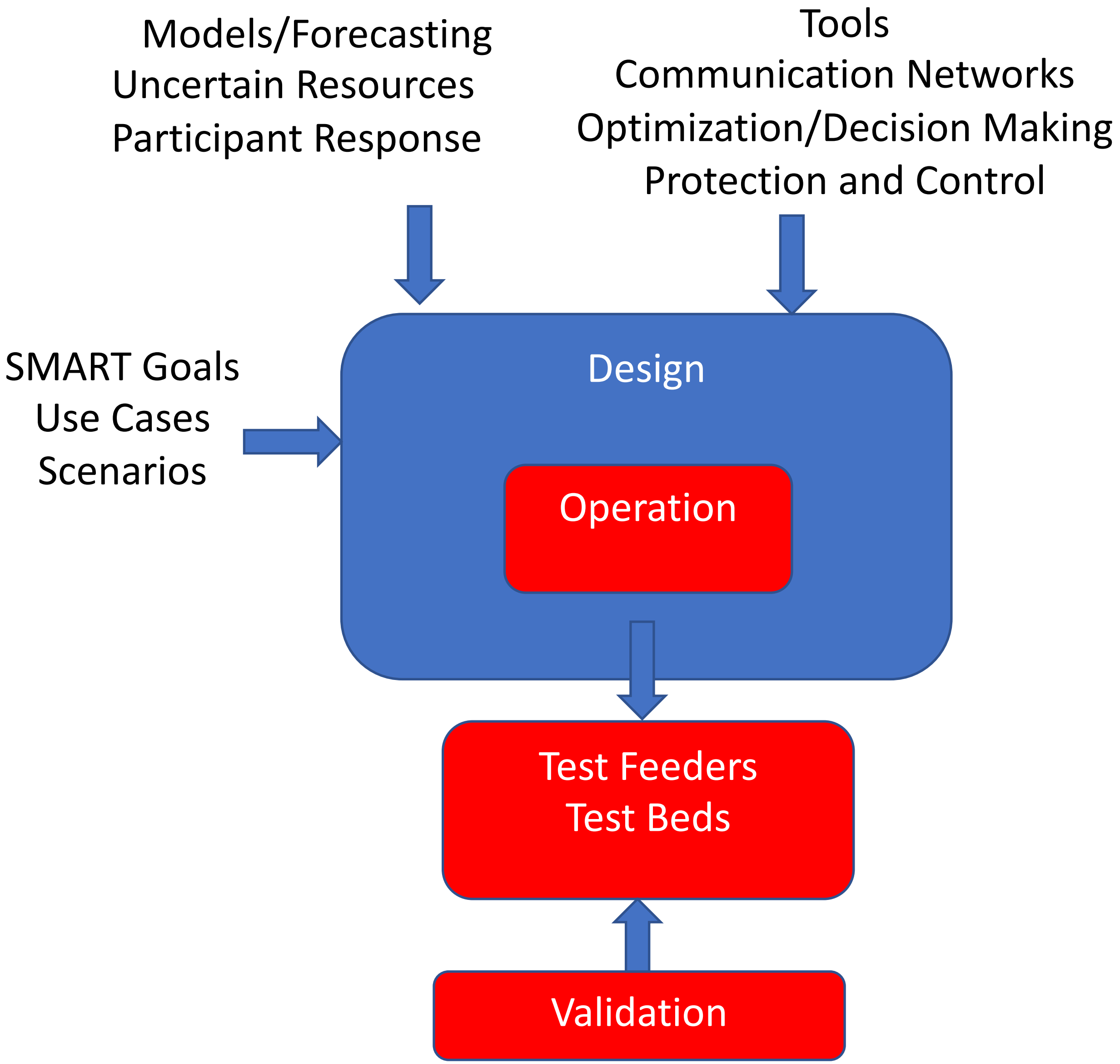
ACCOMPLISHMENTS(UNM):

- Reviewed the EPRI use cases that will form the basis of our DFM use cases
- Survey 1 was administered in late spring, preliminary results will be presented in poster form at the NM Academy of Science Research Symposium
- Second survey is in the planning stages
- Developing experimental protocols to model consumer response and behavior
- Dynamic clustering of DFMs
- Publications:
  - *1 Journal paper accepted*
  - *7 Journal papers under review*
  - *2 conference papers*



RG1 Architecture

FUTURE RESEARCH



Year 2 activities:

1. Incorporate characterization of the variable parameters within the mathematical models in the optimization engines
2. Define metrics to test resilience and sustainability
3. Implement data-driven decision-making tools from Research Goal 3 and compare their performance against the stochastic optimization

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Research Goal 2: Networking

Presenter: David Mitchell, NMSU

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Overview of Research Goal & Objectives

Goal: Design network architecture for DFM infrastructure that is scalable, resilient, secure, and privacy preserving

Activity 1: Design overarching network architecture (Misra, NMSU, Devetsikiotis, UNM)

Activity 2: Employ novel wireless technologies (Mitchell, Huang, NMSU)

Activity 3: Enhance security level against cyberattacks (Zheng, NMT, Misra, NMSU)

Activity 4: Preserve user privacy (Shin, NMT)

Image Credits: https://techziffy.com/tag/smart-grid-it-systems-future-growth/

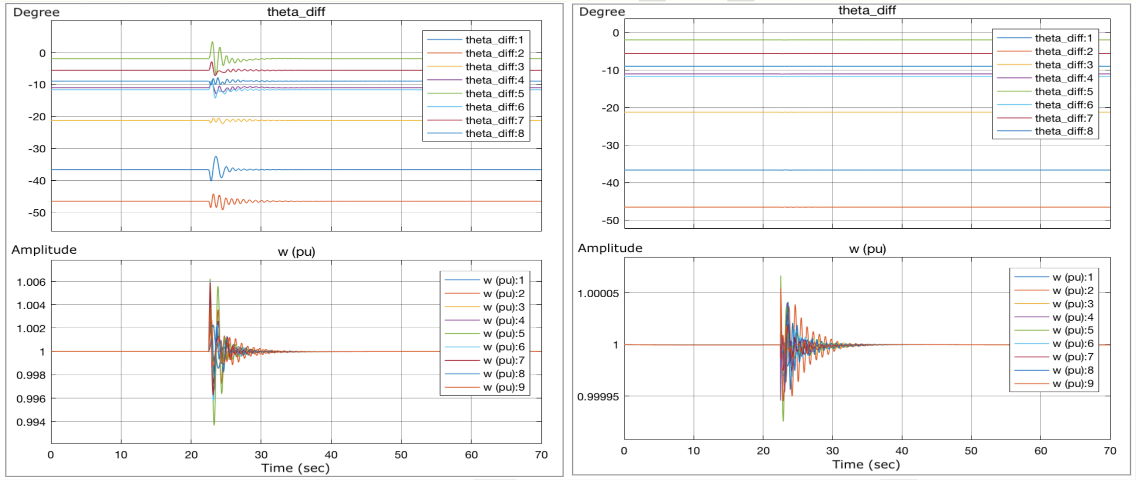
Activity 1: Overarching Network Architecture

Y1 Highlights:

- Named Data Networking shown to have improved packet delivery
- Studied two-way comm. between electric vehicles and microgrid

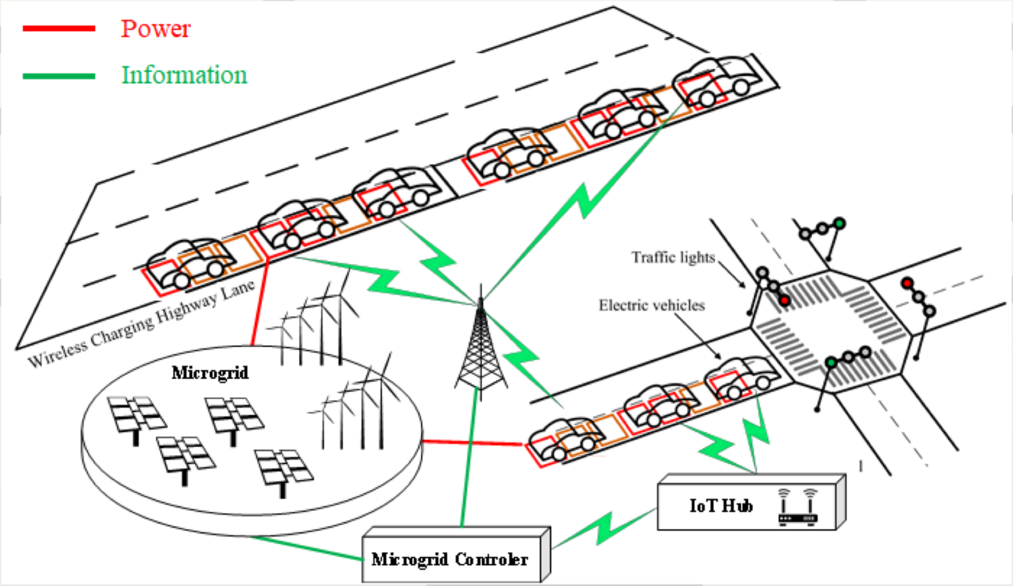
Y2 Goals:

- Implement router token bucket
- Deploy scheduling system in large scale simulations
- Integrate code base into OpalRT



(b) UDP (c) NDN

Tourani et al., 2019, *Journal of Internet of Things*



Kong et al., 2018, *IEEE ICC*

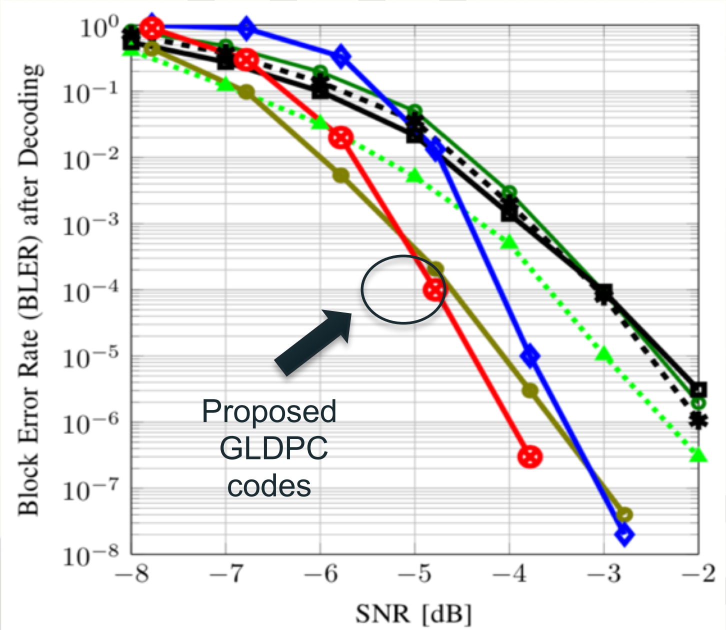
Activity 2: Advanced Wireless Technologies

Y1 Highlights:

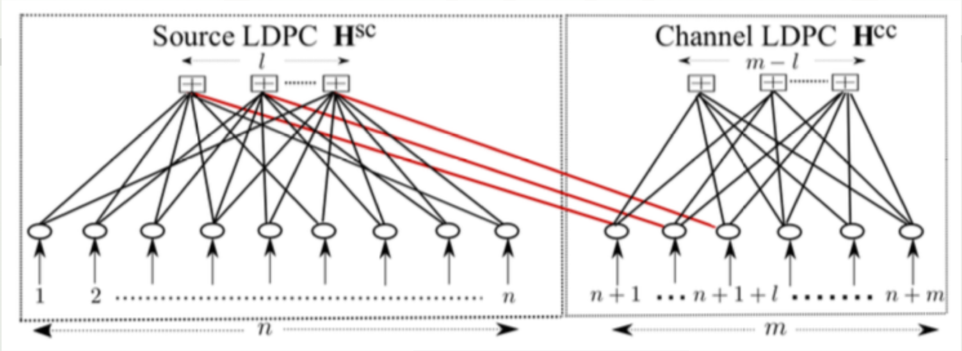
- Schemes for low latency, ultra reliable data (<4ms)
- Proposed concatenated graphical models for joint source-channel coding

Y2 Goals:

- Extend communication protocols to network setting
- Investigate networked data compression schemes
- Apply compressive sensing to DFM



Liu et al., 2018, *IEEE Access*



Golmohammadi et al., 2018, *IEEE ISIT*

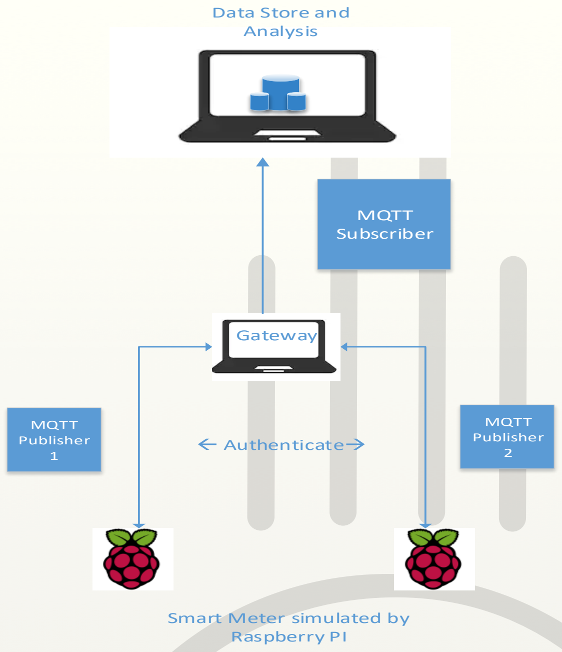
Activity 3: Enhance Security Level

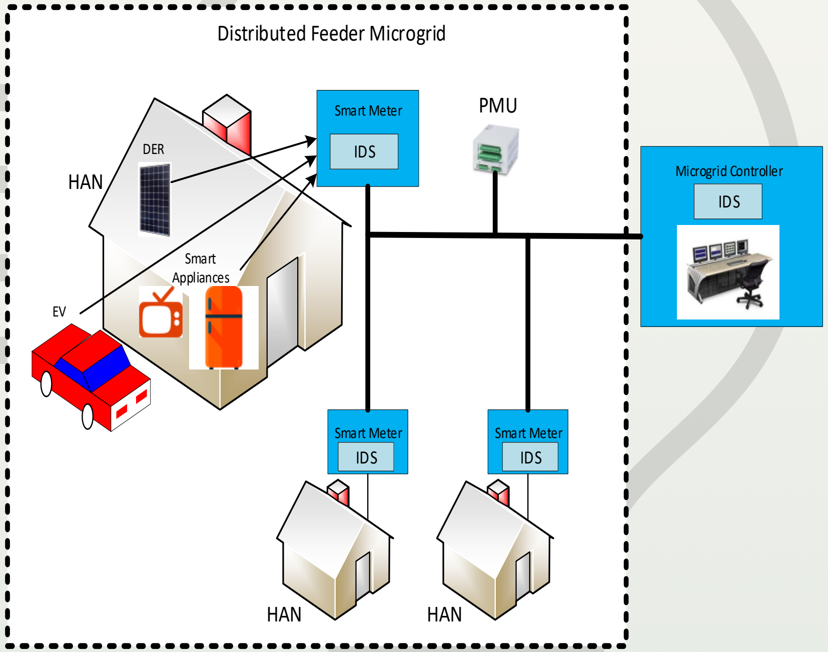
Y1 Highlights:

- Designed a lightweight secure device authentication protocol
- Investigated a distributed data-driven cyber-physical intrusion system

Y2 Goals:

- Develop authentication protocol using identity-based cryptography
- Study secure group communication
- On-line fast intrusion detection using un-/semi-supervised learning





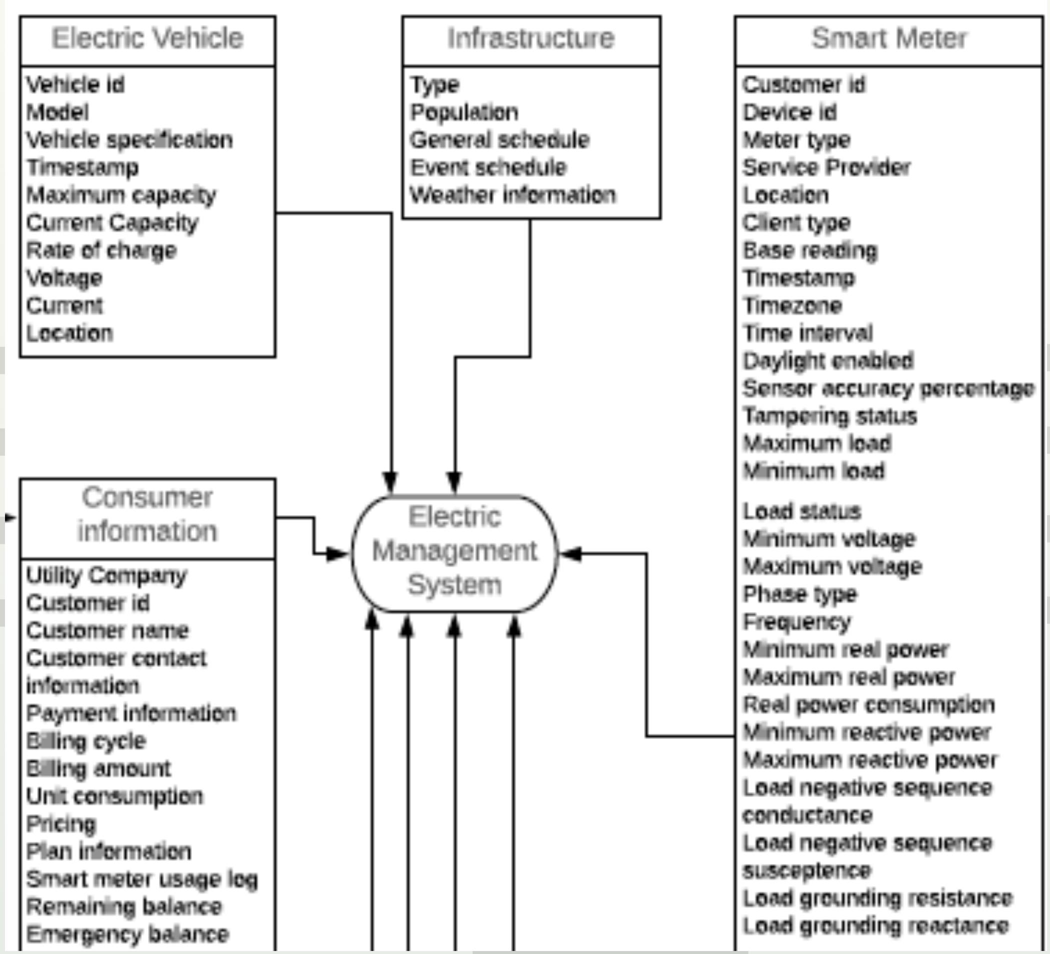
Activity 4: Preserve User Privacy

Y1 Highlights:

- Performed privacy analysis of the DFM architecture
- Developed an extensive privacy data ontology for DFM

Y2 Goals:

- Characterize uncertainty of privacy threats in DFM
- Construct privacy-preserving scheme
- Conduct cost-benefit analysis



Areas for Cross-Research-Group Coordination

Architecture & Networking:

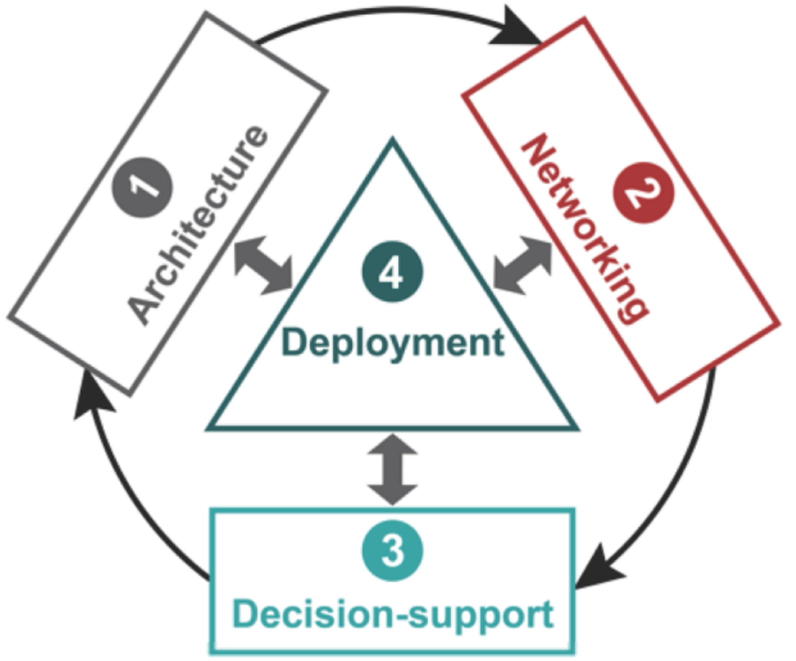
- Interplay between power & information networks

Decision-support & Networking:

- Data processing
- Unsupervised/semi-supervised learning

Deployment & Networking:

- Large scale simulation with communication modules
- Development/integration of OpalRT simulator



Research Goal 3: Decision-Support

Presenter: Manel Martínez-Ramón, UNM

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Overview of Research Goal & Objectives

Objectives:

1) Clean, preprocess data: Preserve data integrity

2) Knowledge to the DFM: AI in anomaly detection, forecast, database quering...

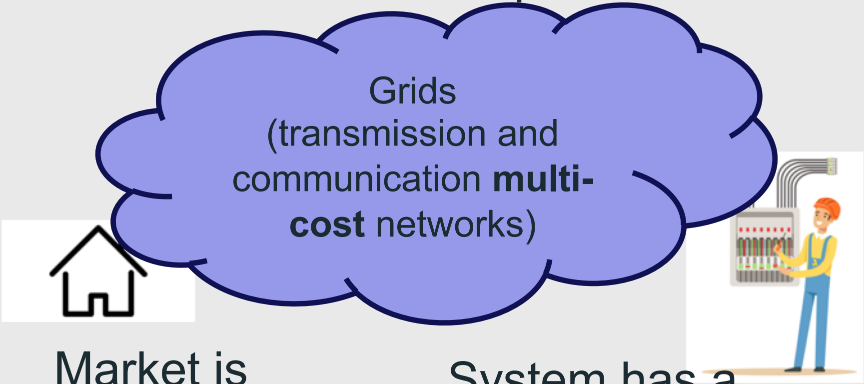
3) Design decision making tools: AI for development of planning technologies

Goals: provide machine intelligence for decision making

Skyline Queries Constrained by Multi-Cost Networks

ALGORITHMS TO EXTRACT INFORMATION FROM DATA

Multi-criteria queries

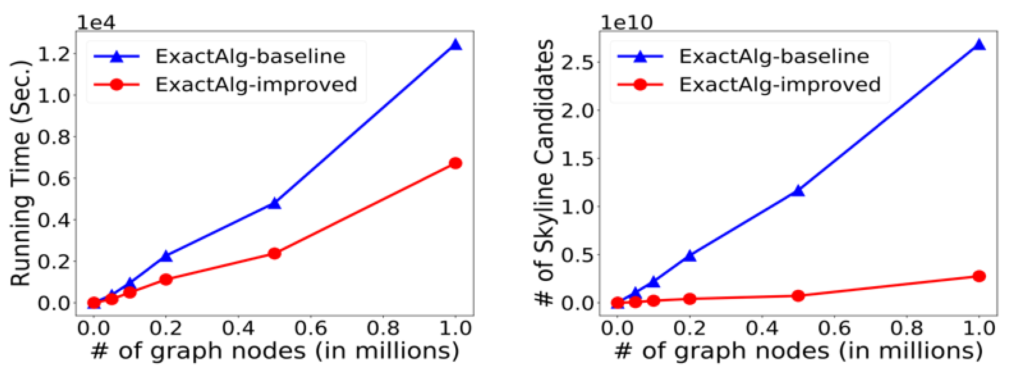


Market is dynamic… Where get my energy?

System has a problem! best service, resealable price, come to fix it?

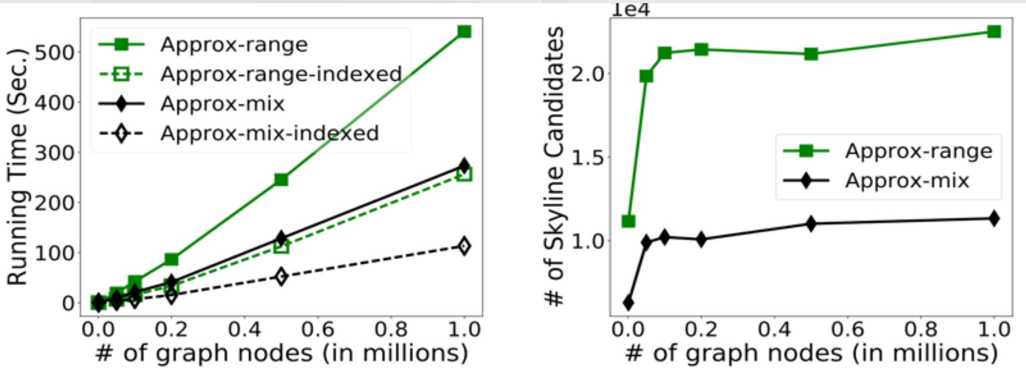
- **Exact/approximate algorithms**
  - **Find useful information to match multi-criteria queries**

Performance of the exact search methods:



(a) Query time vs. N (b) # of candidates vs. N

Performance of the approximate search methods:

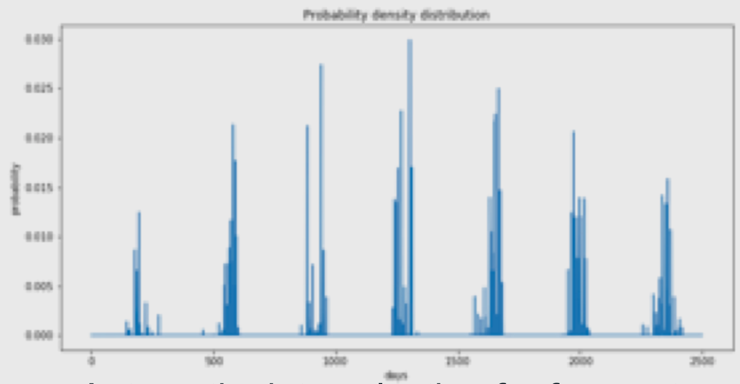


(a) Query time vs. N (b) # of candidates vs. N

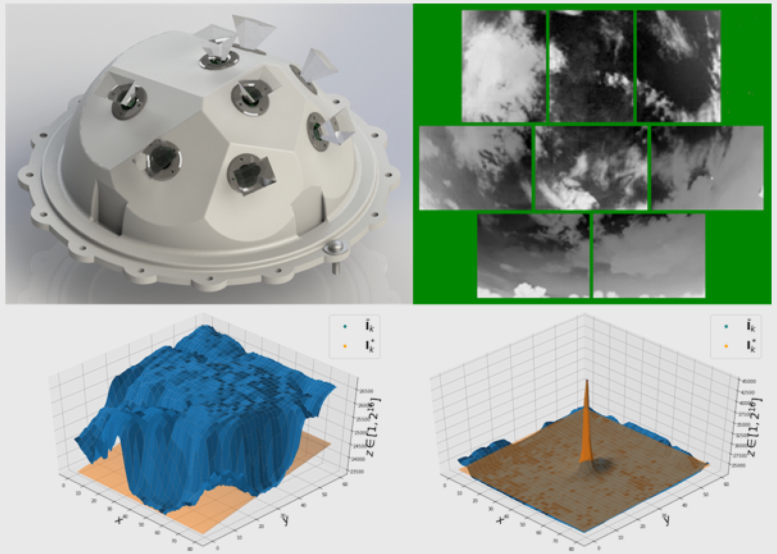
Gong, Cao, Nagarkar, 2019, *IEEE Conf. on Data Engineering (ICDE)*

Bayesian Approaches to Decision Support

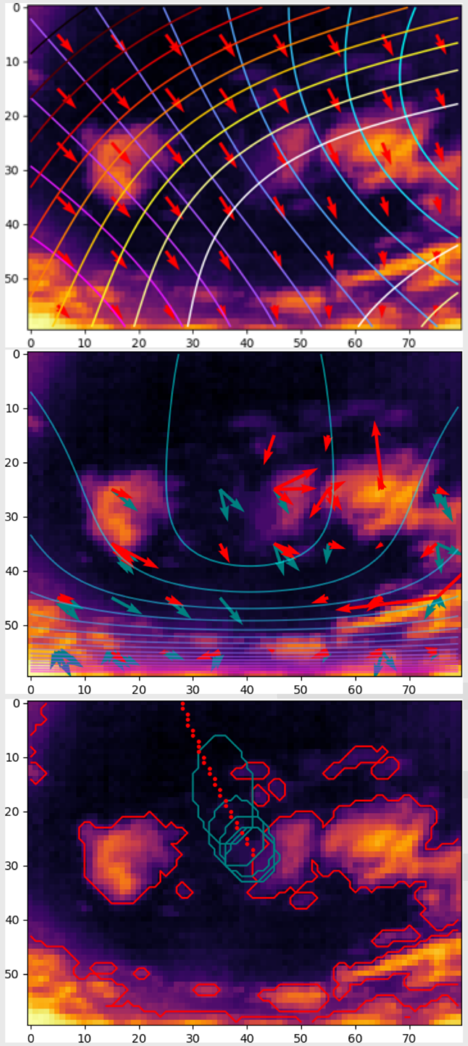
PROBABILISTIC DATA MODELLING



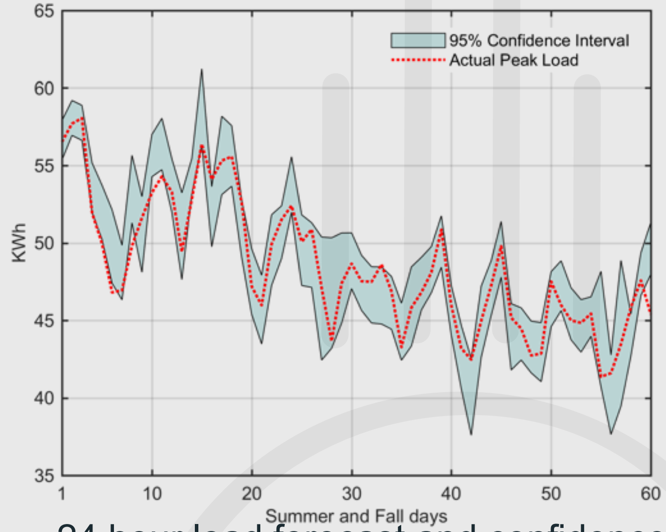
Automatic data selection for forecast



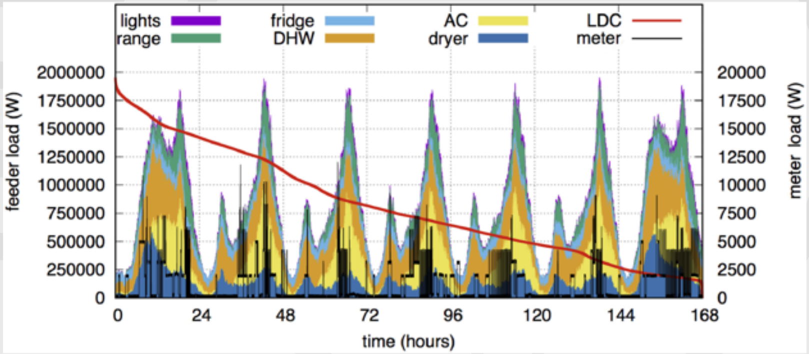
Cloud characterization and forecast system



Cloud dynamics estimation, perspective correction and behaviour prediction



24 hour load forecast and confidence interval

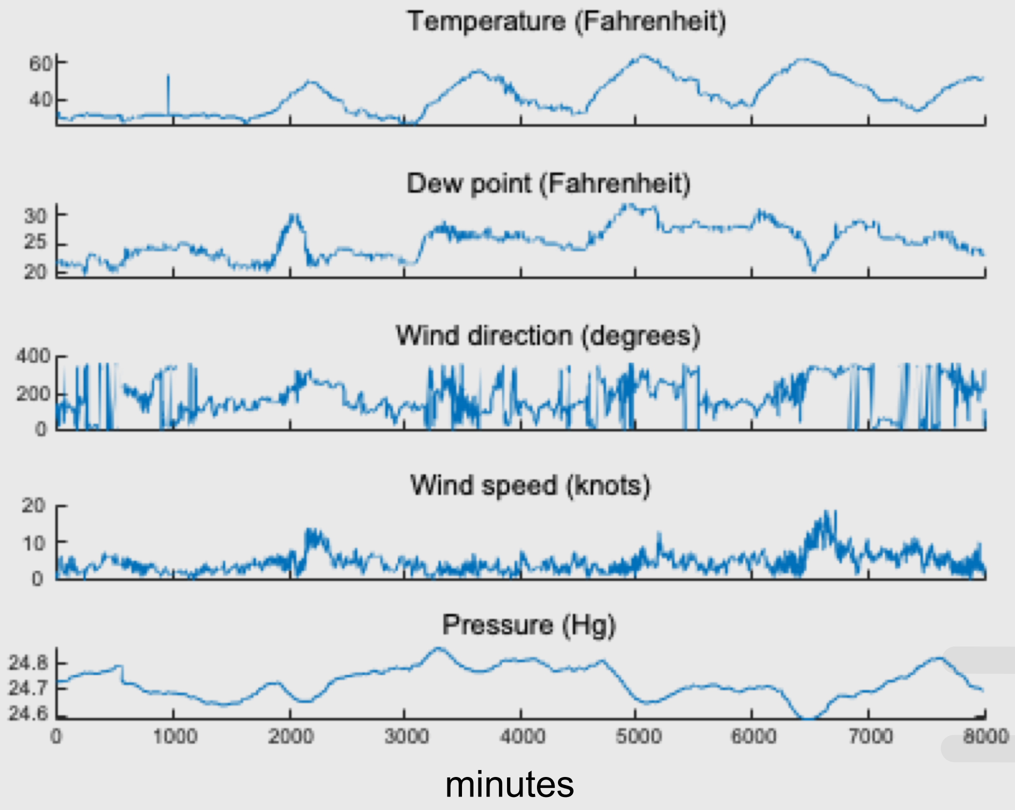


Probabilistic modelling of aggregated residential energy.

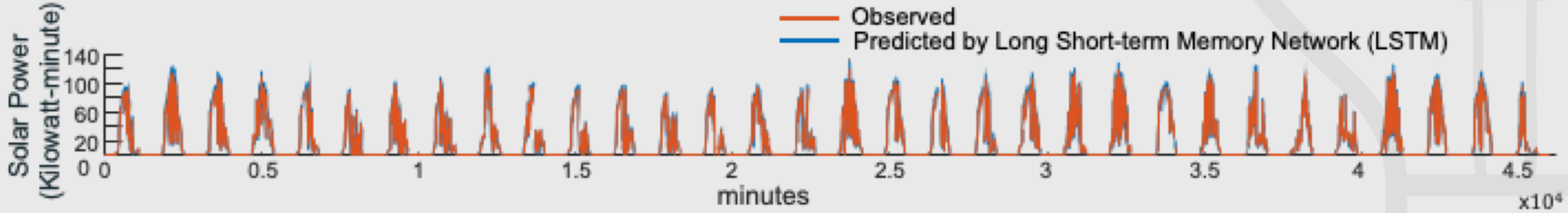
2 published papers, 1 submitted, 2 in progress. Several conferences. 2 PhD dissertations to finish this year.

Deep Learning for Real-time Prediction

LONG SHORT TERM MEMORY NETWORKS FOR SOLAR POWER FORECAST



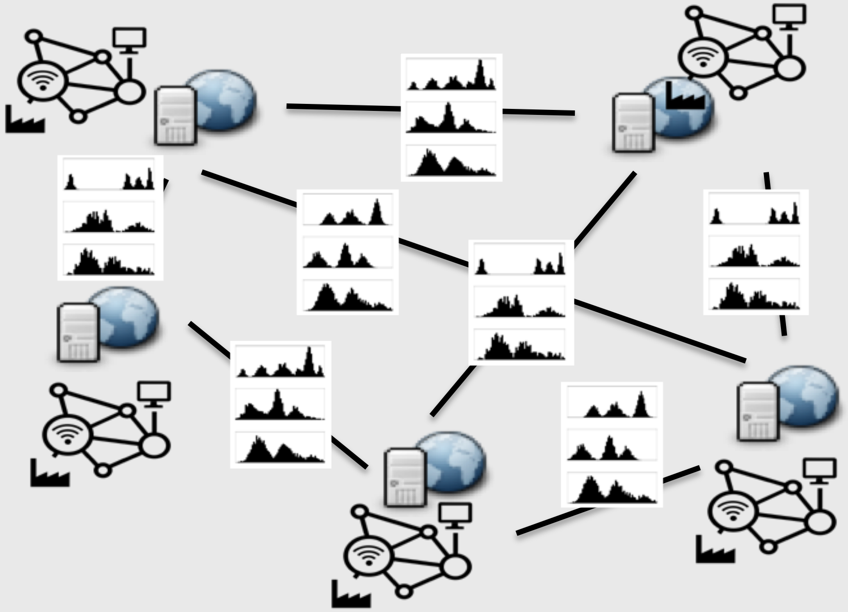
- Deep learning approach.
- Minute or second ahead solar power forecast.
- Exploited weather information.
- Very low prediction error.



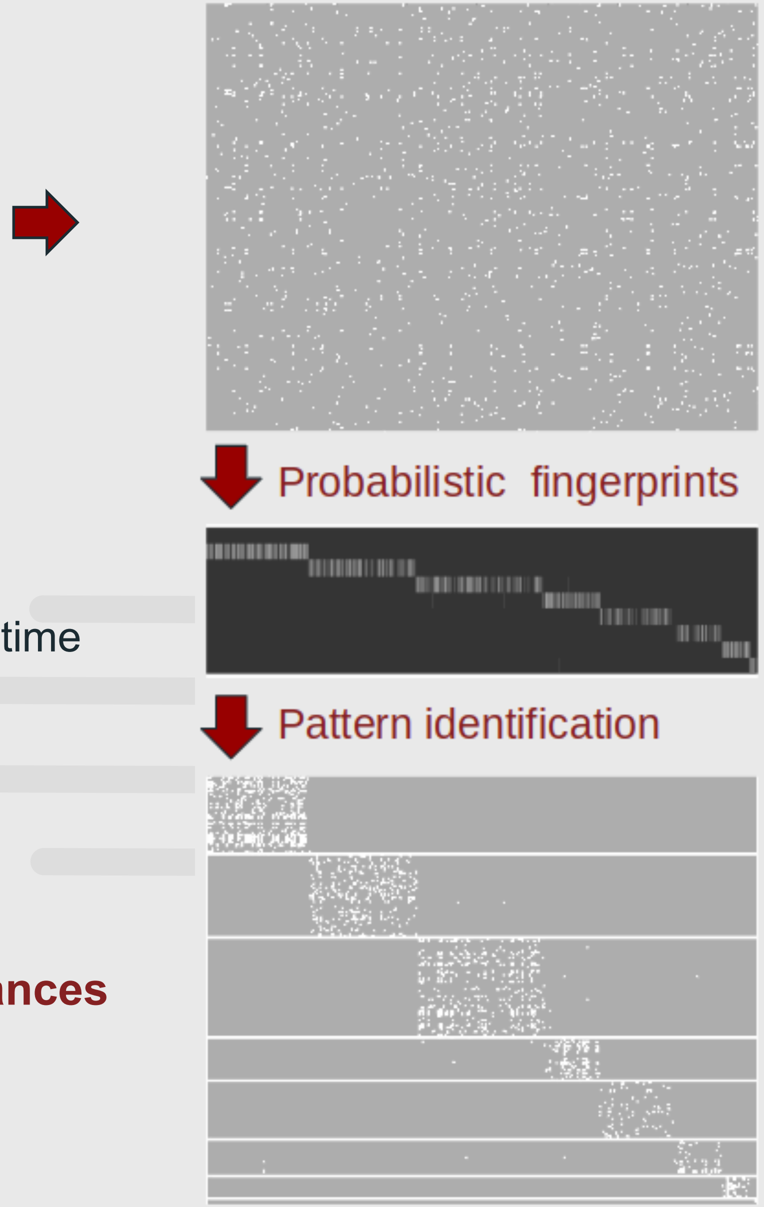
Manuscript under preparation, Mollah and Mueen, 2019.

Distributed Stream Analysis for Morphing Graphs

PROBABILISTIC MODELING FOR DATA FORECASTING



IoT appliances modeled as probabilistic graphs that morph over time



One-shot probabilistic, stream algorithm:

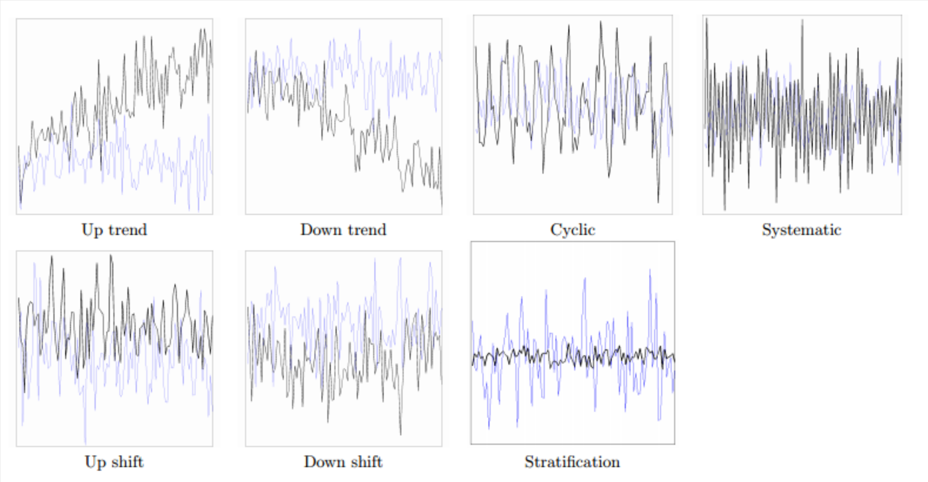
- **Identifies coordinated distributed behavior by building probabilistic fingerprints**
- **Quantifies concept drifting, signaling disturbances of IoT appliances and possible attacks**

Submitted to IEEE Big Data 2019

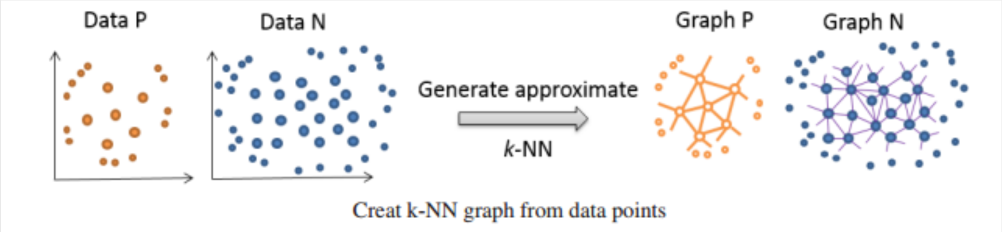
Multilevel Support Vector Machine Approaches to Decision Support

DESIGN AND COMPARE ANOMALY DETECTION MODELS IN ENERGY SYSTEMS

- Necessary to protect and monitor
- Anomalies: ***rare*** but important to detect

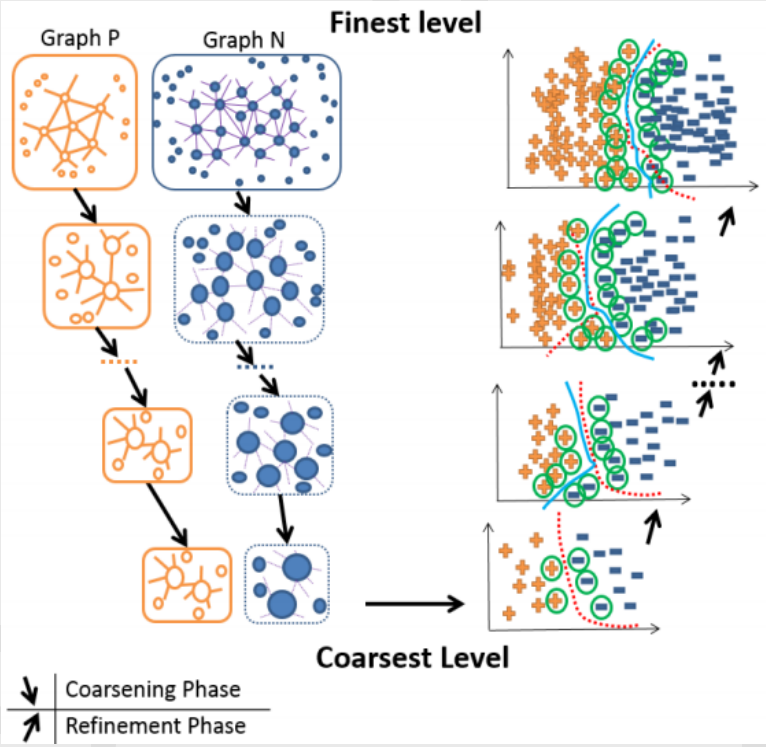


Automatic Detection of Anomalies (Power Quality Disturbances)



Create k-NN graph from data points

Sadrfaridpour, Razzaghi, & Safro, 2019, *Machine Learning*

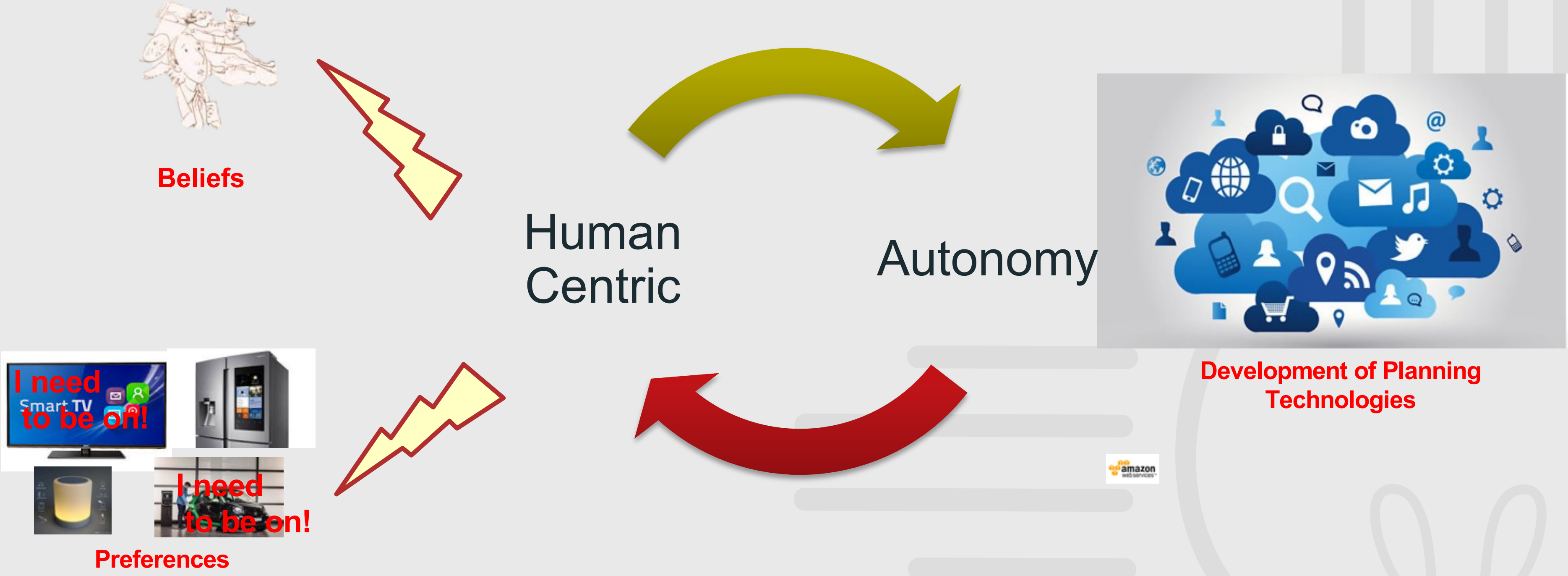


Multilevel Framework

- **Multilevel Relaxed Support Vector Machine (MLRSVM) extends SVM**
  - **Imbalanced, noisy massive data**
  - **Faster model selection**
  - **Anomaly detection**

Autonomous Agents for Complex Systems

KNOWLEDGE REPRESENTATION AND REASONING



Overall Theme: Representation and Reasoning

Year 2 Work Plan

Objective 1: Clean, preproces data

- Activity 1.1
  - **Finish** L2: Data integrity
  - **Start** L3: Data repository

- Activity 1.2
  - **Progress**: L1, CNN feature extraction

Objective 2: Infer knowledge

- Activity 2.1: Pattern mining algorithms
  - **Progress** in L1: Bayesian data modeling
  - **Start** L2: Information fusion

- Activity 2.2: Anomaly detection
  - **Progress** in L1: WR-SVMs for anomaly detection
  - **Start** L3: grid unstability prediction

Objective 3: Computer aided decision tools

- Activity 3.1: Game theoretic models
  - **Progress** in L1: Dynamic models
  - **Progress** in L4: Static schemes
- Activity 3.2: Knowledge representation models
  - **Progress** in L1: Action-negotiation integration

Achievements:

All activities progress as scheduled. No delays
Some activities initiated before scheduled

8 papers published, some more submitted (of 13 commited)
10 presentations (of 14 commited)
7 PhD in progress (of 10 commited)

Several grant proposals submitted

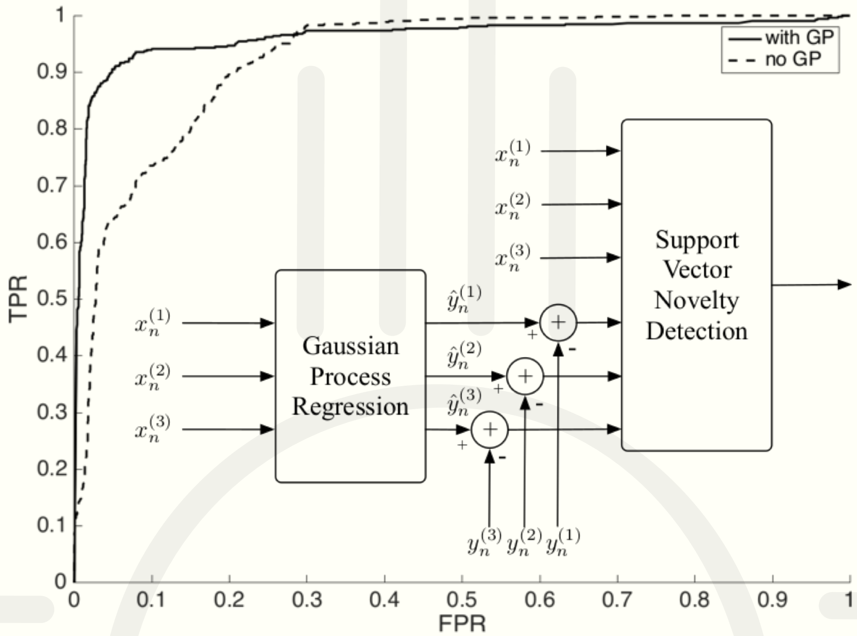
Areas for Cross-Research-Group Coordination

RG1:

1) Modelling and simulation of faults
2) Test of multiobjective fault detection schemes

RG4:

1) Data sharing – Mesa del Sol, Prosperity



Solar panels and Aperture center at Mesa del Sol

Solar panels and Battery rooms at Prosperity, PNM

Research Goal 4: Deployment

Presenter: Ali Bidram, UNM

New Mexico EPSCoR

Overview of Research Goal & Objectives

- **Research Goal:**
  - Addresses resilience and sustainability of DFM and their trade-offs
  - Modeling → simulation → deployment
  - Interaction between power system and communication architectures overlying the decision making and control systems
  - Verification and deployment of achievements made in RG1-3

- **Objectives:**
  - Build integrated hardware-in-loop (HIL) simulation and testbed systems at multiple institutions
  - Develop realistic scenarios for operation of DFMs in various stress conditions
  - Demonstrate improved resilience and sustainability

Team Members (UNM)

- Faculty: Ali Bidram and Jane Lehr (ECE)

- Students: Ansel Blumenthal (ME-UG), Rudy Montoya (ME-UG), Angela Patterson (ME-UG), Jee Won Choi (ME-PhD), Binod Poudel (ECE-PhD), Tohid Khalili (ECE-PhD)

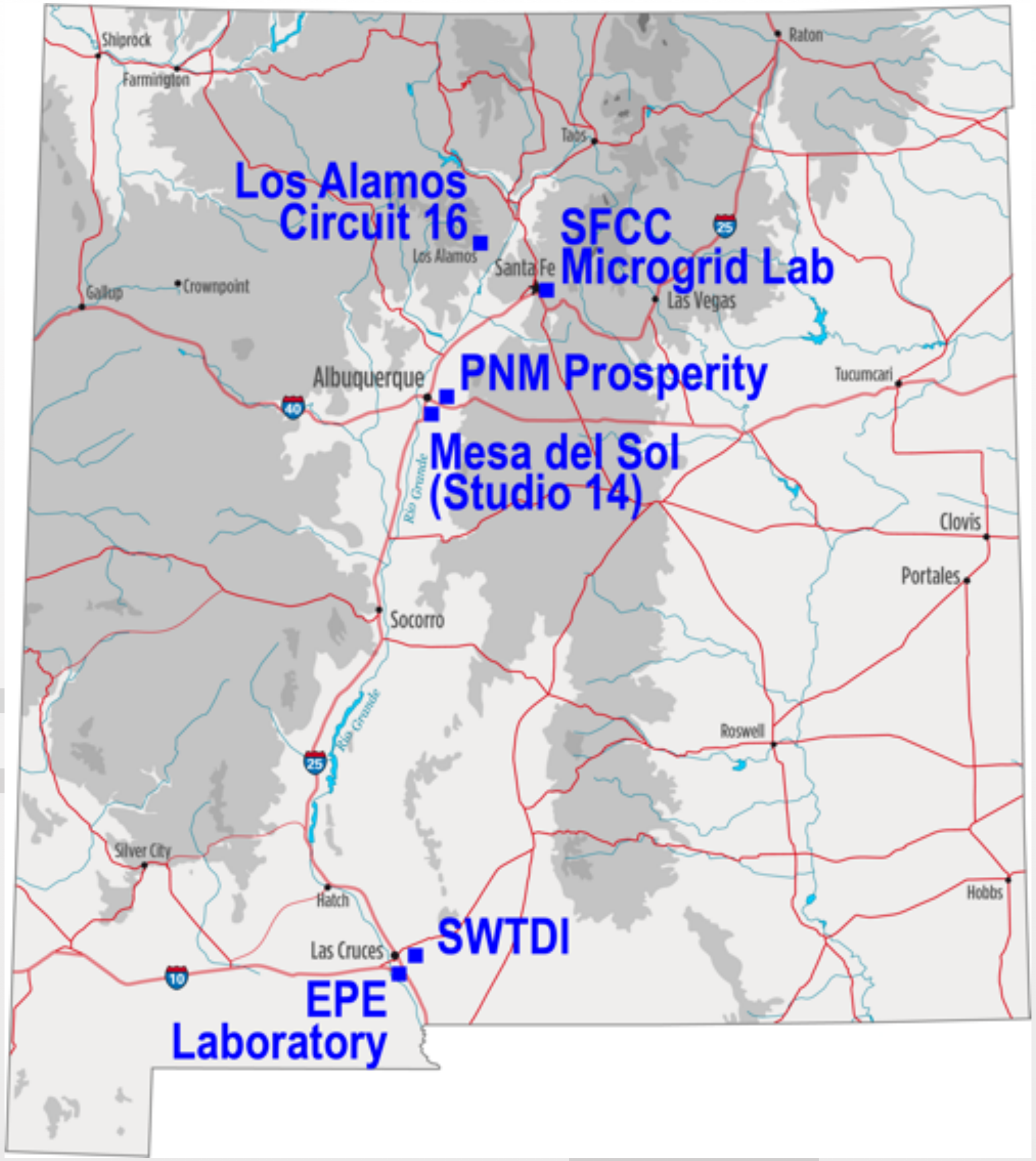
Team Members (NMSU)

- Faculty: Satish Ranade (ECE), Olga Lavrova (ECE), Jay Misra (CS), David Mitchell (ECE), Hong Huang (ECE)
- Students: Shubha Pati (EE-PhD), Anand Dandavate (EE-PhD), Chris Carr (ECE-MS), James Pleasant (ECE-MS), Josh Tellez (ECE-UG)

Southwest Technology Development Institute (SWTDI)

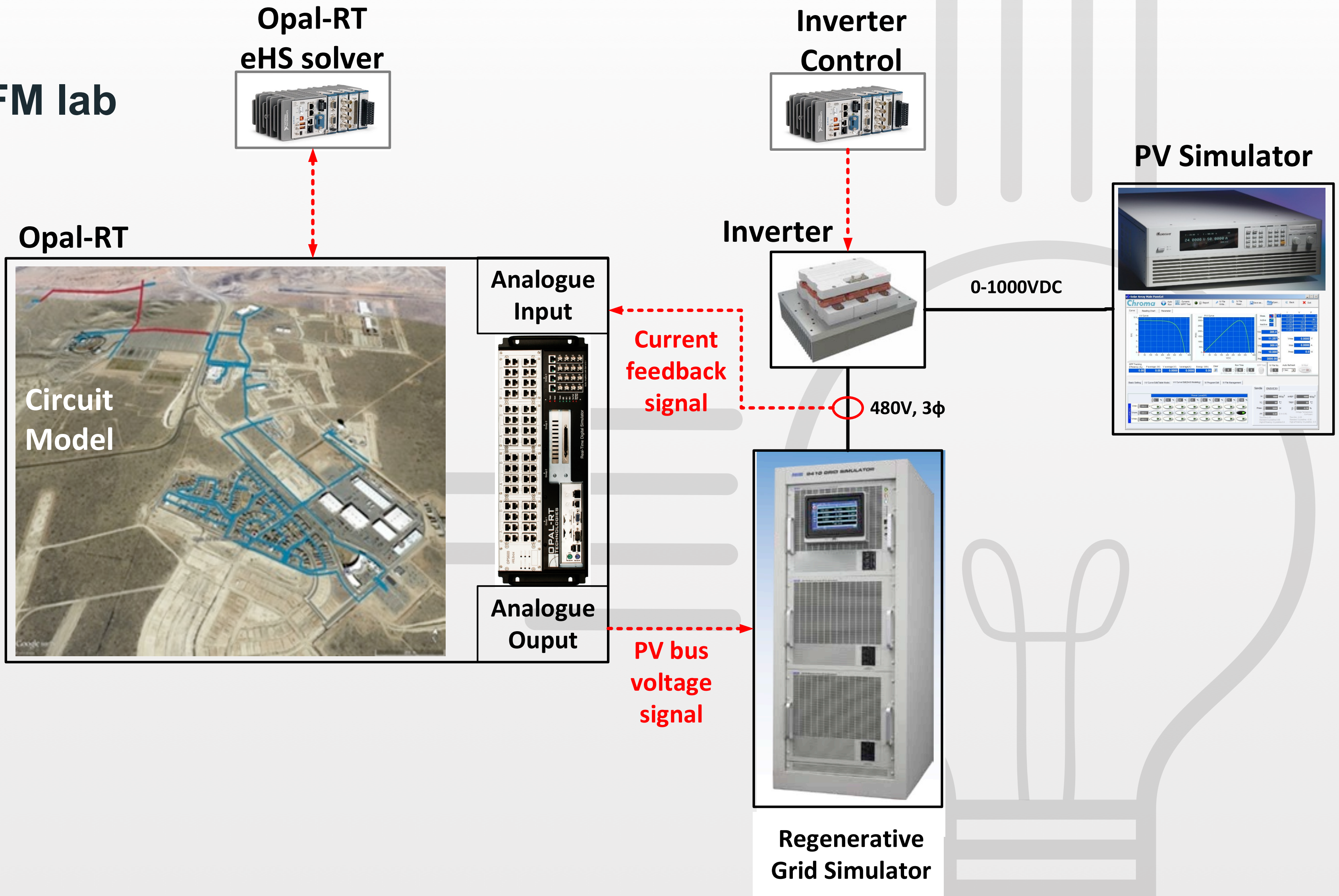
RG4 Testbeds

- **Infrastructure improvements:**
  - –UNM MDS Microgrid: Integrate microgrid with new power and control Hardware-in-the-loop (HIL) simulation components
  - –NMSU SWTDI: Buildings, tracking arrays, storage systems, and loads (including water desalination hub) will form a DFM



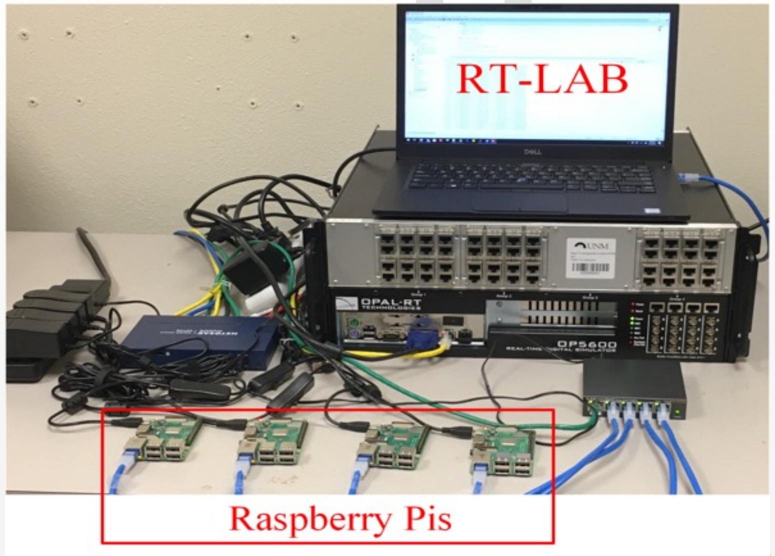
UNM Hardware-in-the-Loop (HIL) Testbed

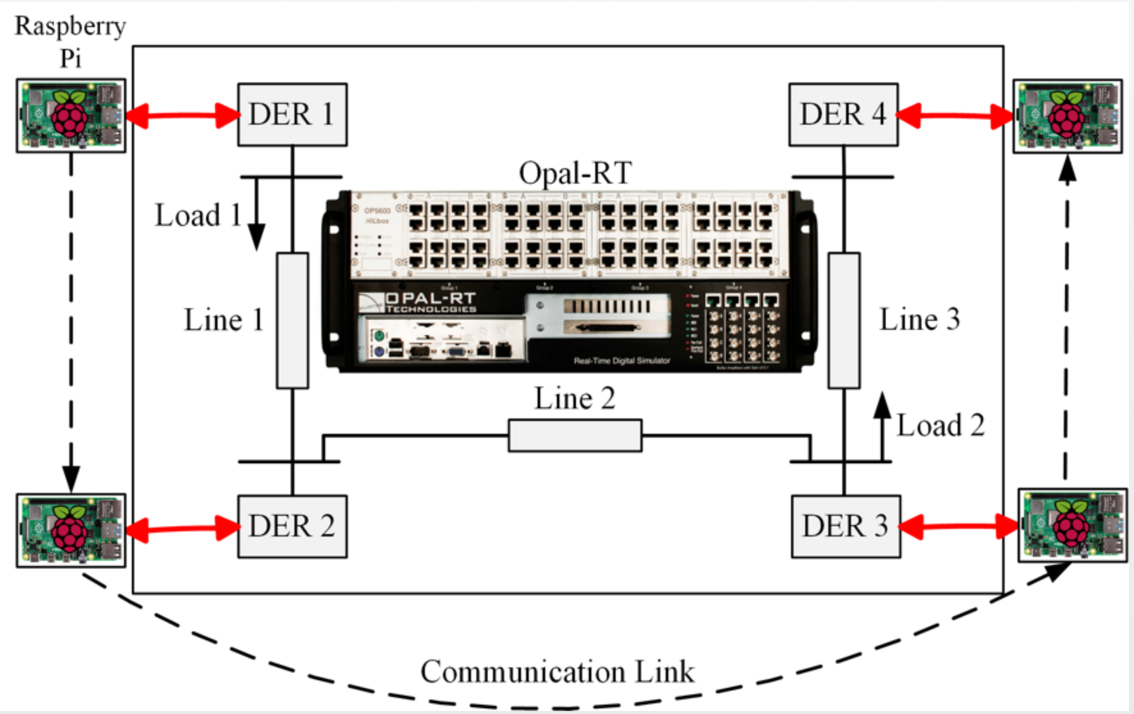
Schematic of HIL simulation setup at the Mesa del Sol DFM lab

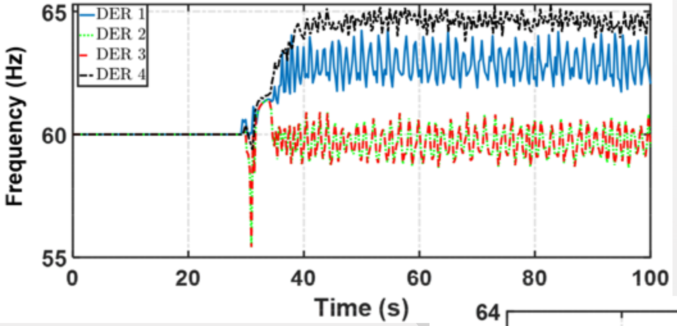


UNM HIL Testbed

- **Control in the loop testbed:**
  - Raspberry Pis
  - Opal-RT

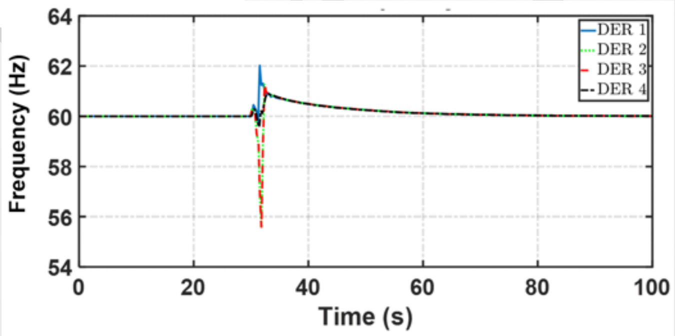






Cyber attack Impact

Attack Detection and Mitigation



Partnerships

- Emera Technologies has interest in community-scale microgrids
- PNM visit to the transmission system control center (PNM goal to be carbon-free by 2040)
- EPRI supports solutions for integrated grid concept
- Siemens supports research on distribution-level PMU utilization
- EPE Planning 2-3 MW / 4 MWH Facility

Year 2 Work Plan

- Complete Mesa del Sol (MDS) testbed
- Complete SWTDI testbed enhancement
- Host workshops to define relevant DFM scenarios to test (October 3-4)
- Build DFM models based on existing & prototypical feeders
- Implement models within OpenDSS and Opal-RT and integrate with survey data

Areas for Cross-Research-Group Coordination

- RG1: Simulation of resilient control architectures in DFM
- RG2: Cybersecurity testing using R-Pis/Opal testbed
- RG3: Dataset acquisition and utilization

New Mexico
SMART Grid Center webinar series

Next Webinar

Save the Date: October 25 @ Noon

Networked DC Microgrids

Presenter: Gary Oppedahl, Emera Technologies

New Mexico
EPSCoR