

# **2014 Smart Grid R&D Program Peer Review Meeting**

## **Modeling and Control Technologies for Near- Term and Long-Term Networked Microgrids**

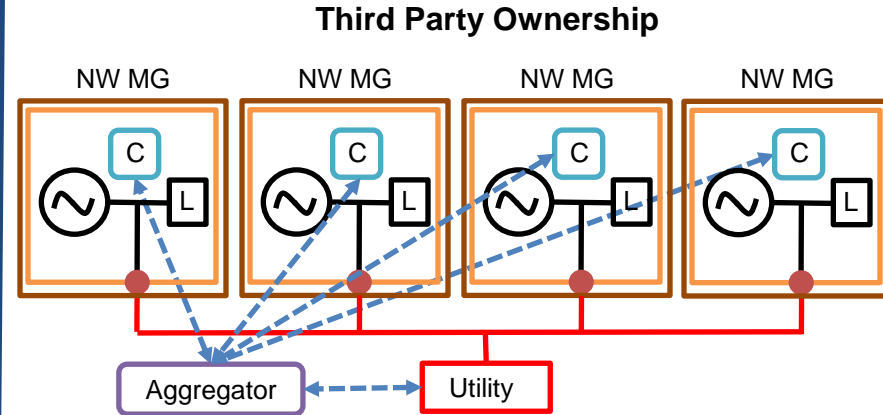
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# MTU Research Overview on Networked Microgrids

## Objectives

- Form a coalition with national labs for Microgrid R&D
- Determine implementable near term Microgrid solutions
- Best practice optimization and control strategies
- Through DOE partnerships, produce FOA on single MG
- Produce a scoping study for Networked Microgrids



## Life-cycle Funding Summary

Prior to FY 14	FY14, authorized	FY15, requested	Out-year(s)
\$0	\$250k	\$0	\$0

## Technical Scope

- Develop AC/DC scalable Networked Microgrid simulation models, optimization and control design tools
- Analyzed the trade-off between resiliency and cost for converting a single Microgrid to a network of advanced Microgrids
- Optimization of Networked Microgrids to reduce peak demand and regulation reserves
- DER-CAM analysis of canonical four Networked Microgrid example
- Top-down/Bottom-up case studies bounding networked microgrids, as requested by customer at quarterly meeting hosted by LBNL

# Introduction

## The DOE's goals are to bring the national electric grid into the 21<sup>st</sup> century

- Through advanced technology the electric grid will **gain enhanced resiliency** not seen before with the central generation paradigm
- While single Microgrids provide pockets of enhanced resilience, only by **networking** these systems will the **full potential benefits** be reached
- The **Advanced Microgrid** will be the building block from which the new grid will grow
- With Networked Microgrids, **new aggregated services** will bolster the grid and provide new opportunities for investors and consumers

### Networked Microgrid Definition:

Interoperable groups of multiple Advanced Microgrids that become an integral part of the electric grid while providing enhanced resiliency through self-healing, aggregated ancillary services, and real-time communication. They result in optimal electrical system configurations and controls whether grid-connected or islanded and enable high penetrations of distributed and renewable energy resources.

# Networked Microgrid – Today's Barriers

## **Institutional and Regulatory**

- Standards for Interoperability are only being developed
- Regulatory rules forbid many interconnection methods
- Utility rate rules are not standardized & must be negotiated
- Energy storage and energy exchange rules are uncertain
- Communications and integrated system security must be insured

## **Technological**

- Communications issues are still undefined (security, reliability, default modes, standards, and more)
- Microcontrollers are not commercially available
- Sensors and electronic device reliability are unproven
- Prioritization of power flows are undefined

## **Financial**

- If a microgrid is needed and provides customer value then the Networked Microgrid is a relatively small incremental additional expense provided institutional and technical barriers are resolved

# Current Challenges and Practices

**Networked** Microgrid functionalities must be addressed from the interconnected utility perspective as well as for the networked system.

**The** technical challenges are widely varied and comprehensive, but some have already been addressed by the industry and utilities.

**Technical** solutions will be implemented within the system microcontroller, within some inverters or within ancillary devices. They include:

- Function 1. Frequency control
- Function 2. Volt/VAR control
- Function 3. Grid-connected-to-islanding transition
- Function 4. Islanding-to-grid-connected transition
- Function 5. Energy management
- Function 6. Protection
- Function 7. Ancillary services (grid-connected)
- Function 8. Black start
- Function 9. User interface and data management

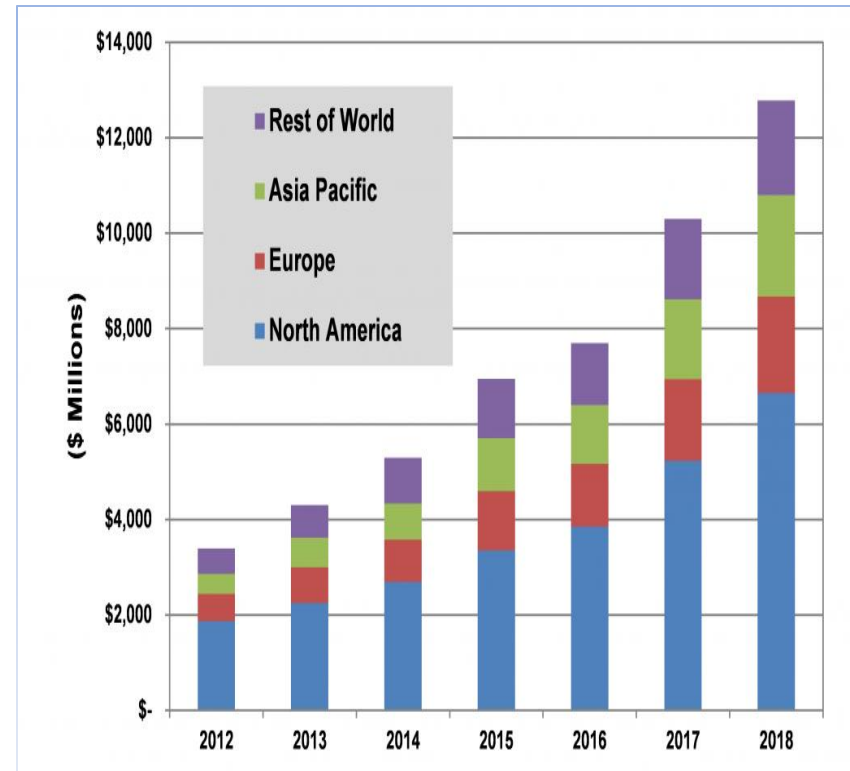


**PCC Controls at Santa Rita Jail**

# Why Networked Microgrids?

- **Aggregations** of Microgrids that are “networked” will stabilize grid tied and autonomous operations
- **Networking** will be necessary for MG to Utility and some MG to MG and High Penetration of microgrids
- Microgrids are organically **gaining traction** in industry, many are driven by pure economics or resiliency concerns
- The DOE and other government entities spend \$M/yr to develop new solar and battery technologies. The resulting **lower cost will increase Microgrid penetrations** to the grid.
- Networked Microgrids with **advanced controllers** will improve the legacy grid and new technology needs to be developed and ready for this paradigm change

Projected Worldwide Microgrid Market



Source: Pike Research (Forbes.com)

# Tasks - FY 14

**Task 1, Form Coalition with National Labs and other stakeholders:** The realization of Networked Microgrids will take a multi-year effort and research from multiple entities.

**Task 2, Near Term Microgrid Solutions:** Using Michigan Tech's campus Microgrid as a test case, determine near, mid, and long term solutions that can be implemented with cost and benefits identified.

**Task 3, Optimal Design and Control of Future Networked Microgrids:** Demonstration of robust Networked Microgrids will require optimal layout and control architecture to explore expandability and self-healing.

**Task 4, Collaborate with DOE and produce FOA whitepaper on single Microgrids:** Through continued participation with DOE, regulatory, and standards commissions, funding can be strategically placed to solve implementation issues with Microgrids.

**Task 5, Produce a scoping study on Networked Microgrids:** This study will provide the technical, financial, and institutional incentives to progress R&D needs for Networked Microgrids.

# Task 1

## Form Coalition with National Labs and Other Stakeholders

Collaboration with National Labs and other microgrid stakeholders will best utilize the DOE's research assets to achieve solutions to the multifaceted needs of implementing Networked Microgrids

- A Networked Microgrid core team was formed and being lead by Steve Glover at Sandia National Laboratories
- Weekly meetings ensure team cohesiveness
- To achieve Networked Microgrid adoption, significant R & D will be needed over multiple years
- DER-CAM (LBNL) Studies completed by SNL
- Top-Down/Bottom-up case study suggested by LANL
- Used CERTS/LBNL Microgrid references on Coupled Microgrids
- ANL networked vehicles and communication strategies
- PNNL/WSU collaboration agreement on reliability analyses for Networked Microgrids
- Referencing Dynamic Microgrids (BNL)



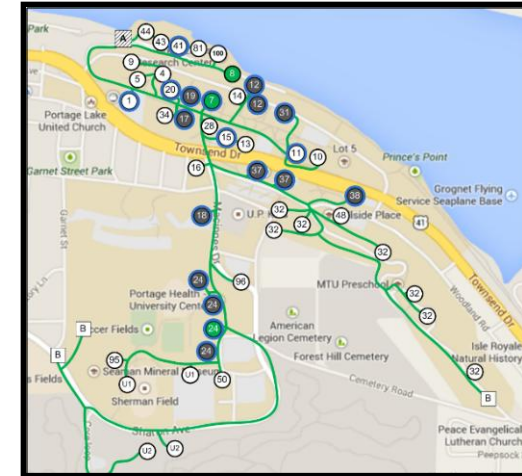


# Task 2

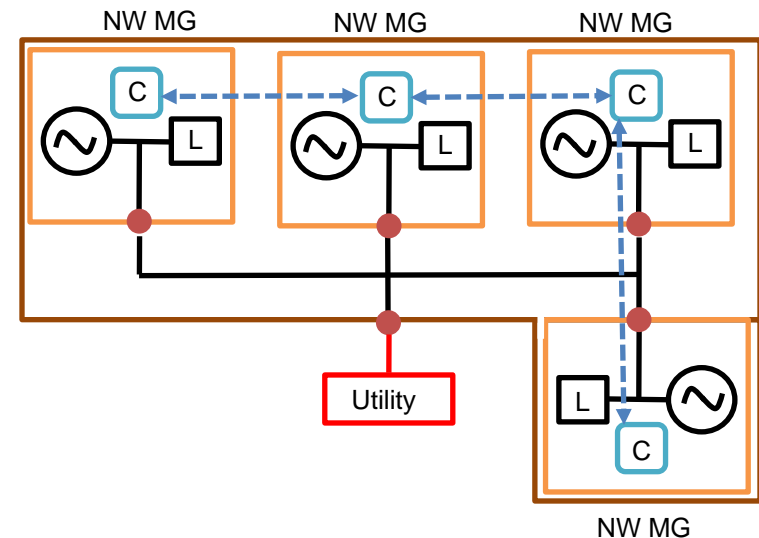
## Near Term Microgrid Solutions (Top-Down Case Study)

Considering Michigan Tech campus Microgrid as a test case, what near, mid and long term solutions could move toward the networked microgrid architecture

- Determined feasible Networked Microgrid configuration
- Perform cost/benefit analysis of Networked Microgrid configurations – near, mid, and long term scenarios



### Private Ownership



# Task 2

## Near Term Microgrid Solutions (Top-Down Case Study)

	Updates	Benefits	Costs
Near-Term Solutions	<ol style="list-style-type: none"> <li>1. Introduce <b>Energy Capitalization Scheme</b> for Buildings</li> <li>2. Extract Energy-Related Information from Images of existing electromechanical meters</li> <li>3. Identify Communication Means for Networked Microgrid</li> </ol>	<ul style="list-style-type: none"> <li>• Improve system <b>observability</b></li> <li>• Identify investment possibilities and revenue opportunities</li> </ul>	<ul style="list-style-type: none"> <li>• Mobile devices = \$8k</li> <li>• MTU Telecommunication Services = \$5k</li> </ul>
Mid-Term Solutions	<ol style="list-style-type: none"> <li>1. Study campus revenue opportunities with UPPCO, a local utility</li> <li>2. Identify possible <b>bilateral contracts for exporting power</b> for reliability</li> <li>3. Evaluate regional impact</li> </ol>	<ul style="list-style-type: none"> <li>• Potential savings, investment in on-campus generation, and revenue opportunities</li> <li>• Communication and physical <b>infrastructure enhancements</b></li> </ul>	<ul style="list-style-type: none"> <li>• Load break switch = \$5k</li> <li>• Feeder control device = \$35k</li> <li>• Additional line = \$45k/mile</li> </ul>
Long-Term Solutions	<ol style="list-style-type: none"> <li>1. Increase the number of remote-controllable tie switches for <b>reconfiguration</b> possibilities</li> <li>2. Coordination with distributed energy resources (storage + generator) and utilities</li> <li>3. <b>Dynamic pricing</b> scheme</li> </ol>	<ul style="list-style-type: none"> <li>• Improve system <b>reliability</b></li> <li>• Increase the number of mobile devices for estimating real-time consumption</li> <li>• Storage can be used to <b>shave peak demand</b> when dynamic pricing is implemented</li> </ul>	<ul style="list-style-type: none"> <li>• Cost of medium and large generators varies</li> <li>• Cost of energy storage and installation</li> </ul>

# Task 3

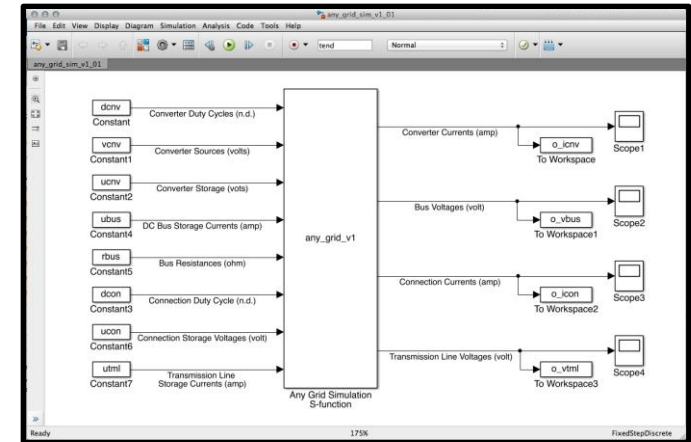
## Optimal Design/Control of Future Networked Microgrids

### Motivation

- **Optimization** is needed to most efficiently use the limited resources during an outage event
- **To** best utilize available resources, the concept of self healing and system reconfiguration must be explored

### Results

- **A** scalable simulation was developed in Matlab and Simulink using a Networked Microgrid architecture from literature
- **Configuration** is extremely efficient and handled with an external configuration file, allowing for quick setup
- **A** DC version of this simulation contains the full dynamic power flow behavior.
- **An** AC Networked Microgrid model was developed using the steady state admittance matrix approach utilizing transformers vs. boost converters



$$L_{ij} \frac{di_{ij}}{dt} = -R_{ij}i_{ij} - \lambda_{ij}v_{B_j} + v_{ij} + u_{ij}, \quad 1 \leq i \leq m_j, 1 \leq j \leq p$$

$$C_{B_j} \frac{dv_{B_j}}{dt} = \left( \sum_{i=1}^{m_j} \lambda_{ij}i_{ij} \right) - \frac{v_{B_j}}{R_{B_j}} + u_{B_j} - \left( \sum_{l=1}^{\sum_{k=1}^q E_{jk}} i_{C_{j\kappa_j}(l)} \right), \quad 1 \leq j \leq p$$

$$L_{C_{j\kappa_j}(l)} \frac{di_{C_{j\kappa_j}(l)}}{dt} = -R_{C_{j\kappa_j}(l)}i_{C_{j\kappa_j}(l)} - \lambda_{C_{j\kappa_j}(l)}v_{T_{\kappa_j}(l)} + v_{B_j} + u_{C_{j\kappa_j}(l)},$$

$$1 \leq j \leq p, 1 \leq l \leq \sum_{k=1}^q E_{jk}$$

$$C_{T_k} \frac{dv_{T_k}}{dt} = \left( \sum_{i=1}^{\sum_{j=1}^p E_{jk}} \lambda_{C_{jk}(l)k}i_{C_{jk}(l)k} \right) - \frac{v_{T_k}}{R_{T_k}} + u_{T_k}, \quad 1 \leq k \leq q$$

Source: Hamiltonian Control Design for DC Microgrids with Stochastic Sources and Loads with Applications, D. G. Wilson, et al.

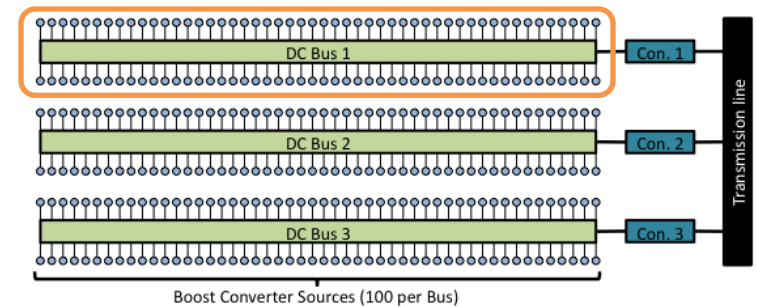
# Task 3

## Optimal Design/Control of Future Networked Microgrids

Optimal closed form solution exploration based on previous work from Sandia Grand Challenge LDRD

- The purpose of investigating a closed form solution is energy optimal set points could be calculated **nearly instantly at large scale**
- The power flow equations yield one constraint equation per Microgrid bus and one per transmission line or interconnection bus
- Due to **coupling in Lagrange multipliers**, a closed form solution was not found
- Therefore a **numerical solution** will be implemented
- However, if the total power into and out of each bus was prescribed, then closed form solutions would exist for each microgrid

Closed Form Solution is known for single Microgrid. Can this be expanded to networked topologies?



Goal: Minimize power loss in all boost converters

$$f = \int_{t_i}^{t_f} \frac{1}{2} (R_{ij} i_{ij}^2) dt$$

Subject to constraints:

$$g_k = \text{Steady State Power Flow Eqns.}$$

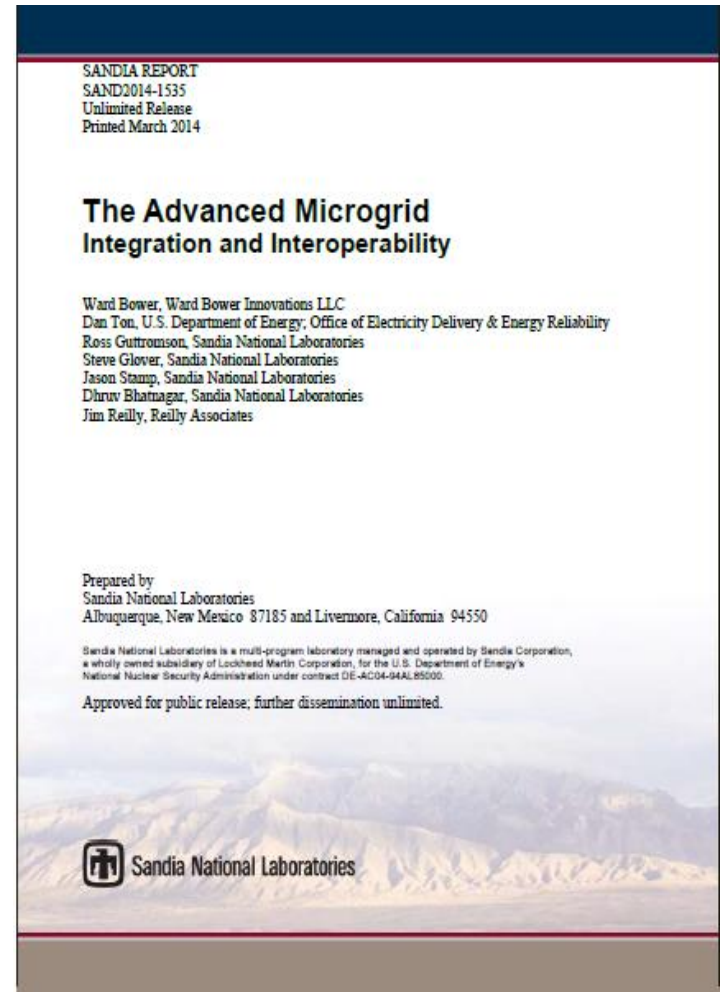
When resolving out Lagrange Multipliers from constraints, coupling was found between buses

$$g_1 = \left( \frac{\Lambda_1 (\Lambda_1 + 1)}{(2 \Lambda_1 + 1)^2} \right) \sum_{i=1}^n \frac{v_{i1}^2}{R_{i1}} - v_{B1} \left( v_{B1} - \sqrt{\frac{v_{B1}^2 (2 \Lambda_1 + 1)^2}{(2 \Lambda_4 + 1)^2}} \right) / (2 R_{C11}) - P_{B1} = 0$$

# Task 4

## Collaborate with DOE to produce FOA whitepaper on single Microgrids

- The paper was **completed in Dec 2013** and published in March 2014 and is available for microgrid related DOE funding activities.
- The report introduces the **Advanced Microgrid** as a concept that can become a part of the electricity distribution system.
- It is being used as one reference for providing guidance for the **FY2016 AOP**.
- It has been widely distributed as hard copy and electronically and is used in the **SGIP** activities primarily **Subgroup C**.
- It was recently used as a resource for part of the IEEE microgrid course sponsored by the **PES Boston Chapter**.



# Task 4

Collaborate with DOE to produce FOA whitepaper on single Microgrids

**Each of these tasks involve teaming with DOE, Sandia (and other National Labs) and E2RG to develop a FOA for advancing the DOE Microgrid program through workshops, Request for Information (RFI) and reviews of proposals.**

The following will be completed soon or has been completed:

- **RFI** was reviewed and comments related to standards were provided to E2RG
- The **FOA** has been posted and proposals received
- The **proposal review process** has begun and will be completed by June 5, 2014
- Workshops are scheduled (June 10 & 11) with E2RG and NEDL leading the effort. **Resilience is a leading topic**
- A core team is currently preparing the **AOP guidance for FY2015**
- Participation at several of the DOE National Laboratory Team meetings has provided a comprehensive understanding of collaborative efforts to build an infrastructure for designing, modeling and analyzing Microgrid systems

# Task 5

## Networked Microgrids Scoping Study

### Scoping Document Topics

- Technical Challenges
- Policy Barriers
- Regulatory Barriers
- Value Streams
  - Economic Benefits: Higher efficiency, Increased Reliability, Peak Demand Charge Reduction, Ancillary Service Participation
  - Social Benefits: Reduced Green House emissions, Increased security
- Ownership models and how specific **value streams differ because of ownership**
- Approach: top-down and bottom-up Case Studies

Goal: to identify the required research and development areas and to provide guidance for Annual Operating Plan (AOP) and later Funding Opportunity Announcement FOA on Networked Microgrids

### Ownership Models Explored

**Third Party  
(virtual)  
Ownership**

**Private  
Ownership**

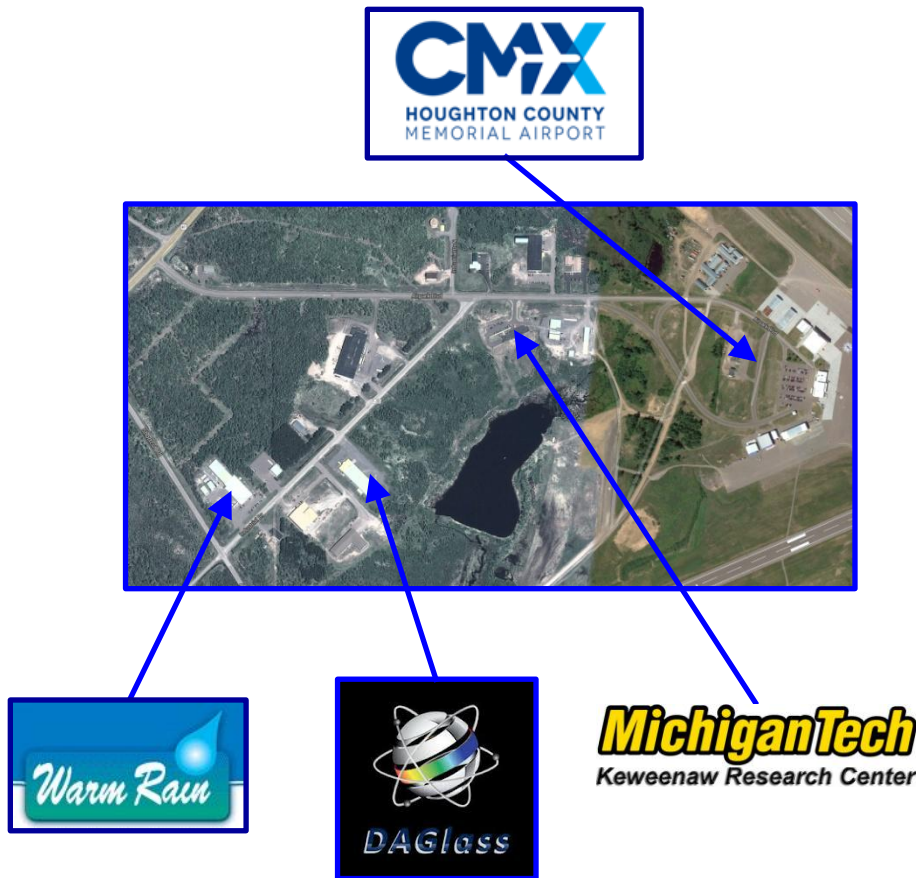
**Utility  
Ownership**

**Private/Utility  
Co-Ownership**



# Task 5

## Networked Microgrids Scoping Study (Bottom-Up Case Study)



### Identified Problems:

- **Substation is inadequate** which requires an upgrade
- High power draw from KRC interfering with airport and other businesses
  - Testing must be coordinated with airport
  - Power quality issues: Harmonics associated with dynamometers
- Economic costs and regulatory issues of key concern for all players
- Bundled Industrial electric costs approx. \$0.18-0.19/kWh

### Opportunities:

- Presently, no installed Microgrids at industrial park, but DA Glass has Microgrid hardware to install
- KRC Building has proper switch gear for grid connection (bi-directional power)
- Airport has backup Gensets



# Task 5

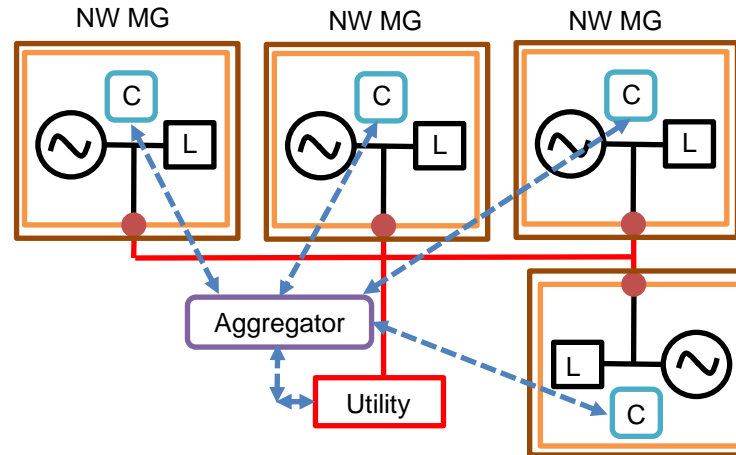
## Networked Microgrids Scoping Study

### Third Party

Similar to private ownership, but Microgrid ops and communications through an aggregator working with the interconnected utility

**Value Streams:** Ancillary service participation, flattened load curve for utility, reduced communication effort for utility

### Ownership Scenarios



### Private

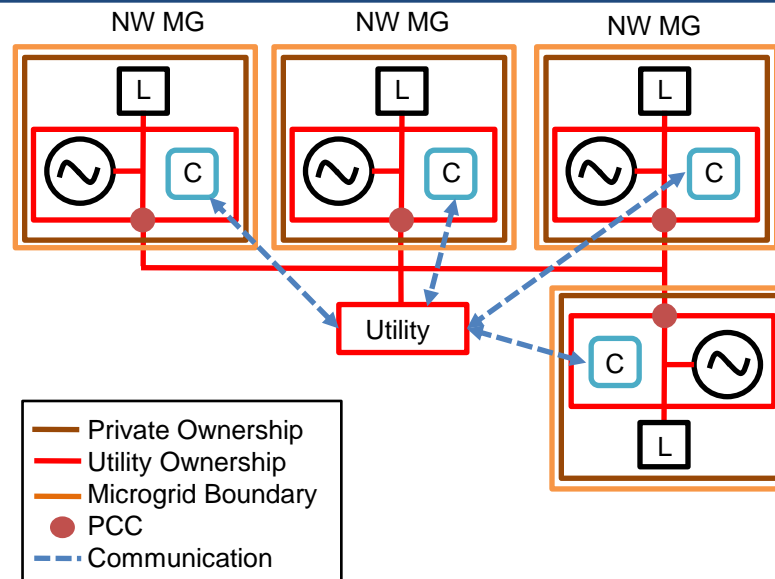
Private entities own all hardware of the Networked Microgrid. **Aggregator is NOT** part of communications

**Value Streams:** Reduced electric purchases and demand charges for the owner

### Utility

Utility owns the Networked Microgrid Hardware, purchases or leases land for microgrid

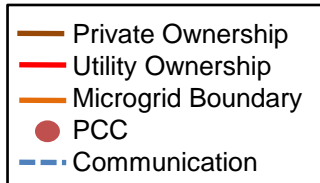
**Value Streams:** private entities defer investment. MG costs recovered by increased rates, utility retains tight control



### Private/Utility Co-owned

Utility owns Networked Microgrid hardware, land leased from private owner through use agreement

**Value Streams:** Increased reliability, private entities defer investment costs at increased rates, utility retains tight control



# Prior-Year Progress and Results

Month/Year	FY 2014 Milestones	Status as of June
Nov/2013	Scalable, Dynamic DC Networked Microgrid Model	100%
Dec/2013	Closed Form Optimal Control for DC Networked Microgrid Explored	80%
Feb/2014	Scalable, Steady State AC Networked Microgrid Model	80%
Mar/2014	Networked Microgrid Core Team Formation	100%
May/2014	Paper: Defense Strategies for Advanced Metering Infrastructure Against Distributed Denial of Service	100%
May/2014	Paper: Image-Extracted Energy Information Based on Existing Electromechanical Analog Meters	100%
Jun/2014	Scoping Study Report	75%

# Future Work

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## Remainder of FY14

- Task 2: Summarize the virtual energy market and extrapolate to Networked Microgrid solutions Aug 2014
- Task 3: Deploy numerical optimization for DC Networked Microgrid Aug 2014
- Task 4: Complete Networked Microgrid scoping study Aug 2014
- Task 5: Continue working with DOE throughout the next FY to facilitate AOP guidance and later Networked Microgrid FOA development

# Collaborations and Technology Transfer

- **Sandia National Laboratory** – Working collaboration with Networked Microgrid core group. Conducted DER-CAM Studies.
- **US Army: ARL and TARDEC** – Ongoing work involving networked vehicles and generators and agile energy management for FOBs
- **Oak Ridge National Laboratory (ORNL)** – Site visit from 11/18/2013 to 11/20/2013, networked vehicles and communication strategies
- **Washington State University with PNNL researchers** – Site visit 2/13/2014, collaboration agreement on reliability analyses for Networked Microgrids
- **Argonne National Laboratory (ANL)** – Site visit 2/26/2014
- **Lawrence Berkeley National Laboratory (LBNL)** – One meeting at Michigan Tech, site visit – 4/23/2014 and 4/24/2014, Microgrid references on Coupled Microgrids
- **Los Alamos National Laboratory (LANL)** – Suggested top-down and bottom-up case studies
- **Brookhaven National Laboratory (BNL)** – Reference for Dynamic Microgrids

# Lessons Learned

**Ongoing** partnerships and collaboration between industry partners, national laboratories, and Universities has allowed for thorough consideration of the implications of Networked Microgrids

**Restructuring** a “large” microgrid into a network of smaller microgrids can positively impact: observability, reliability and peak demand charges.

**The** bottom-up canonical case study of an aggregated, network of microgrids design reduced electricity costs by 14% as compared to individually designed microgrids

**We** could not replicate the closed form optimal “solution” of a single microgrid for a general networked microgrid topology

**The** FOA white paper on advanced microgrids has been a successful document in shaping the path forward with Microgrid technology (Best Practice)

**The** scoping study will provide incite to how networked microgrids may be utilized in the future, the value streams they will generate, and how ownership models could vary. (Follow FOA whitepaper Best Practice)

# Contact information

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