NOTICE

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NOTICE

2017 Professional Engineers CONFERENCE

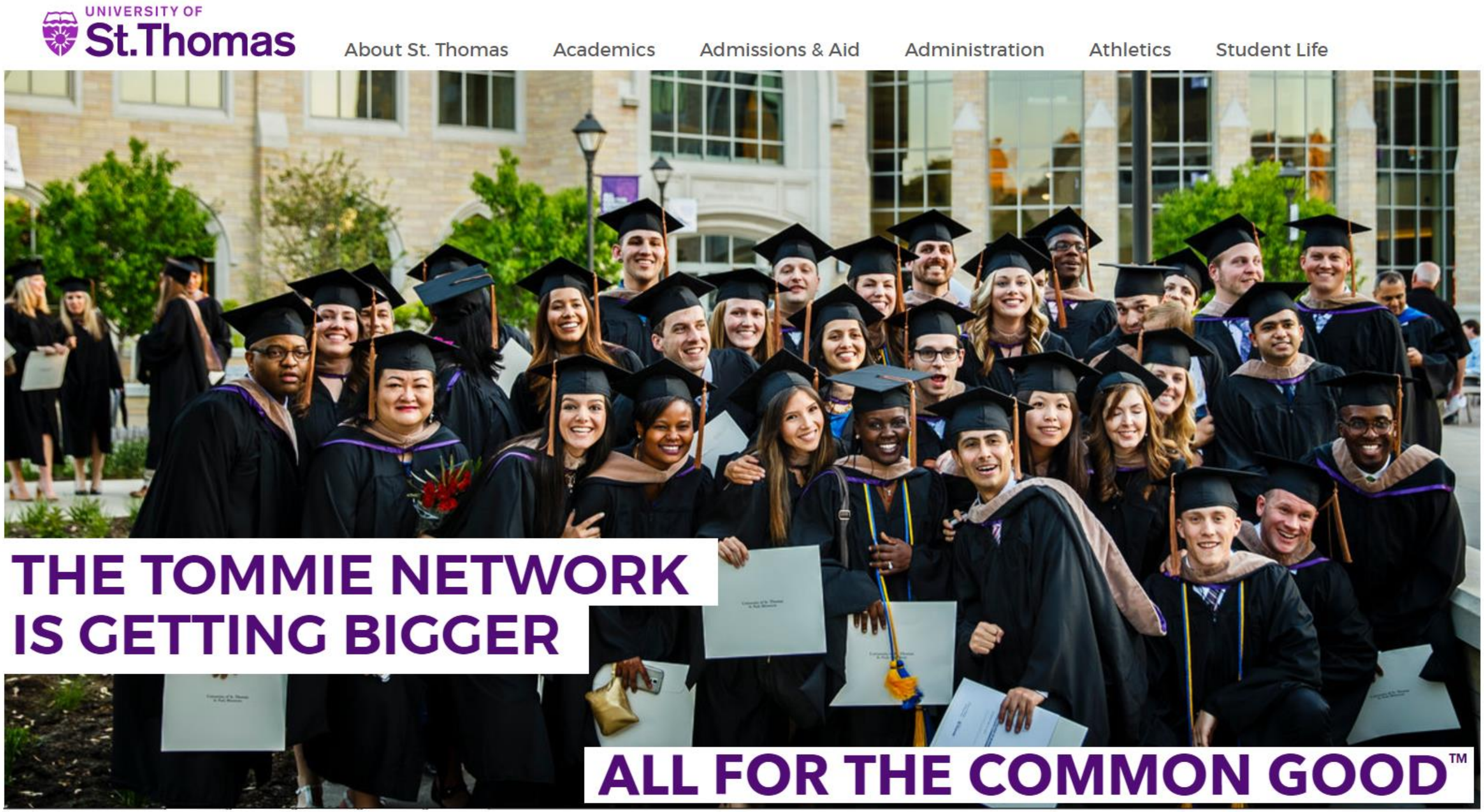
Introduction to Microgrids for Commercial and Humanitarian Needs

Prof. Greg Mowry
University of St Thomas
gsmowry@stthomas.edu

NSPE™ NATIONAL SOCIETY OF PROFESSIONAL ENGINEERS

Learning Objectives

- Learn what constitutes a microgrid and how microgrids are defined;
- Develop an understanding of how a microgrid differs from the grid;
- Learn about economic and technological factors that are driving the worldwide microgrid market;
- Develop an understanding of how microgrids are controlled;
- Learn about microgrid applications in developing countries.


UNIVERSITY OF St.Thomas
About St. Thomas
Academics
Admissions & Aid
Administration
Athletics
Student Life
THE TOMMIE NETWORK IS GETTING BIGGER
ALL FOR THE COMMON GOOD™

The UST Power Program

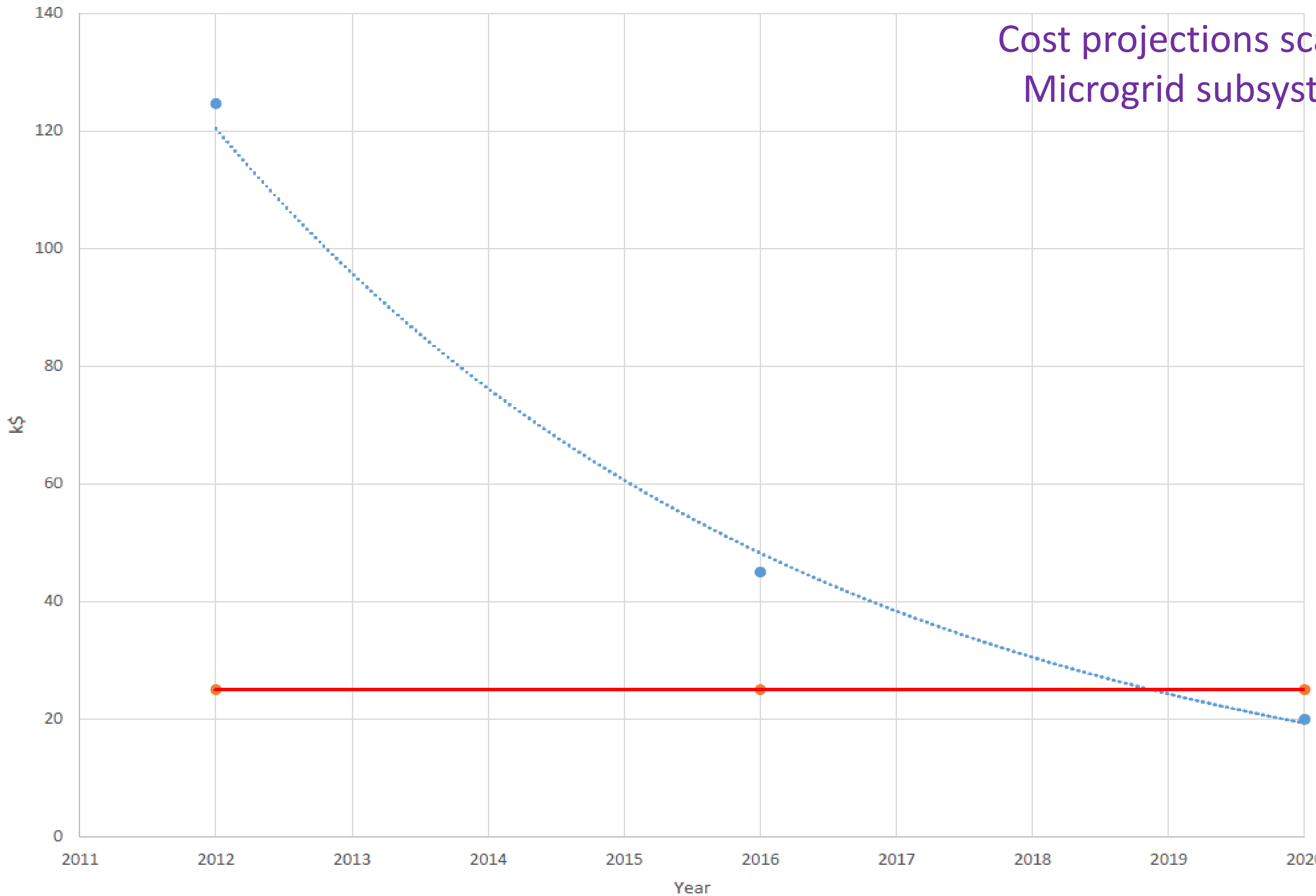
- Large MSEE power program: ~ 80 grad students
- REAL = **R**enewal **E**nergy & **A**lternatives **L**aboratory
- Undergrad power track in EE & ME emphasis
- Multimillion dollar research microgrid project

Presentation Topics

1. Disruptive Power Technology

2. The UST Research Microgrid

Projected Cost of 10 kW PV+Storage System (Blue)
Cost of an Automobile (Red)



Cost projections scaled from Microgrid subsystem bids

Sendai Microgrid, Tohoku Fukushi University, Japan

SO WHAT IS A MICROGRID?

A microgrid is:

- A spatially small power system (L << λ; the grid has L ~ λ)
- having **D**istributed **E**nergy **R**esources (DERs; DG)
- with Loads (which may be & most likely are controlled)
- Often having some form of demand-management control (EMS)
- **AND** is capable of operating in island-mode or with the GRID

MICROGRIDS → UBIQUITOUS

Ships, aircraft, spacecraft, EVs

Emergency Services; e.g. hospitals

Commercial businesses and in homes

Developing countries

Islands and remote locations; e.g. DNRs and tourist sites

Mines (often located in remote regions)

Educational Campuses; e.g. universities

MICROGRID ADVANTAGES

- Provide power in places where there is no grid

- May augment the grid by:
  - Reducing fuel consumption & emissions
  - Improve resiliency, local reliably, and robustness
  - Increase the amount of renewable energy contributing to power needs
  - Increase energy diversity portfolio
  - Supporting a more flexible and efficient electric grid

- They readily integrate renewable energy sources (solar and wind), DERs such as CHP, storage, and demand response

What is a Microgrid (cont.)

- DERs utilize a wide range of technologies:
  - Solar PV
  - Wind turbines
  - Fuel cells
  - Diesel gensets
  - Low-head hydro
  - Gas-turbines, micro-turbines
  - Storage (batteries, fly-wheel, and so forth) …

- Loads in a microgrid often have mission-critical characteristics as well as common characteristics such as heating and lighting

WHAT IS A MICROGRID (CONT.)

- Demand-management is achieved using an energy management system (EMS) with:
  - Communication subsystems
  - Load presence/status & control
  - Interconnectivity interactions of the microgrid with the main/primary electrical power GRID

MICROGRIDS

- Microgrids can operate in 2 modes & transition between:
  - Grid connected
  - Island mode

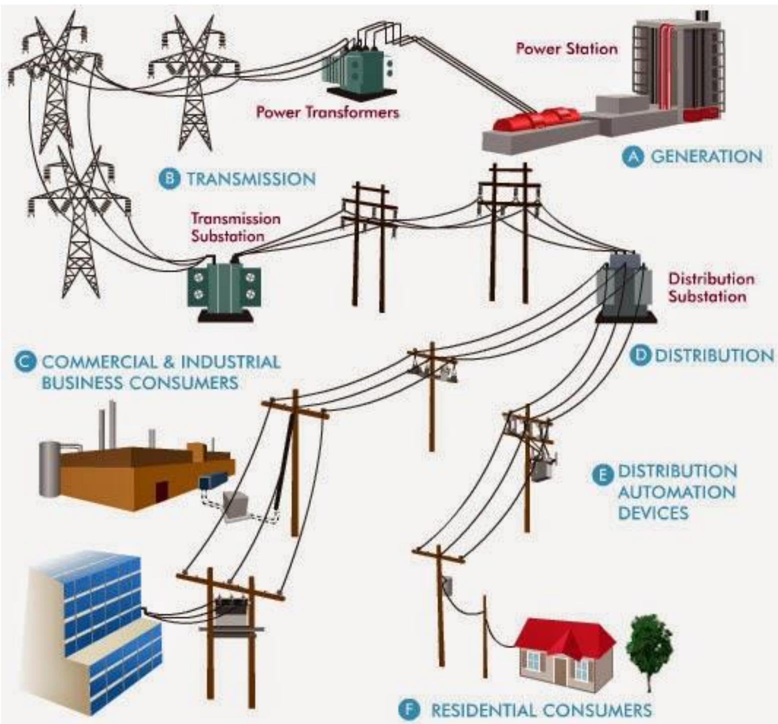
- **Grid-connected mode:** the dynamics of the microgrid are dominated by the Grid with f and V fixed by the grid at the PCC

- **Island mode:** a microgrid should be able to maintain its own f and V reference as well as being able to dispatch power to meet demands and spread the P & Q requirements among its DG units

COMPARISONS

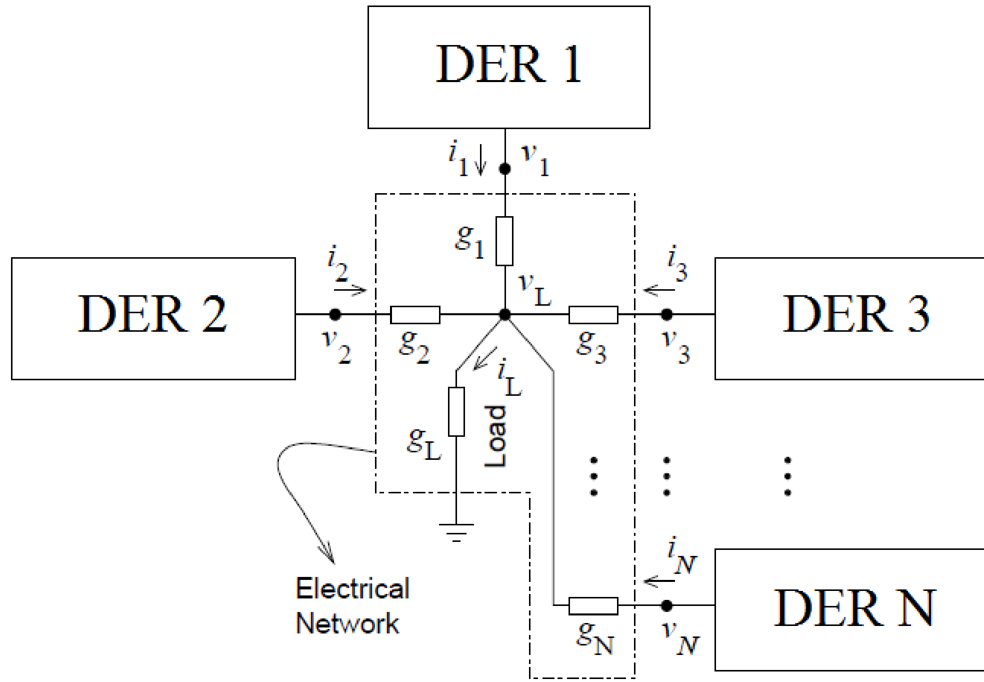
THE GRID: A BIG MACHINE

The Grid



X or R Dominated wrt
Transmission & Distribution respectively

A μG Circuit Model



R Dominated (L << λ)

SUMMARY COMPARISON

The Physics	Grid	Microgrid
Spinning Reserve	Significant	Almost none
Magnetic Field Energy (due to i)	Significant	Small
Electric Field Energy (due to v)	Significant	Small
Analytics	Transmission (TL) System	Circuit

MICROGRID GAME CHANGERS

Storage

- Equivalent to grid potential energy
- Dramatically simplifies the microgrid EMS
- Trillion $$ (really big) market; efficient storage is coming
- All of the micrograds that I design utilize storage
    - Reduces overall system costs
    - Enhances reliability, resiliency, and robustness

ACSS PFA MATH

- From 2-Bus Power Flow Analysis (reactance dominated; the grid)
  - $P_2 = \frac{V_1 V_2}{X} \sin(\delta)$
  - $Q_2 = \frac{V_1 V_2}{X} \cos(\delta) - \frac{V_2^2}{X} \cong \frac{V_2}{X} (V_1 - V_2)$

- From 2-Bus Power Flow Analysis (resistance dominated; microgrids)
  - $P_2 = \frac{V_1 V_2}{R} \cos(\delta) - \frac{V_2^2}{R} \approx \frac{V_2}{R} \Delta V$
  - $Q_2 = -\frac{V_1 V_2}{R} \sin(\delta)$

MICROGRID CONTROL

Control Methods

Grid-tie &/or Island

- Central
  - Droop control
  - Active control
- Distributed
  - Distributed intelligence
  - Master-slave
- Self-Organizing
  - VOC
  - Non-Linear

MICROGRID CONTROL

- Centralized control
  - Mini-me grid control concept
  - Old-school; use what we know, have, and understand
  - By far the most common re-packaged method; $$$

- Distributed control
  - Actively being researched
  - Leverages modern embedded systems and control methods

- Self-organizing
  - Active theory; beginnings of practical application
  - Potentially ‘the future’ of microgrids

MICROGRID CONTROL

Droop Control Method

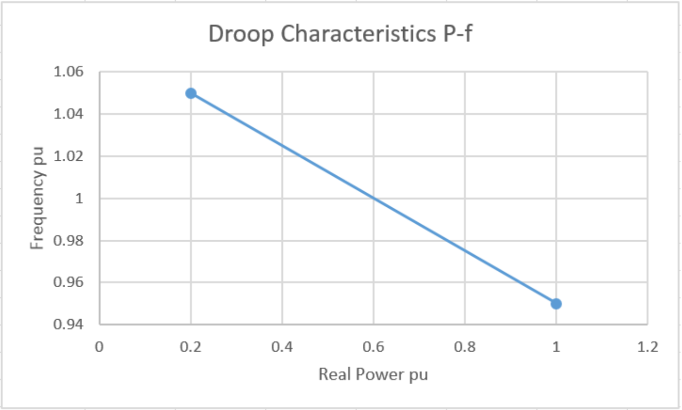
- From 2-Bus Power Flow Analysis (reactance dominated)
  - $P_2 = \frac{V_1 V_2}{X} \sin(\delta)$; $X \propto \frac{1}{f}$ $therefore\ P_2 \propto f$
  - $Q_2 = \frac{V_1 V_2}{X} \cos(\delta) - \frac{V_2^2}{X} \cong \frac{V_2}{X} (V_1 - V_2)$
- These equations serve as the foundation for droop control methods
  - Frequency and real power are proportional
  - Voltage and reactive power are proportional

MICROGRID CONTROL

How Droop Control Works

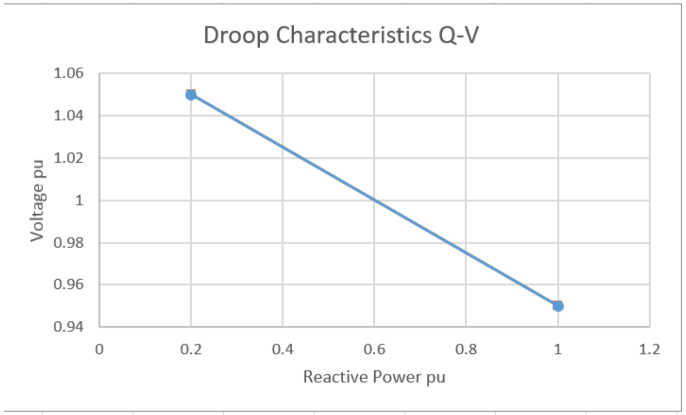
$$f_{setpoint} = f_{nominal} - K_p(P_{Desired} - P_{measured}) \rightarrow$$

Allows frequency to slide along slope to control P



$$V_{setpoint} = V_{nominal} - K_v(Q_{Desired} - Q_{measured}) \rightarrow$$

Allows voltage to slide along slope to control Q



MICROGRID CONTROL

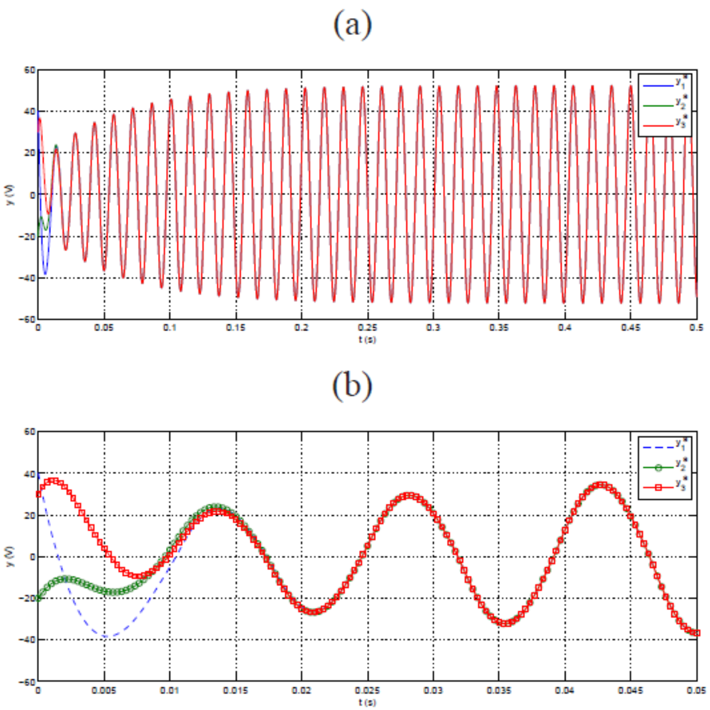
Microgrid Control Methods

Self-Organizing

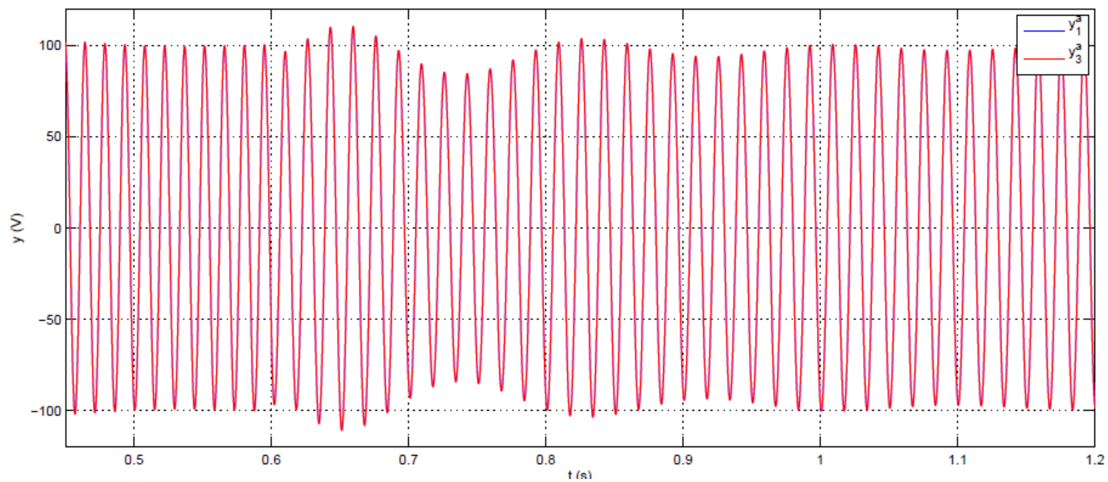
- Virtual Oscillator Control (VOC)
  - A voltage-controlled non-linear resonant circuit in a control loop enables multiple inverters to self- synchronize frequency
  - Accomplished without an interactive inverter-to-inverter control loop or communications
  - Local sense

- Nonlinear Control (NLC)
  - Coupled nonlinear resonance self-synchronizes inverter frequencies
  - Accomplished without an interactive inverter-to-inverter control loop or communications
  - Local sense

Self-Synchronizing DERs



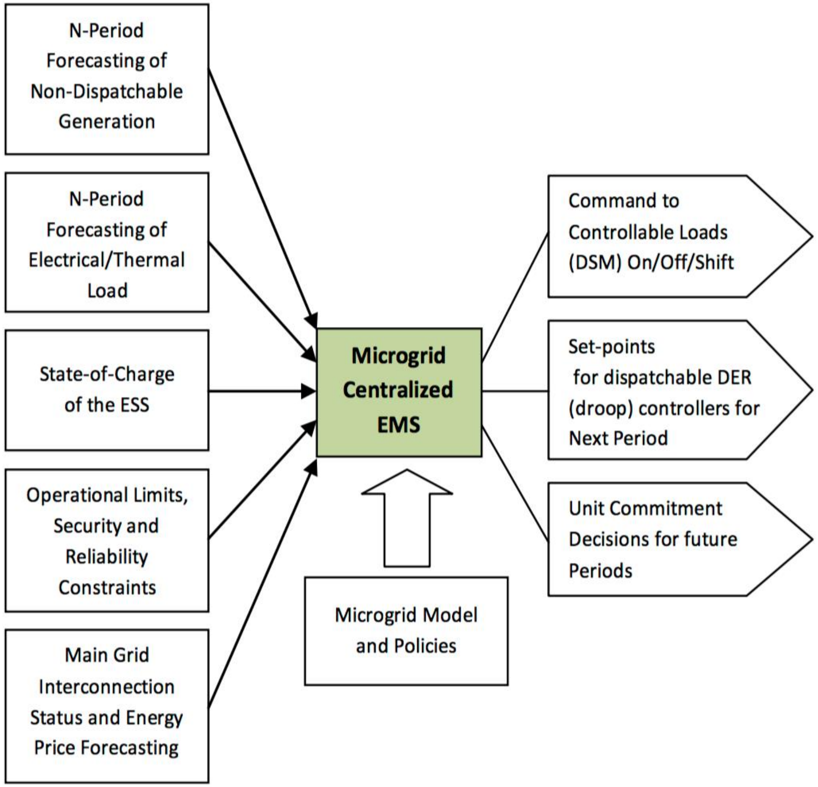
Impact of suddenly removing a DER



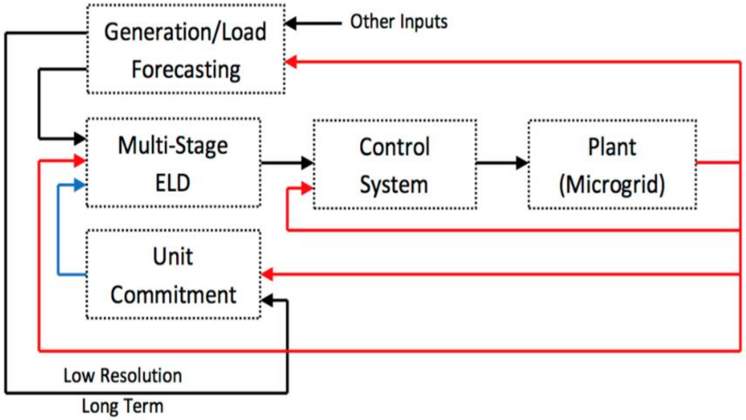
'Power Supply Synchronization without Communication', Torres etal

ENERGY MANAGEMENT SYSTEMS

Energy Management System (EMS) in Microgrid Centralized

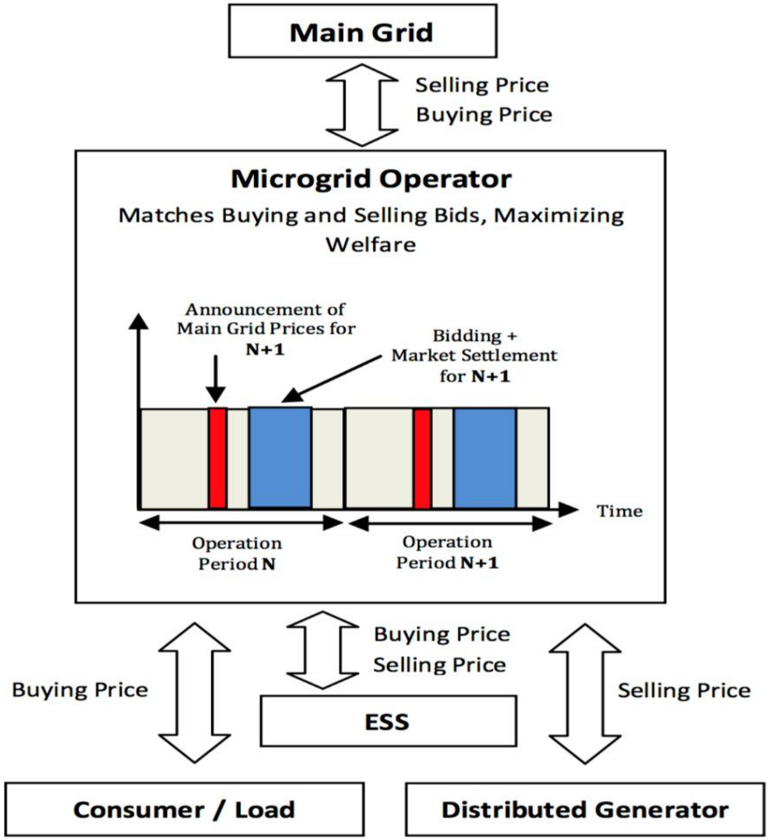


The CEMS architecture consists of a central controller provided with the relevant information of every distributed energy resource within the microgrid and the microgrid itself (e.g., cost functions, technical characteristics/limitations, network parameters and mode of operation), as well as the information from forecasting systems (e.g., local load, wind speed, solar radiation) in order to determine an appropriate UC and dispatch of the resources according to the selected objective.



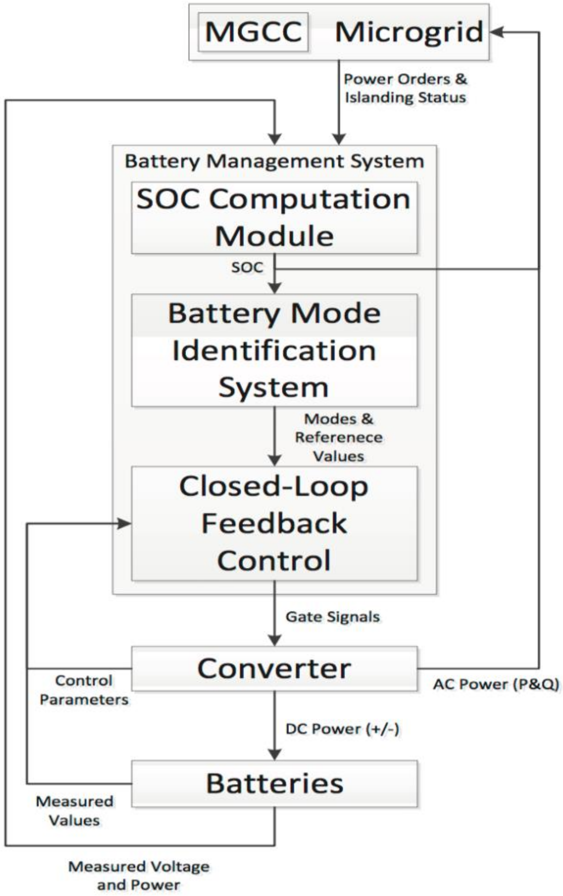
Energy Management System (EMS) in Microgrid Decentralized (Distributed)

On the other hand, DEMS provides a market environment through the use of Multi-Agent Systems (MAS) where each microgrid agent sends buying and/or selling bids to a Central Microgrid Operator (CMO) according to their particular needs and cost structures; the CMO then performs a binding process to determine the operation of the microgrid for the next period. In this case, a separated unit commitment (UC) process must be realized to determine the agents that will operate in each particular period.



Battery Management System (BMS) in Microgrid

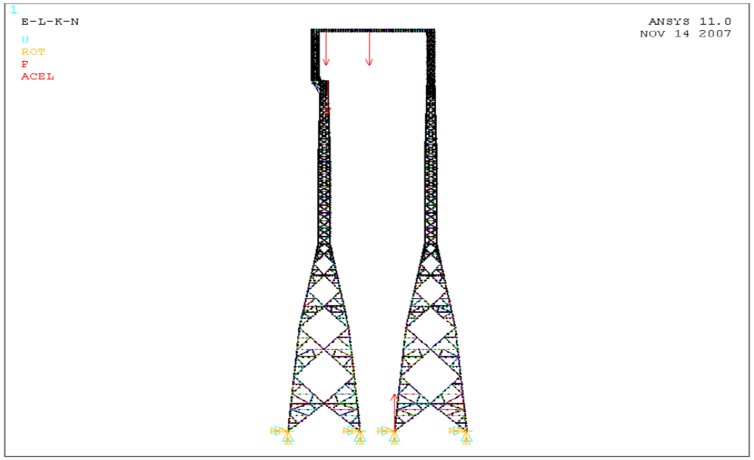
A BMS consists of charging-discharging strategies, state-of-charge (SoC) estimation, voltage balancing, and temperature measurement. In this paper, the first two will be discussed. Appropriate charging strategy is important for keeping the battery well-conditioned. Large voltages cannot be used for battery charging because the aeration speed may exceed the absorbing speed of electrolyte under large voltage conditions. The charging voltage and time need to be carefully considered to prevent battery from overcharging. State-of- charge (SoC) estimation is also one of the most important part of the BMS. SoC informs the user how long the battery capacity can be used. Also, SoC is very important to determine when to stop charging or discharging. Inaccurate SoC estimation or failing to predict SoC will cause overcharge or over-discharge of the battery, may lead to irreversible permanent damage to battery cells.

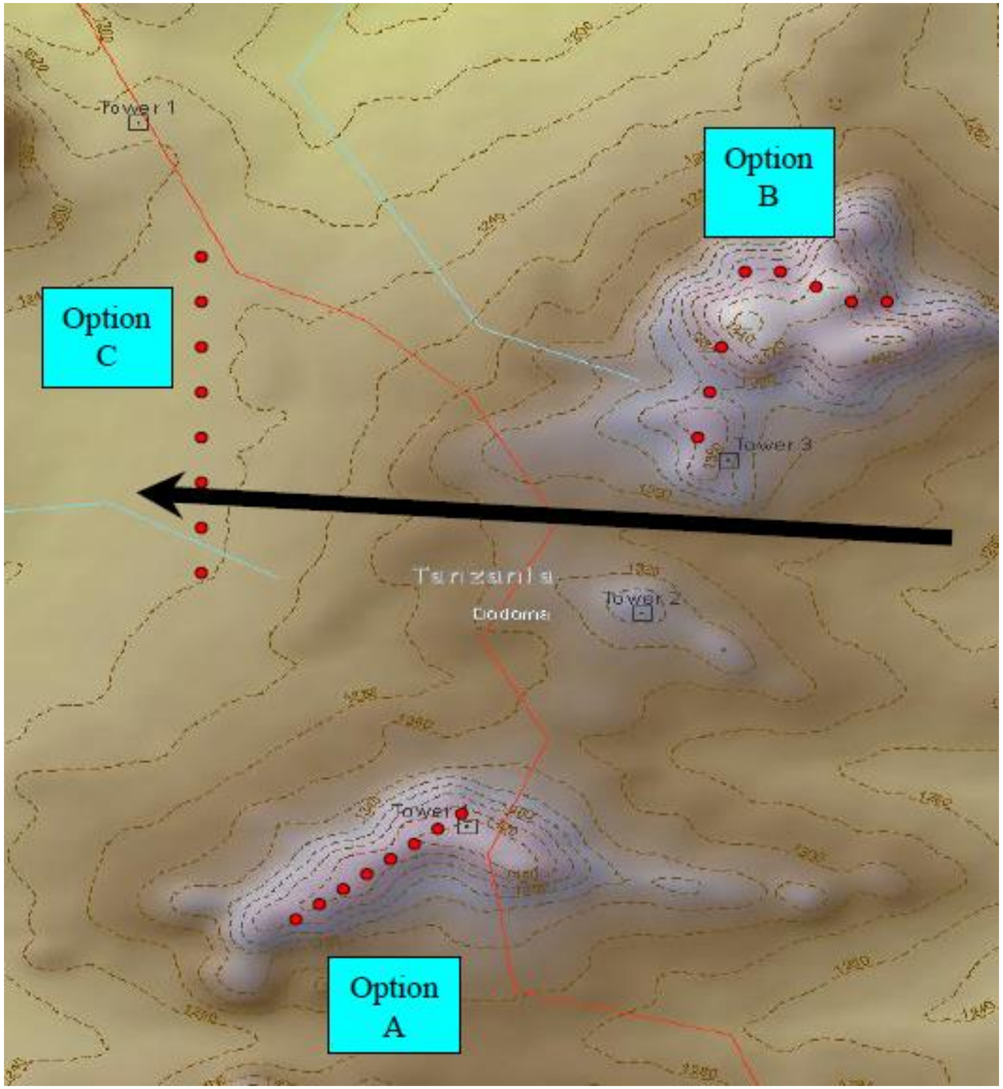


DEPLOYED MICROGRIDS

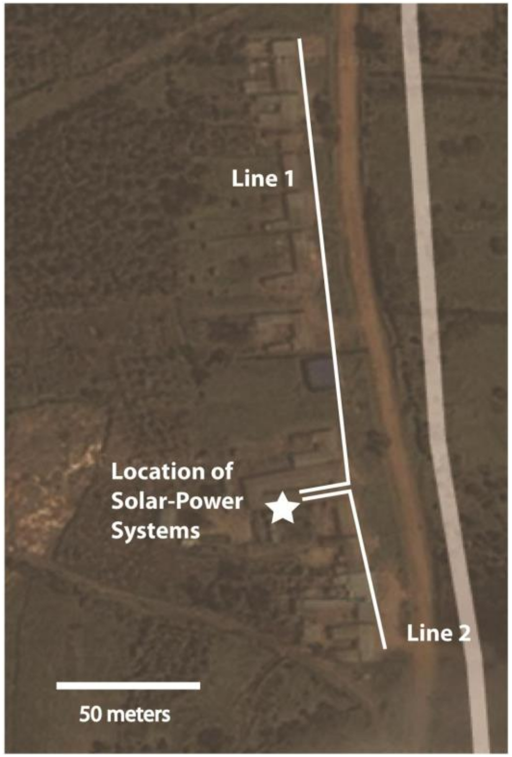
Moldavian Microgrid Development: TUM

DTHD microgrid Development in Dodoma, Tanzania



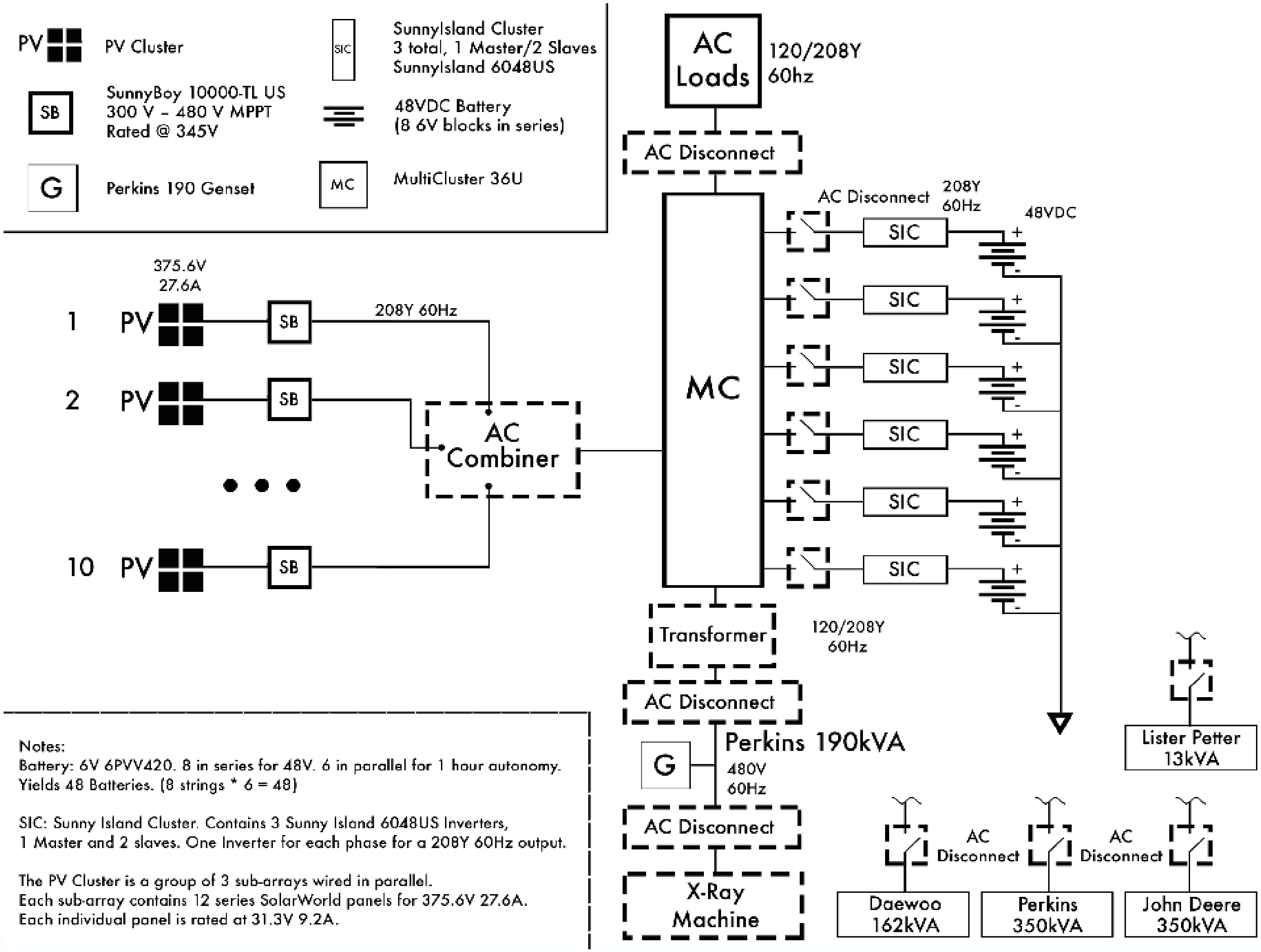


Kitembe Village Microgrid, Uganda



Phebe Hospital Microgrid Project, Liberia

Phebe Hospital Microgrid Project, Liberia



Will Steger Microgrid – Ely, MN

The Steger Wilderness Center (Photos by John Ratzloff)

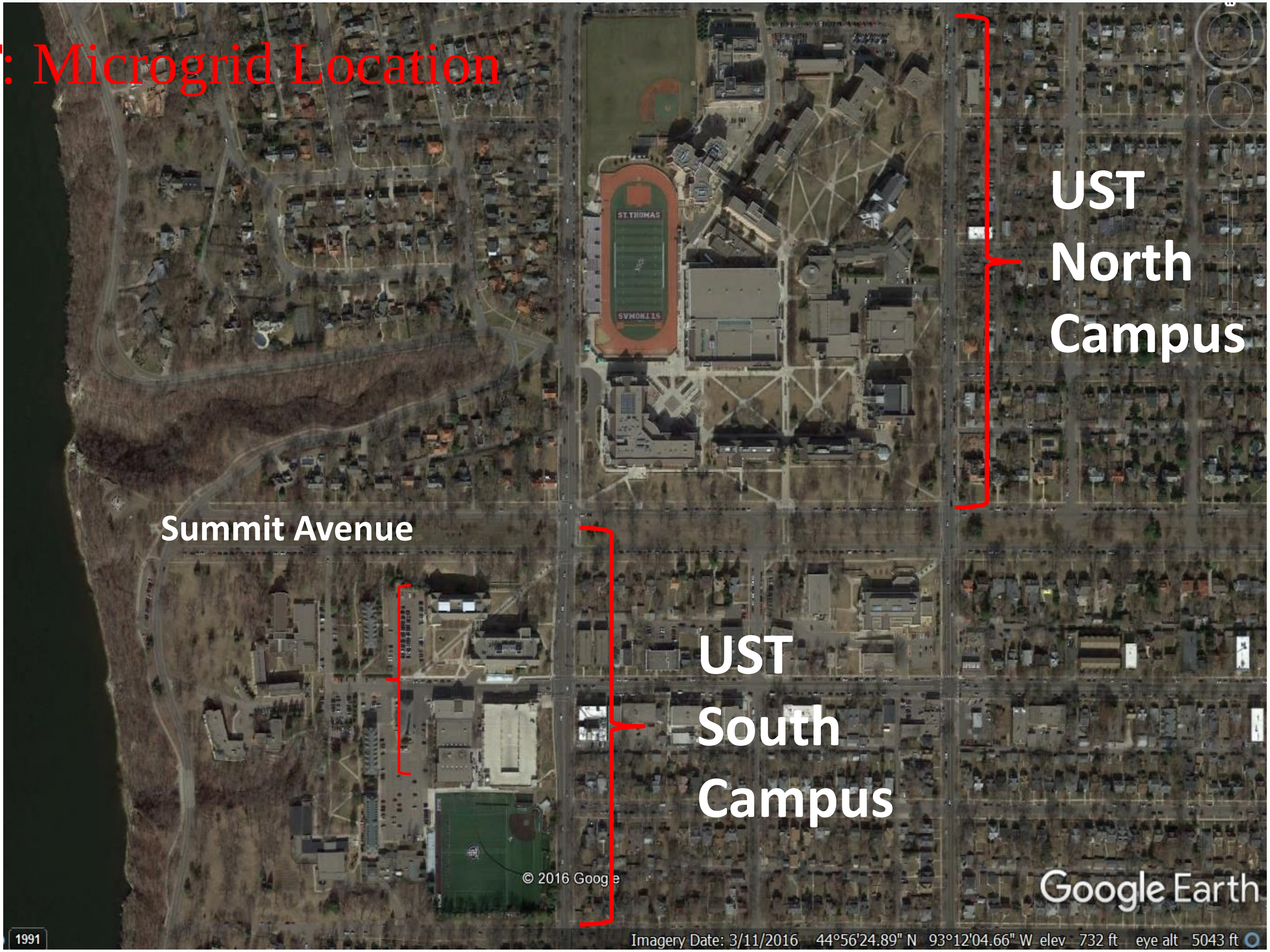
The Steger Wilderness Center is made of glass, native timber and stone, and recycled wood.

Will Steger Microgrid – Ely, MN

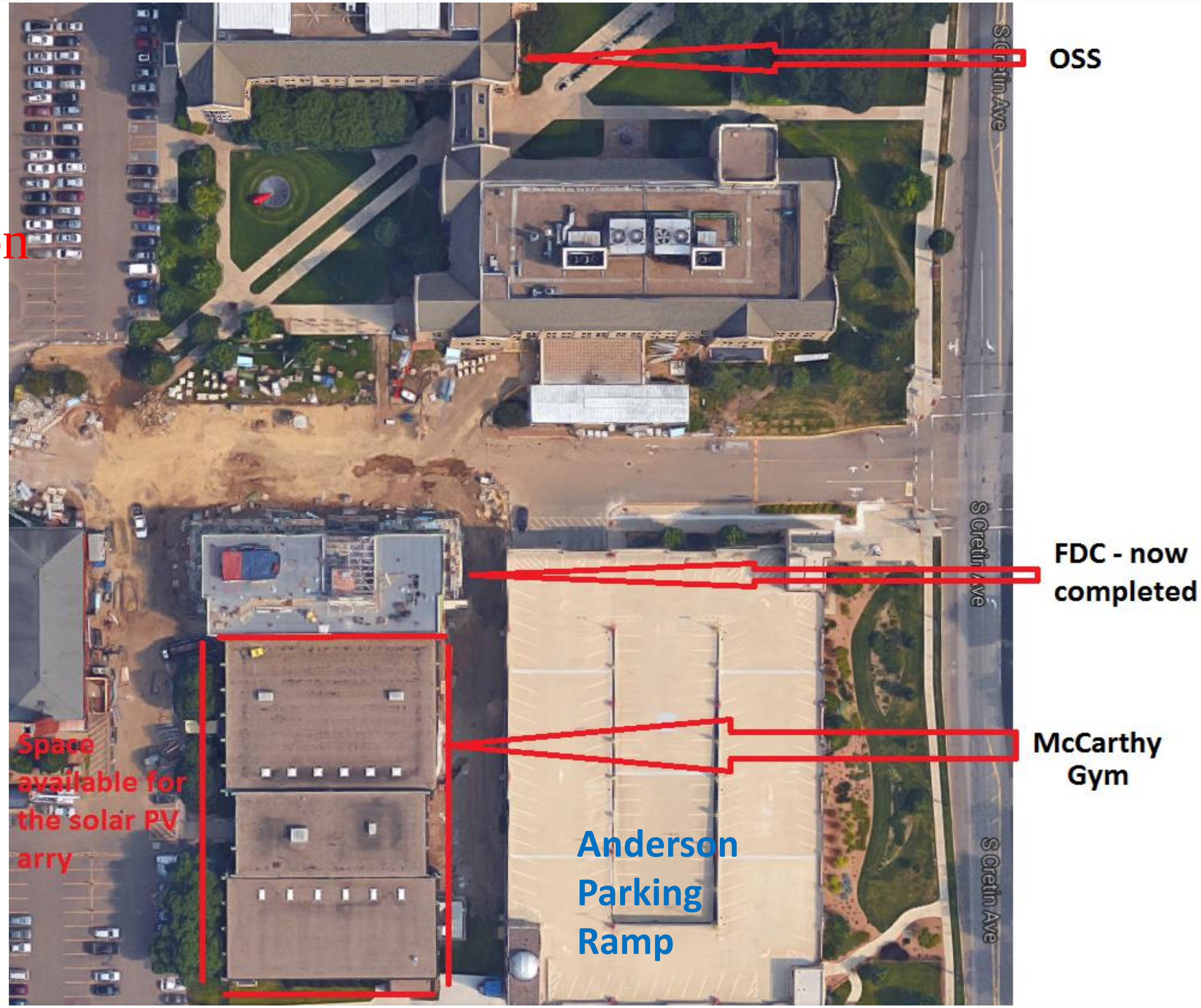
THE UST MICROGRID

The UST Microgrid Location: the Facilities and Design Center

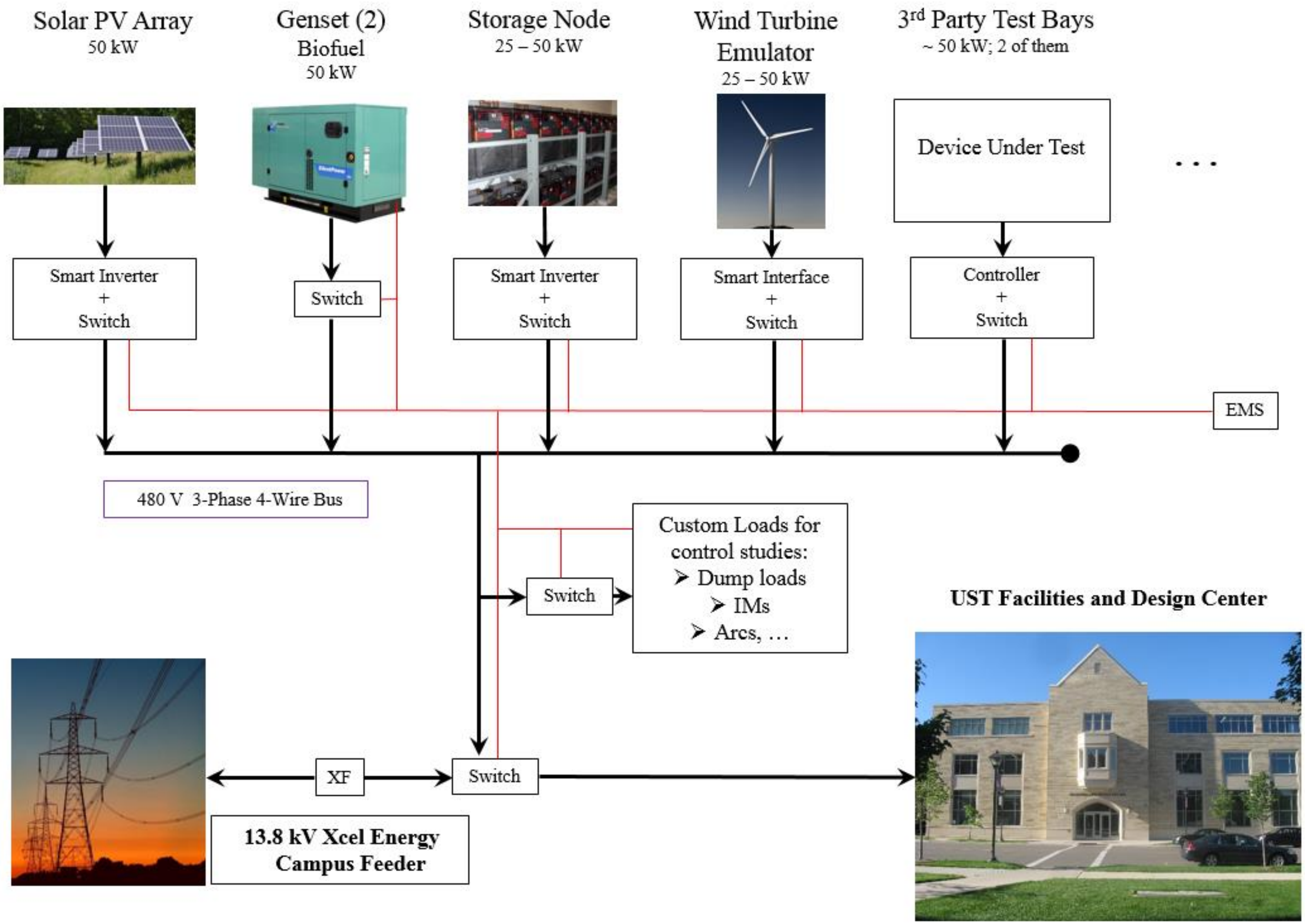
UST: Microgrid Location



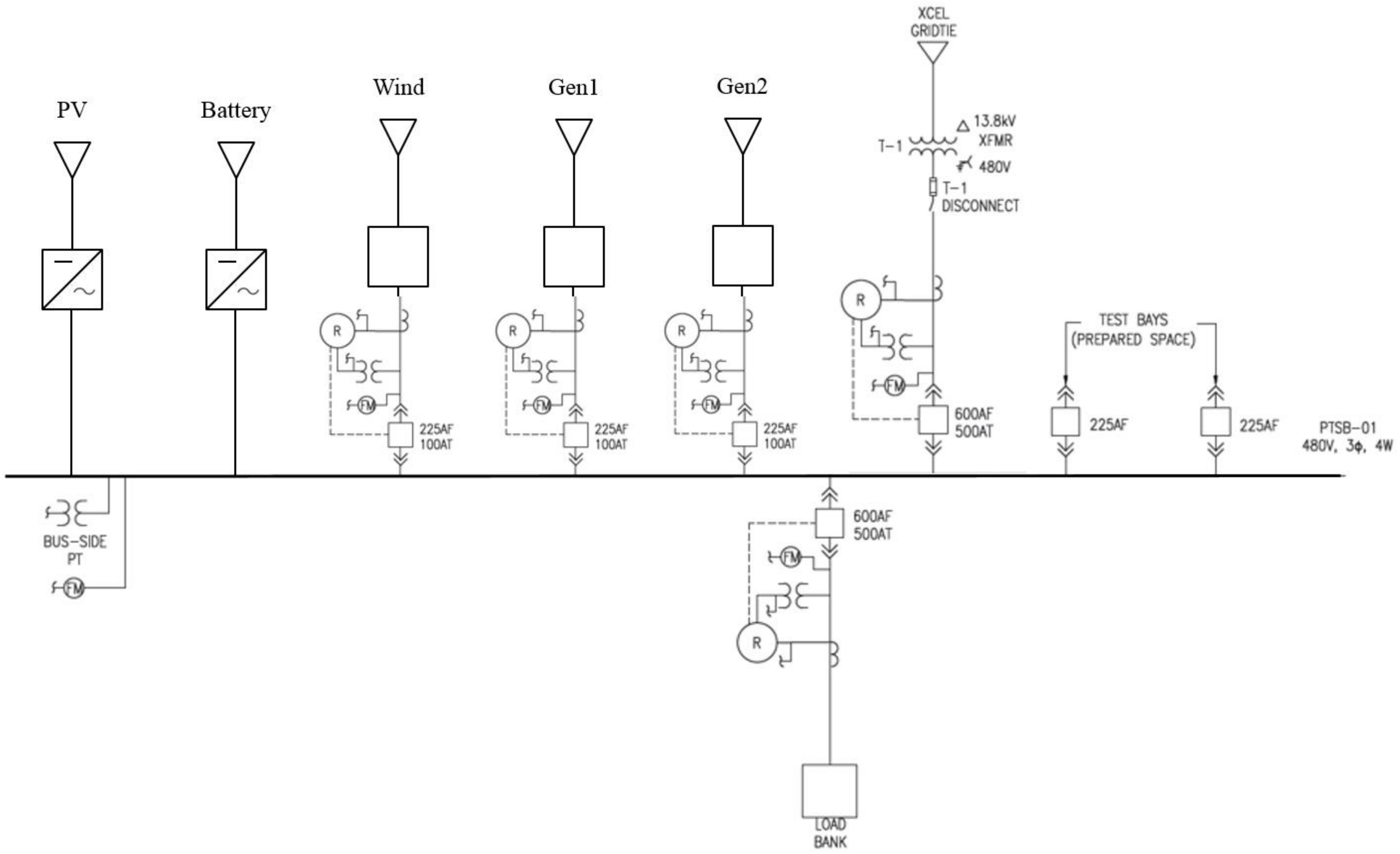
The UST Microgrid Location: Construction



The UST Microgrid Location: Completed


Solar PV Array
50 kW
Genset (2)
Biofuel
50 kW
Storage Node
25 – 50 kW
Wind Turbine
Emulator
25 – 50 kW
3rd Party Test Bays
~ 50 kW; 2 of them
Device Under Test
. . .
Smart Inverter + Switch
Switch
Smart Inverter + Switch
Smart Interface + Switch
Controller + Switch
EMS
480 V 3-Phase 4-Wire Bus
Switch
Custom Loads for control studies:
➢ Dump loads
➢ IMs
➢ Arcs, …
UST Facilities and Design Center
XF
Switch
13.8 kV Xcel Energy Campus Feeder

One-Line Diagram of the research Microgrid



FOCUS

- Research & development of efficient, robust, and resilient distributed control intelligence of microgrids
- Intelligent inverter research; e.g. the synch. Gen. inverter
- 3rd party research – UST does not own intellectual property
- Advanced power electronics research
- Carbon-neutral UST campus by 2030

SCHEDULE

✓Full funding release August 2016

✓Civil engineering planning completed in Q1 2017

RFQs & asset ordering: Q2 2017

Grid-connection studies with Xcel Energy Q3 – Q4 2017

Island mode operation by Q4 2017

Grid tie to Xcel Energy Lindstrom feeder in 2018

THE END

☺

PROFESSOR GREG MOWRY
GSMOWRY@STTHOMAS.EDU
HTTP://WWW.STTHOMAS.EDU/ENGINEERING/FACULTY/GREG-S-MOWRY-.HTML
UNIVERSITY OF ST THOMAS, SCHOOL OF ENGINEERING
DIRECTOR MSEE POWER PROGRAM AND REAL
(RENEWABLE ENERGY AND ALTERNATIVES LABORATORY)