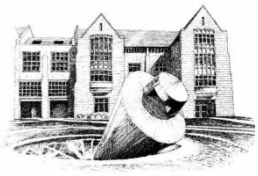
University of St. Thomas Microgrid Research and Testing Program – HE4-2

Annual Report (January to December 2017)

Project funding provided by the Xcel Energy Renewable Development Fund (RDF)

UNIVERSITY of ST. THOMAS MINNESOTA



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Executive Summary

This annual report is submitted in compliance with the Article 7 of the Grant Contract Terms and Conditions covering the project "University of St. Thomas Microgrid Research and Testing Program" supported by the customers of Xcel Energy via a grant from the Renewable Development Fund.

This Annual Report covers the period January to December 2017 and summarizes activities initiated to begin the 'University of St. Thomas Microgrid Research and Testing Program'; the USTREF. This report summarizes actions taken in the January to December 2017 time-frame.

The relocation of the University of St Thomas Microgrid Research and Testing Program (USTREF by reference) in 2016 to the St. Paul campus of the University of St Thomas, located at 2115 Summit Avenue, St. Paul, Minnesota laid the foundation for completing the detailed planning, layout, and asset ordering for the project; all of which was successfully executed in 2017.

With support from key partners, UST Facilities, and Hallberg Engineering, the one-line diagram for the USTREF was completed in fiscal year 2017.

Research on the USTREF commenced.

An oral presentation on HE4-2 for 2017 to NSP and the Renewable Development Fund advisory group was completed.

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Introduction

The University of St. Thomas (UST) entered into an agreement with the Northern States Power Company (doing business as Xcel Energy in Minnesota) in regard to a $2.1 Million research grant for a period of three years. The funding was allocated from the Higher Education block grant component of the Renewable Development Fund, supported by the ratepayer Xcel Energy's ratepayer and managed by Xcel Energy. Pursuant to the conditions of the said agreement (Section 7; Exhibit C of "REPORTING"), the UST provides this annual report on progress made-to-date in implementing the said research project.

The objective of the "University of St. Thomas Microgrid Research and Testing Program" is to install a sustainable, ~ 0.25 MW peak, multi-purpose microgrid at the St. Paul Campus of the University of St. Thomas. The primary objective of this facility will be to promote industry/academic collaboration in the design/build/test and validation of near commercial concepts in the areas of electricity generation and microgrid/subsystem control. The research will also contribute in the strengthening and expansion of the renewable energy industry in Minnesota through the study of how distributed-energy-resources interact in a microgrid and how this microgrid interacts with the distribution feeder that powers the University of St. Thomas, St. Paul Campus. This project has significant potential for impacting the commercial viability of microgrids and the control of the distributed energy resources contained within a microgrid.

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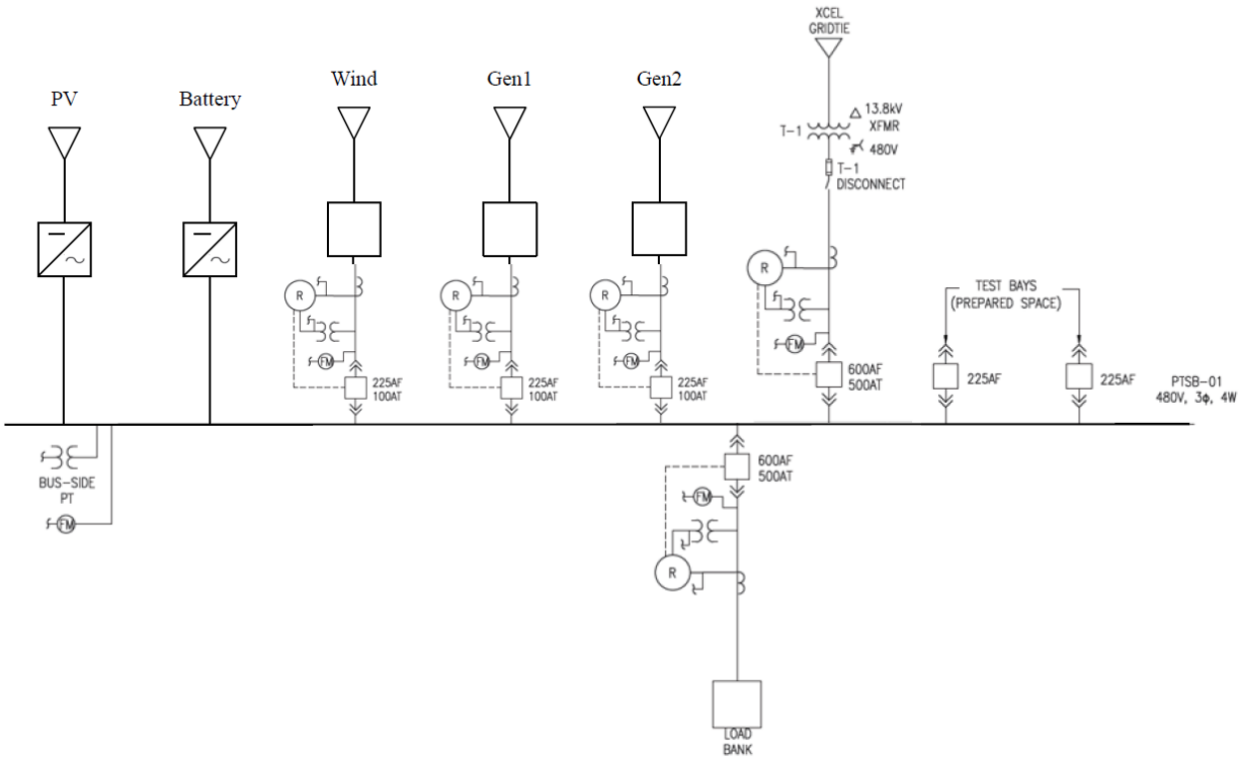
Progress in 2017

The Microgrid

The functional and detailed one-line diagrams for the University of St. Thomas renewable Energy Facility (USTREF) were finalized.

The functional one-line diagram of the University of St. Thomas renewable Energy Facility (USTREF) is illustrated in the following figure. This was a necessary precursor for the construction phase of the project.

Final One-Line Diagram of the research Microgrid



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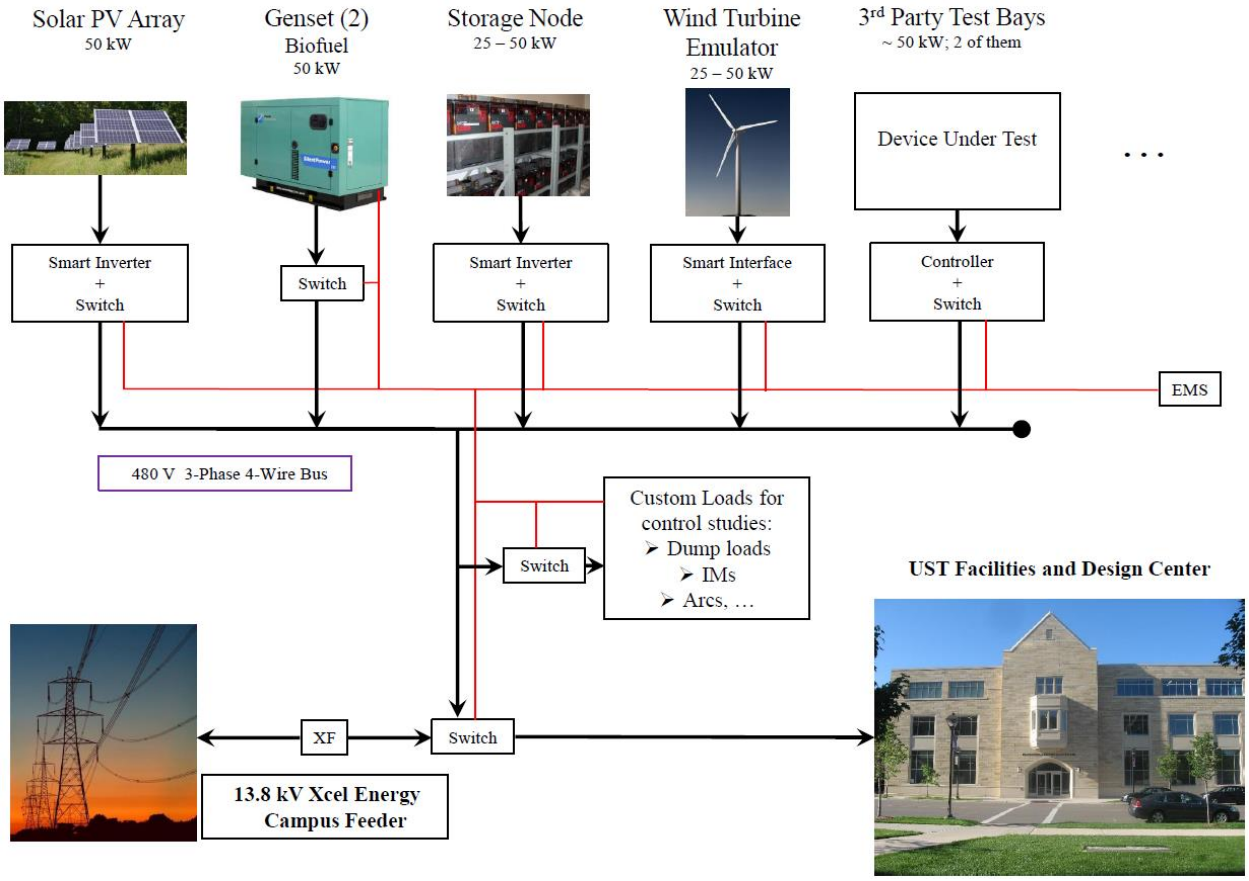
Each vertical leg in the functional one-line diagram represents the various parts of the USTREF along with protection and switch-gear. The grid-tie to the Xcel Energy feeder, along with load banks and provisions for 3rd party hardware are also illustrated. A simplified version of the USTREF one-line diagram is illustrated next. The information in both figures are essentially identical.



The detailed one-line diagram for the University of St. Thomas renewable Energy Facility (USTREF) is shown in the following two figures (below). Shown in the first figure are the system asset connections, switchgear, and protection. The second figure captures the hardware details of the portion of the microgrid that will be used to control the USTREF. These figures are necessary for the asset procurement process.

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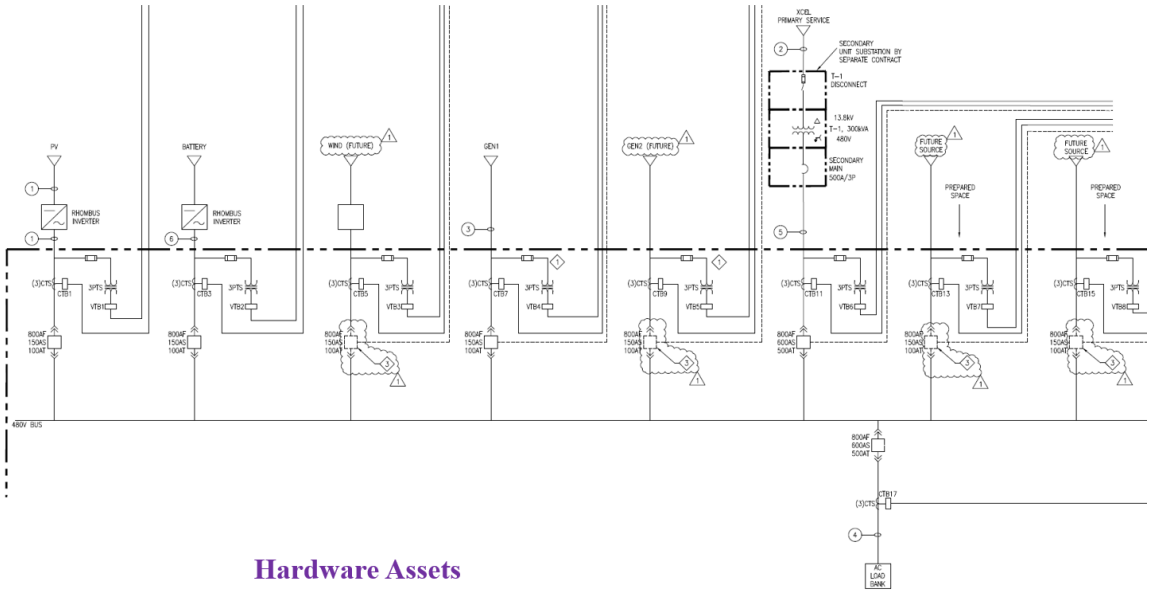
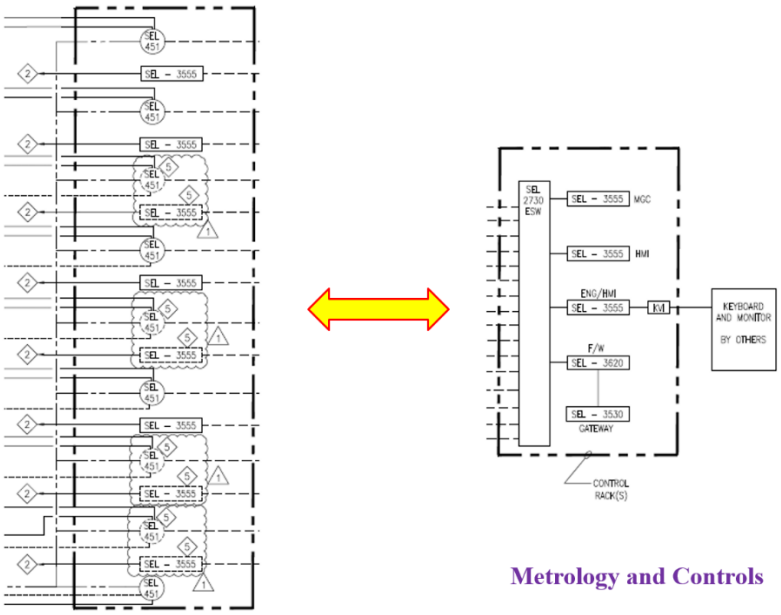
One-Line Diagram of the Research Microgrid



Hardware Assets

One-Line Diagram of the Research Microgrid



Metrology and Controls

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Vendors and Partners

Through an almost year-long effort, the process of identifying and selecting key vendors and project-partners was completed. The various asset vendors and partners are summarized in the following table. With the exception of the Energy Management System (EMS), all of the necessary assets for running the microgrid were ordered in 2017. The EMS is a special case with unique partners that will lead to very exciting developments in 2018. One final point with regard to the project vendors and partners, the majority of them are from the state of Minnesota. Hence this research is contributing and strengthening the expansion of the renewable energy industry in Minnesota through the study of how distributed-energy-resources interact in a microgrid and how a microgrid can interact with the main grid.

	Asset	Vendor/partner	Vendor/Partner HQ Location
1	Solar PV Array	All Energy Solar	Minnesota
2	Inverters	Rhombus Energy Solutions	Michigan
3	Energy Storage System	EnerSys	Pennsylvania
4	Diesel Genset	Cummins	Minnesota
5	Load Bank	ASCO - Emerson	Minnesota
6	Switchgear and Protection	States Manufacturing	Minnesota
7	Energy Management System	In process	In process
8	Engineering	Hallberg Engineering	Minnesota
9	Electrical	Collins	Minnesota

Selections and Discussion

There are three research important research goals outlined in the HE4-2 grant proposal. The three research goals are (i) Develop distributed intelligence energy management system (EMS), (ii) perform advanced inverter design research, and (iii) provide the opportunity for third-party university/industry research collaborations. These objectives figured prominently into the vendor and partner selections – along with their business location.

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Based on the accumulated experiences gained from deploying microgrids around the world during the past 12 years (~ 10 of them), developing intelligent DERs (distributed energy resources) would significantly improve the state-of-art of the microgrid. While the EMS needed to manage the intelligent microgrid DERs will be the focus of 2018 research, the DER subsystems themselves must have native intelligence in order to lay the foundation for a new generation of EMSs. A careful inspection of the detailed one-line diagram above illustrates how this is being achieved. Every asset in the research microgrid is designed around a common structure consisting of an intelligent switch, smart relays and data acquisition hardware, and a computer hardware-in-the-loop control system. The intelligent switch (aka 'breaker') uses state-of-art relays and protection that will enable researchers to capture all necessary operating data. The computer controller works with the intelligent switch and the particular energy resource (or load) to enable assets to be connected and disconnected to the microgrid at will – something that is virtually impossible to do with electric machines in the macro grid – as well as manage power flow in a collaborative manner with other assets. These characteristics were achieved through the use of Schweitzer Engineering Laboratories (SEL) hardware – the industry leader for this type of gear. The distributed intelligence EMS will use the standardized communication schemes that all SEL hardware incorporates. Since Xcel Energy and States Manufacturing are very experienced with and use SEL hardware, this figured prominently into their selection.

Another aspect of the microgrid that affects the EMS is the power capability of the various energy assets. It is relatively easy to design a microgrid controller if the power-size of one of the energy assets, e.g. the diesel genset, dominates all others. It is an entirely different control problem if all of the energy assets are similarly sized. Consistent with the advanced EMS 2018 research goals, this led to sizing all of the energy assets in the 25 kW to 50kW range; with none dominating the power landscape. Hence the 50 kW each of solar PV, diesel genset, and battery storage power-sizes.

Another objective is advanced inverter research. This led to the selection of Rhombus Energy Solutions as a project research partner. Independently, their assessment of microgrids suggested to them that the EMS strategies outlined above represent the path to the microgrid system of the future. This made Rhombus an ideal choice for advanced inverter research partner and the use of their inverters in the microgrid. Rhombus also makes a very intelligent inverter that is design to meet evolving smart grid standards.

Finally, the microgrid test bays. To provide the foundation for industry/university collaborations, the microgrid hardware described in the various one-line diagrams above are being deployed as an integral part of the microgrid in both test bays. When the research microgrid comes on-line in

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2018, third party collaborators will be able to integrate their energy assets &/or EMSs into the research microgrid in a seamless manner and integrate/interconnect with the existing energy assets and load. The possibilities of this unique arrangement for future collaborations, study, and research are very exciting. Finally, the test-bay feature of the microgrid will enable the research microgrid to be connected into the building management systems that house the microgrid at some future date. This will provide the ability to study how a campus microgrid can interact with the building management systems common to university campuses.

Research and Recognition

Project research in 2017 continued research from 2016 with pre-construction emphasis in two focus areas. The first focus area continued with investigations into distributed microgrid control methods (often referred to as peer-to-peer control or distributed-intelligence control) in a world of rapidly evolving standards. Key developments in this focus area are anticipated in 2018.

The second research focus area centers on innovative methods of using inverters. In 2016 it was discovered that via space-vector-pulse-width-modulation (SVPWM) inverters could be controlled to emulate the terminal characteristics of a synchronous generator. This was an important development since controlling synchronous generators is well understood. Hence this discovery paved the way for using existing control strategies to control inverters. Furthermore, this work then led to the hypothesis that it might be possible to design inverters that self-synchronize without requiring traditional synchronization methods such as those used with electric machines. A preliminary example of the output of two low-power self-synchronizing inverters is illustrated in the following screen-shot. Self-synchronization of two inverters was achieved in a hot pluggable manner with no overall control system being used to synchronize the inverters. If self-synchronization can be extended to the high-power inverter assets in the research microgrid (2018), then low-cost methods of controlling microgrids will be possible.

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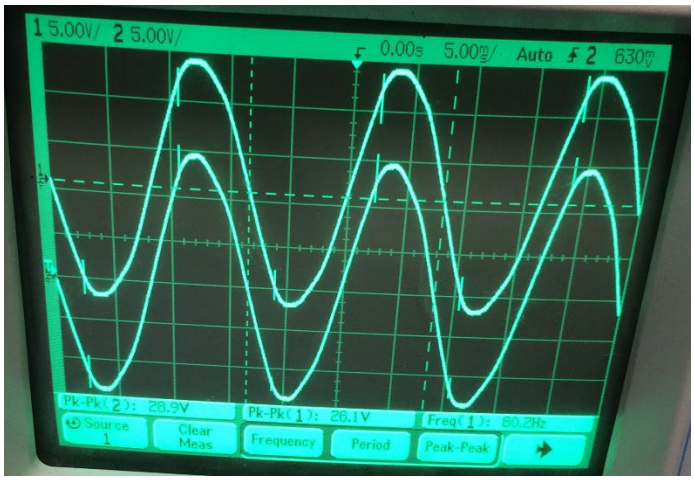

To date the RDF HE4-2 funding has enabled the engagement of 3 graduate students, 2 undergraduate students, and 3 UST engineering faculty in the USTREF microgrid project.

The HE4-2 grant continued to bring visibility to Xcel Energy and the microgrid project in 2017 with 4 invited talks given to utilities and professional organizations (National Professional Engineering Society) as well as many invited microgrid seminar and educational presentations.

The 2017 microgrid results summarized in the sections above continued have a very positive benefit for Xcel Energy and its rate payers, the RDF program, the State of Minnesota, and the University of St Thomas power program. The HE4-2 funding and the USTREF research has led to Minnesota being identified as an innovative leader in the microgrid space.

Lessons Learned

The most significant lesson learned to date is that it takes a long time, with a significant amount of effort, to make even incremental progress in the microgrid space. While the research is necessary and essential, the real long-term benefit of microgrids became apparent in the aftermath of the devastation that Hurricane Maria caused in Puerto Rico. This singular event pushed microgrid technology to the forefront of the news – and development. The HE4-2 funding represents an important and critical step in the overall success of microgrids.

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Budget Summary

To date a total of ~ $2.1 million has been received from the RDF for the HE4-2 grant – the full amount. In 2017 approximately $1.3 million of $1.5 million was released for the subsystems noted in the vendor/partner table. To rounded dollars, the expenditures are summarized below.

- PV array: $142,000
- EnerSys Energy Storage System: $141,000
- Cummins Diesel Genset: $50,000
- ASCO-Emerson load bank: $40,000
- States manufacturing switchgear and protection: $451,000
- Collins and the system interconnect: $336,000
- Substation: $125,000
- Miscellaneous: ~ $3,000
- End of 2017 Balance: ~ $812,000

2017 Conclusion and Next Steps

The site-location of the USTREF was finalized and accepted by all parties.

The functional and detailed one-line diagrams for the USTREF were completed.

With the exception of the energy management vendor/partner, all microgrid subsystems were ordered.

Graduate and undergraduate student research has resulted in the preliminary findings that it is possible to self-synchronize inverters without the need for a control system. This work will continue into 2018.

Construction of the USTREF will begin in February 2018.

Island-mode microgrid studies are planned to begin in the June-July 2018 time period.

Grid connection of the USTREF to the Xcel Energy feeder servicing the south-campus of UST is projected to occur in Q4 2018. The interconnection application process was initiated.

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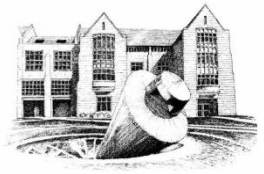
Attachments

1. 2017 Quarterly reports

2. 2017 Speaking Events and Presentation Titles

3. NSP Oral Presentation Material



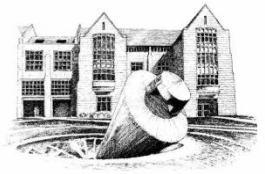
The University of St. Thomas Renewable Energy Facility (USTREF)

HIGHER EDUCATION BLOCK GRANT CONTRACT
WITH THE MINNESOTA STATE COLLEGES AND UNIVERSITIES
RENEWABLE DEVELOPMENT FUND – CYCLE 4
GRANT CONTRACT WITH UNIVERSITY OF ST. THOMAS HE4-2

PI: Dr. Greg Mowry

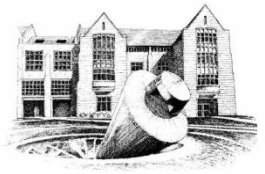
12 Dec 2017

13



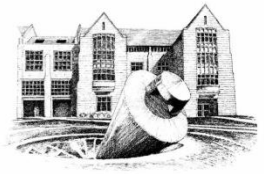
Grateful Acknowledgements

Project funding provided by customers of Xcel Energy through a grant from the Renewable Development Fund.

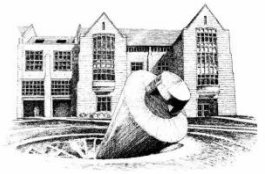


Outline

- Intro and Program Review
- Accomplishments
- Program Benefits
- Budgets and Schedule
- Questions??



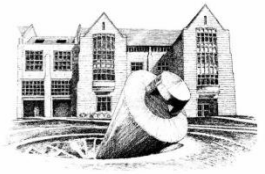
Intro and Program Review



Executive HE4-2 Summary (1)

- Install a multi-purpose **RESEARCH** microgrid which is now referred to as the, "USTREF" [the **U**niversity of **S**t **T**homas **R**enewable **E**nergy **F**acility]

- The primary objective of this facility will be to promote industry/academic collaboration in the design/build/test and validation of near commercial concepts in the areas of electricity generation and microgrid/subsystem control.



Executive HE4-2 Summary (2)

- Incorporate real scale distributed energy resource and microgrid modeling experience into graduate and undergraduate electrical engineering curriculum;

- Develop an educational portal and curriculum for the K-12 grades showcasing sustainability and alternative energy systems in action.

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

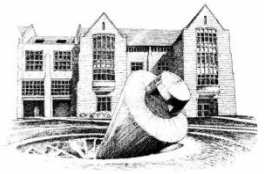
Custom Loads for control studies:
- Dump loads
- IMs
- Arcs, …

XF

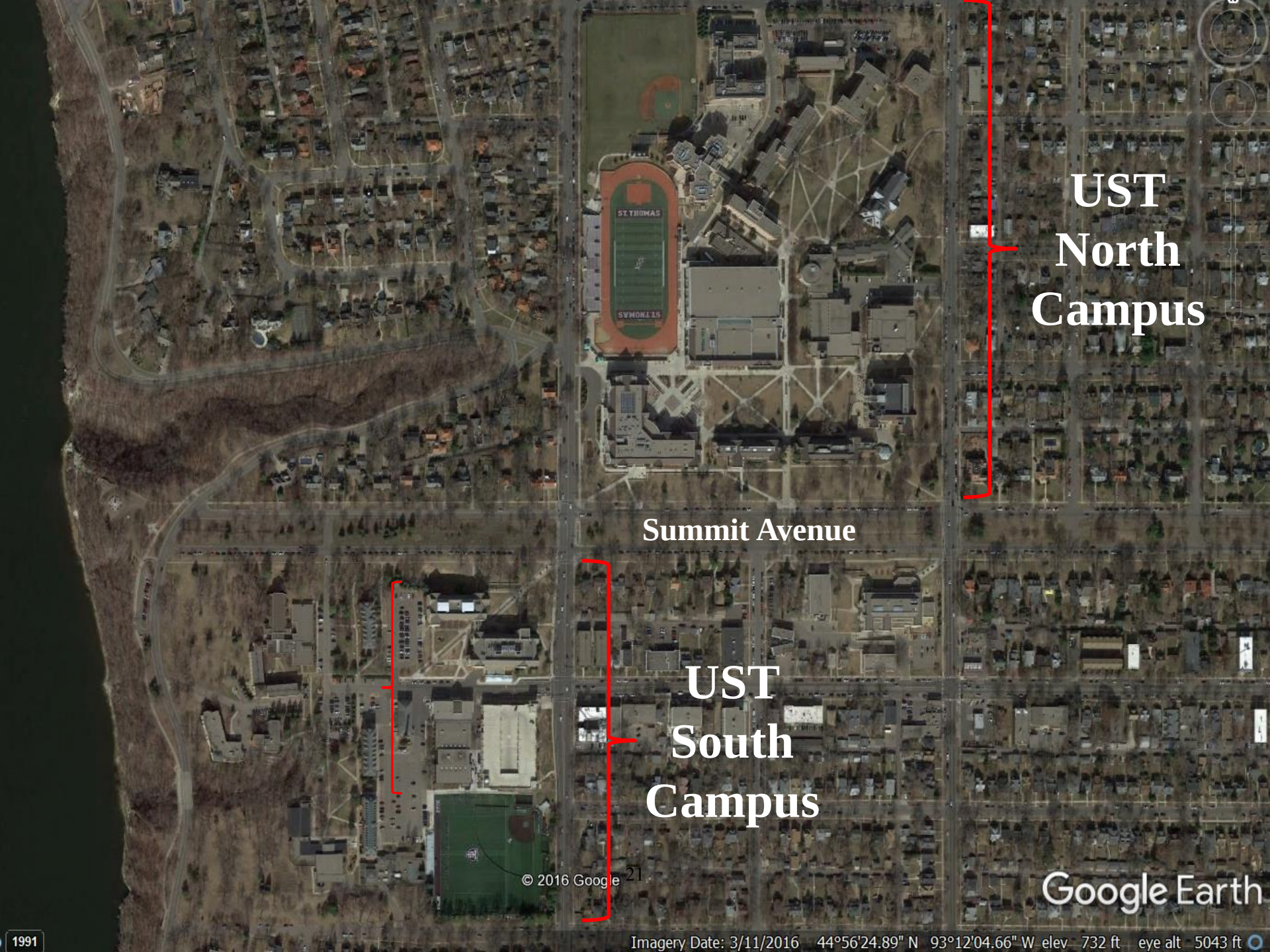
Switch

13.8 kV Xcel Energy Campus Feeder

UST Facilities and Design Center



Accomplishments


UST
North
Campus
Summit Avenue
UST
South
Campus
© 2016 Google
Google Earth
1991
Imagery Date: 3/11/2016 44°56'24.89" N 93°12'04.66" W elev 732 ft eye alt 5043 ft

OSS

My office

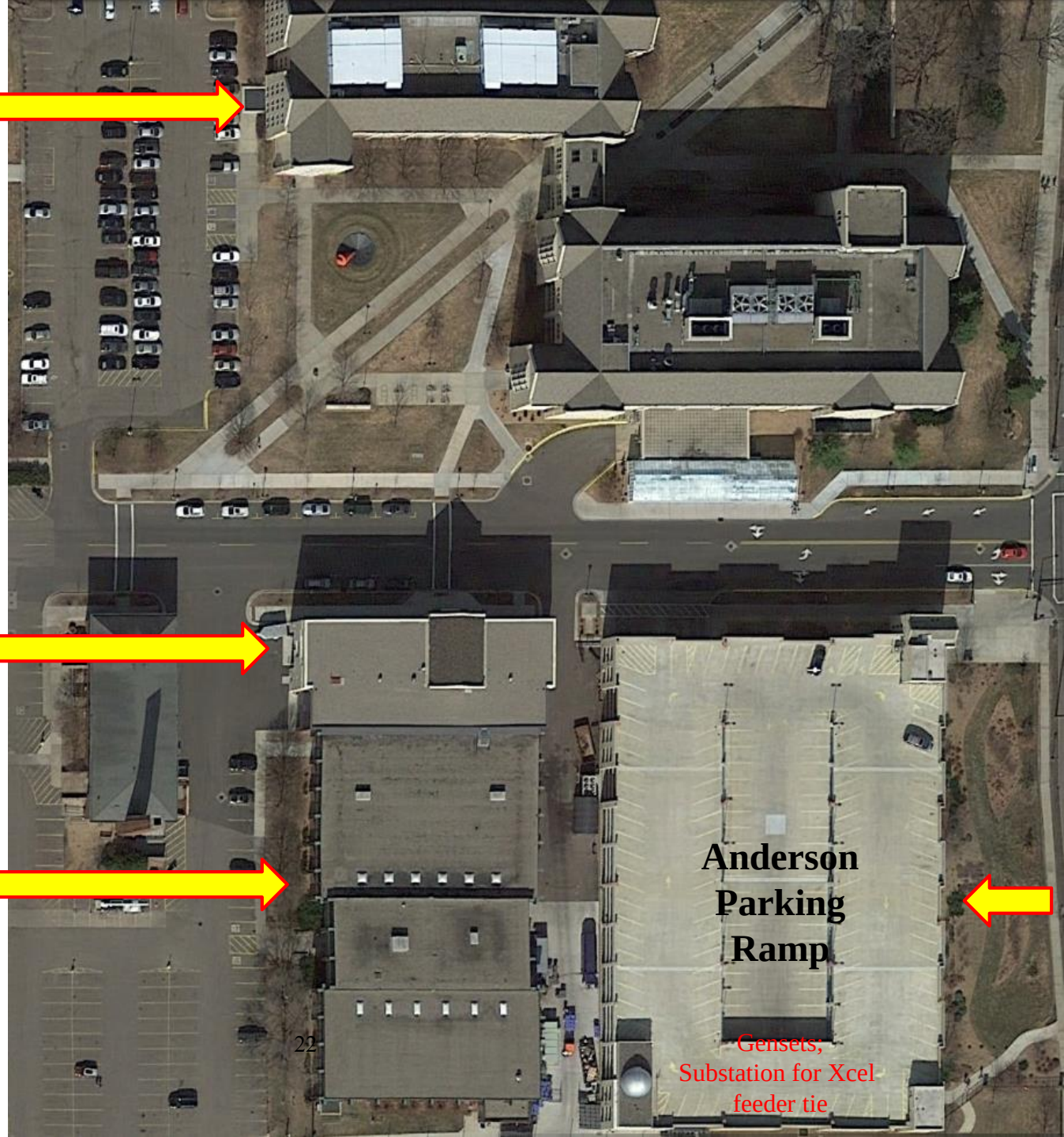
Google Earth view of the UST µGrid location

FDC

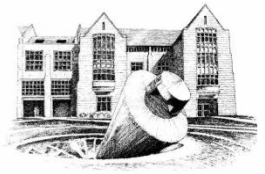
Control Center;
Storage;
Switchgear

McCarthy Gym

PV array & roof space
For 3rd party test



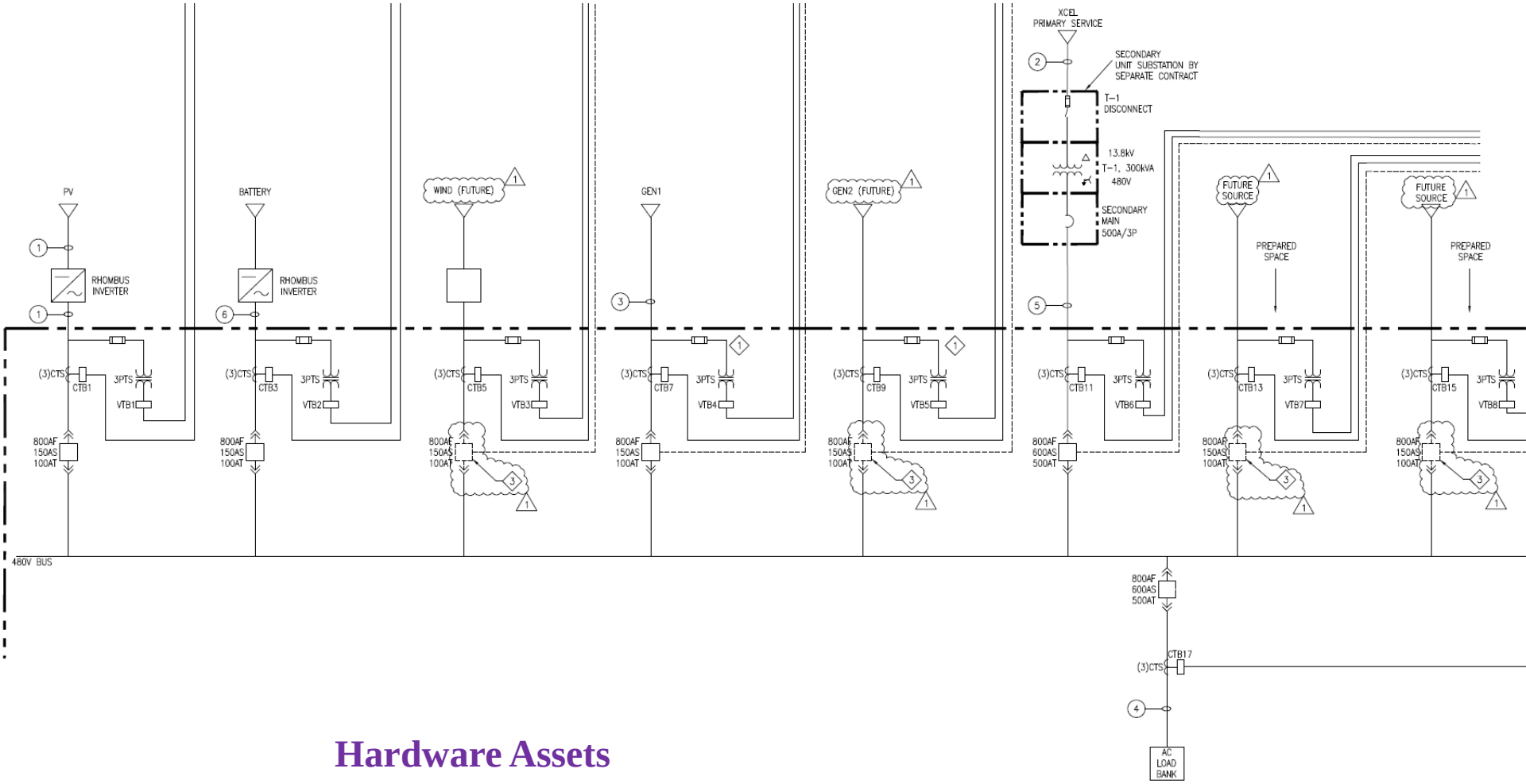
FDC – the Facilities and Design Center; Office View



Accomplishments (1)

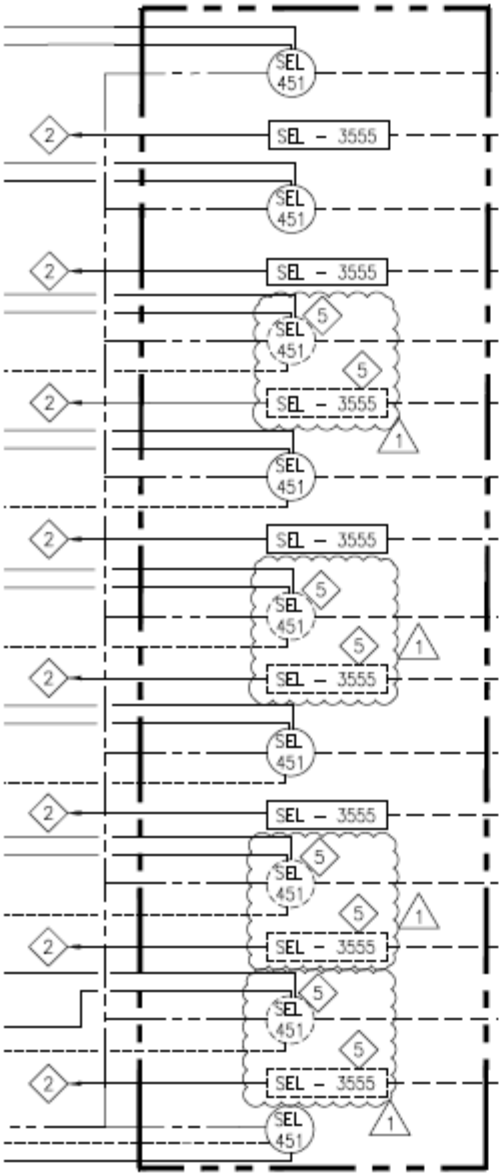
- The one-line diagram that drives all RFPs and RFQs, procurements, and asset deployments was finalized

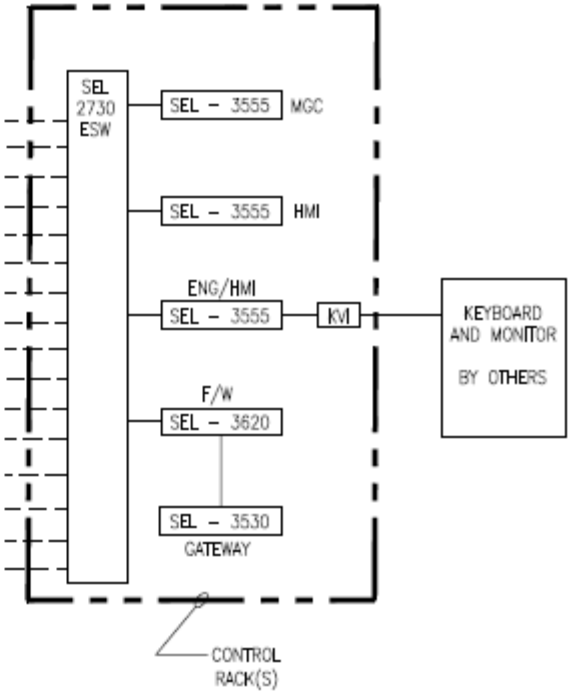
One-Line Diagram of the Research Microgrid

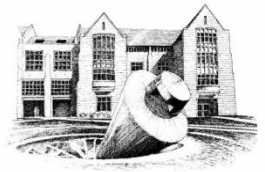


Hardware Assets

One-Line Diagram of the Research Microgrid



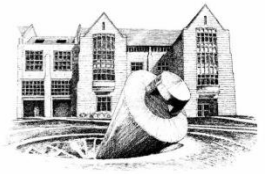




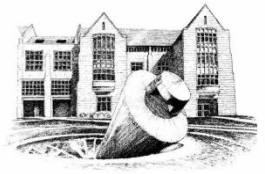
Accomplishments (2)

- Key Partner Arrangements:
  - Xcel Energy: Smart grid development & security – in process
  - Rhombus Energy Solutions: Advanced inverters – done
  - Enersys: storage node – in process
  - Amzur/UST/Xcel distributed intelligence EMS & smart-grid controls – done

- Integration of preliminary R&D into engineering curriculum
  - Microgrid teaching module developed and in use – done
  - Distribution and microgrid course under development for 2018-2019 academic year – in development



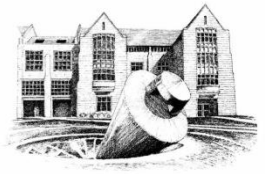
Program Benefits



Program Benefits (1)

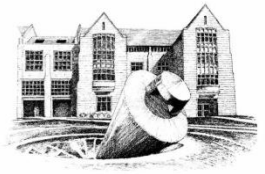
- Xcel Energy is being recognized as leading-edge and proactive in microgrid technology and deployment

- 5 invited microgrid presentations: national visibility
  - National Society of Professional Engineers – national conference
  - UST Smart Climate Event – open to UST alumni & public
  - MIPSYCON presentation
  - 7th Microgrids & Distribution/Generation for Public & Private Sectors
  - MnSEIA – Midwest Gateway to Solar



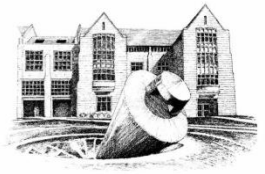
Program Benefits (2)

- Significant boon to the University of St Thomas's School of Engineering power program: at both the graduate and undergraduate level
  - Currently ~ 65 grad students in the MSEE power program
  - Growth of power program into distribution systems and electric vehicles for the 2018-2019 academic year
  - Potential for a new engineering building with major power center



Program Benefits (3)

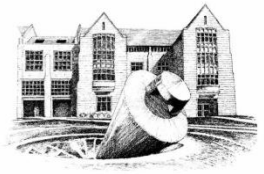
- Development of several key partnerships & 3rd party vendors with leading-edge companies in microgrids and smart-grid research
  - Rhombus energy Systems
  - Enersys
  - Amzur Technology – and possibly Duke energy
  - Schweitzer Engineering Laboratories
  - Oak Ridge national Laboratory (ORNL)



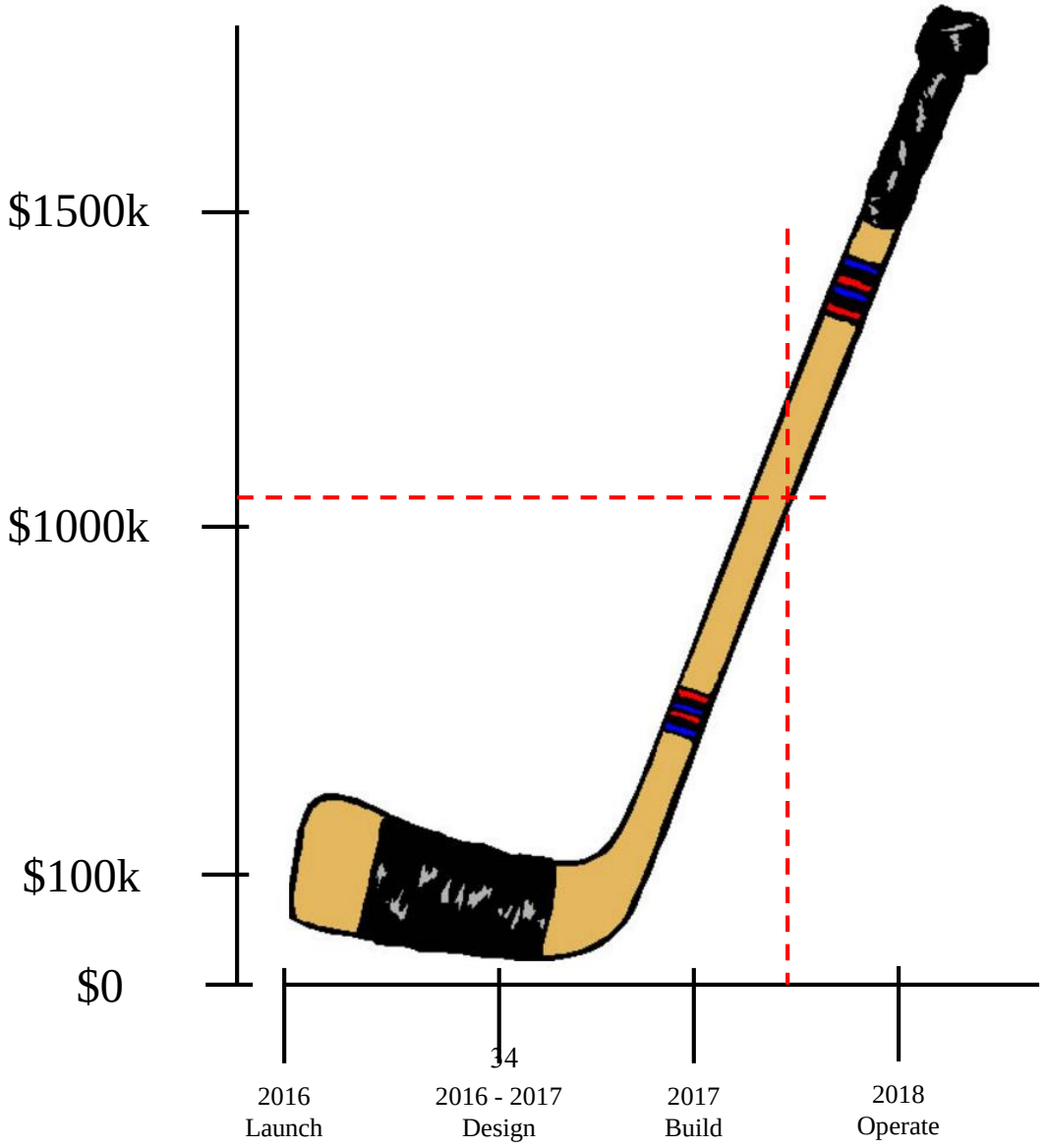
Program Benefits (4)

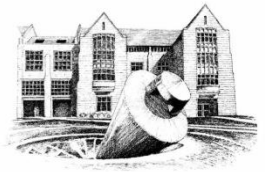
- The Amzur Technologies, UST Power Program, Xcel Energy partnership: Smart-Grid & Microgrids
  - ✓ DERs, distributed intelligence, and modern smart-grid standard – the USTREF EMS is the test platform
    - IEEE 1547.x
    - IEEE 2030.5/SEP2
    - Open FMB
    - ASHRAE201/FSGIM

32



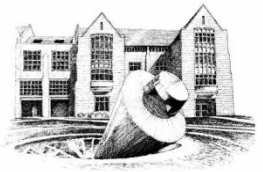
Budgets and Schedule


$1500k
$1000k
$100k
$0
34
2016
Launch
2016 - 2017
Design
2017
Build
2018
Operate



Capital Expenditures

- Switchgear – States Manufacturing – MN Company; $500k
- Gensets – Cummins – MN Company; ~ $50k
- EMS – Amzur Technology – USA Smart-grid Company; $100k
- Storage – Enersys – USA Company; $140k
- PV array – RFP/RFQ IP; ~ $175k
- Construction – MN Companies – RFP/RFQ IP; ~ $250k



Schedule

✓Full funding release August 2016 – Completed

✓Civil engineering planning completed in Q3 2017 – Completed

✓Switchgear to be delivered in December 2017 – Completed circa 12 December 2017

✓ RFQs & asset ordering: Q4 2017 – In process

✓ Grid-connection application to Xcel Energy Q4 2017 – In process

✓ Island mode connection and commissioning Q2 – Q3 2018

✓ Grid tie to Xcel Energy Lindstrom feeder in Q4 2018

Questions??