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8TH ANNUAL PITT ELECTRIC POWER INDUSTRY CONFERENCE
Presented by the Swanson School of Engineering & the Center for Energy

Graduate Student Symposium

Session Moderator:
Brandon Grainger – PhD Student

8th Annual Electric Power Industry Conference
University of Pittsburgh
Swanson School of Engineering
November 11th, 2013

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8TH ANNUAL PITT ELECTRIC POWER INDUSTRY CONFERENCE
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DC and Hybrid Systems Analysis

Shimeng Huang

Augustin Cremer, Emmanuel Taylor

Ansel Barchowsky

8th Annual Electric Power Industry Conference

Swanson School of Engineering

Graduate Student Symposium

November 11th, 2013

Control of Multi-terminal DC Systems

Shimeng Huang

DC Data Center Design

Augustin Cremer, Emmanuel Taylor

Powering Business Worldwide

Electric Power Systems Laboratory

Ansel Barchowsky

University of Pittsburgh

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Multi-Terminal DC Controls

Prepared by: Shimeng Huang
Ph.D. Student

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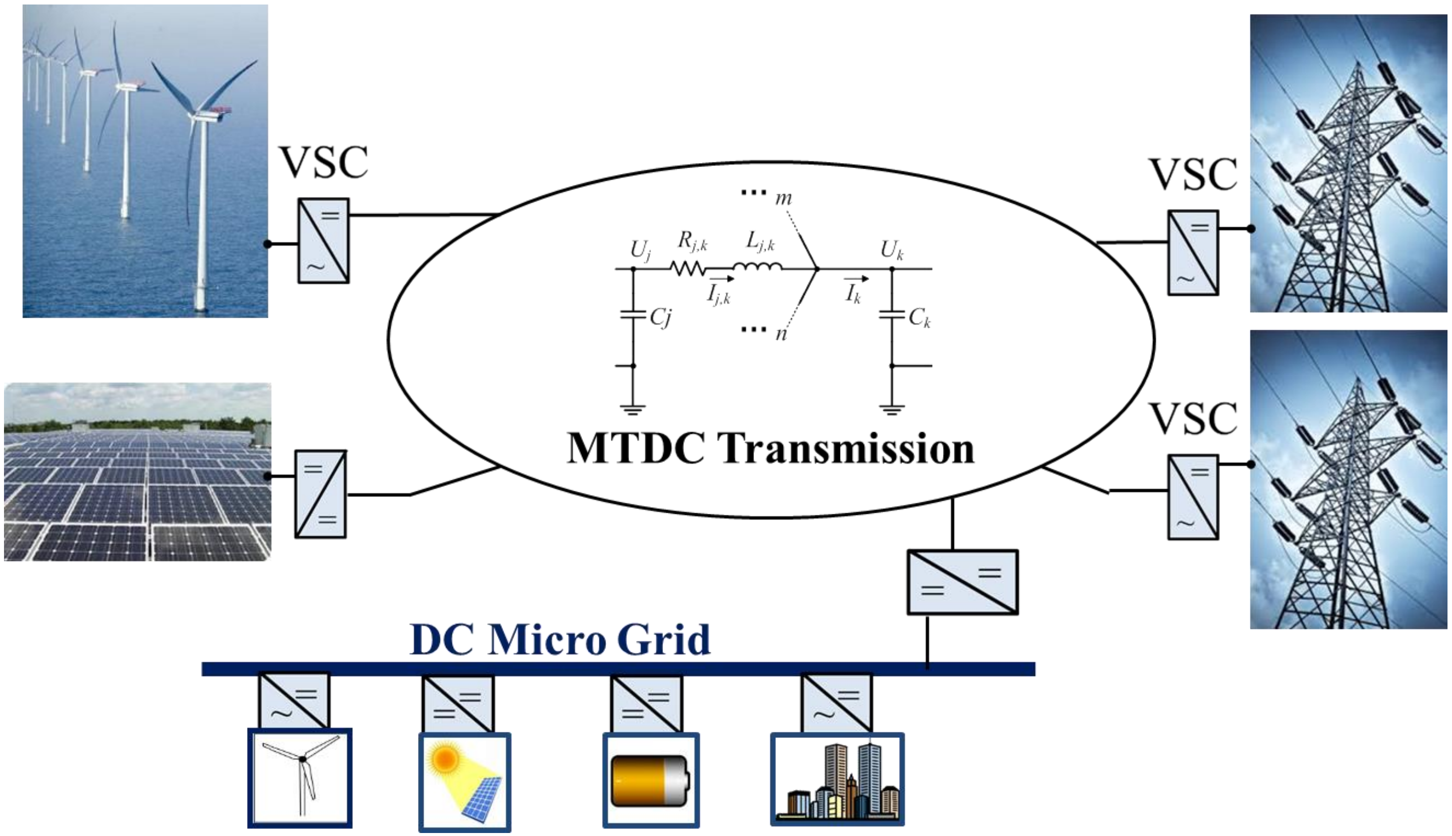
DC and Hybrid Systems Analysis

Multi-Terminal DC Controls

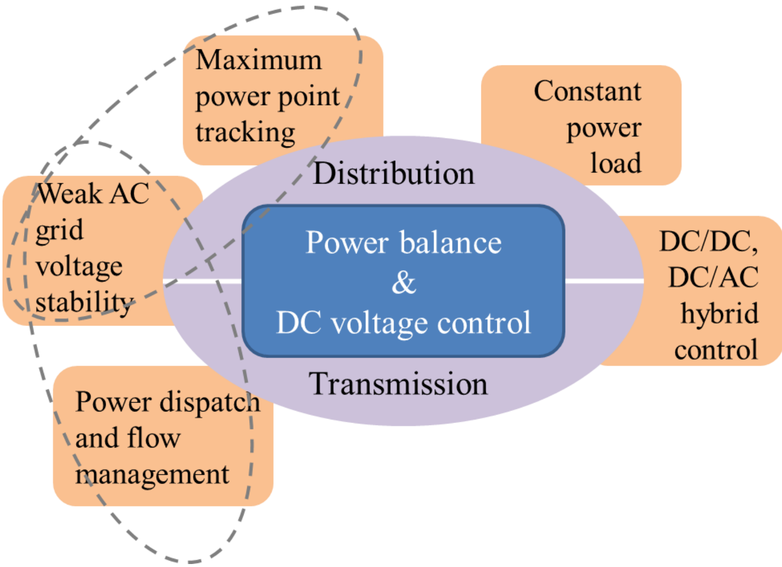
MTDC systems have great potential in transmission and distribution applications

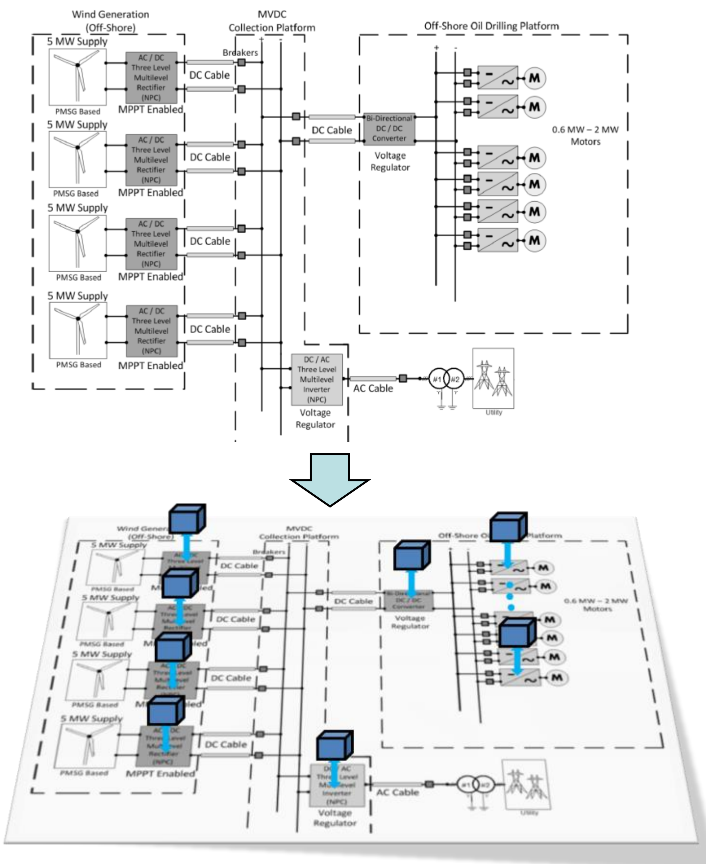


DC and Hybrid Systems Analysis

Multi-Terminal DC Controls

Control of MTDC systems involves trade-off between correlated control goals





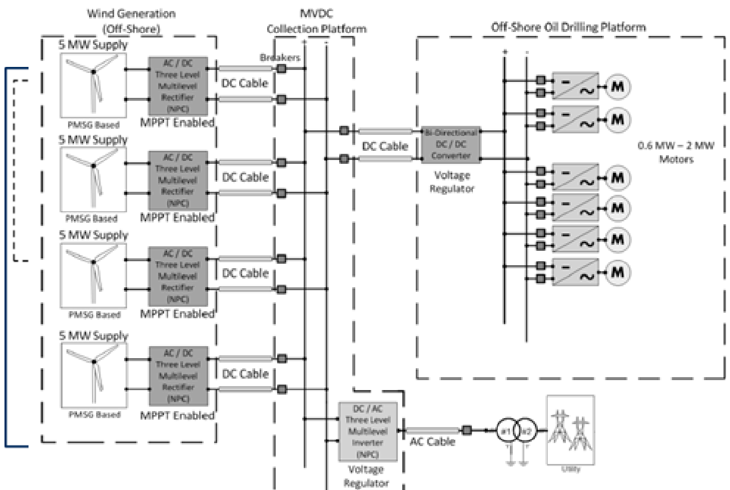
- Research objective

  Study interactions among controllers in a DC grid, develop a control design method that can coordinate local controllers to stabilize the grid and achieve optimal operation in system level

DC and Hybrid Systems Analysis

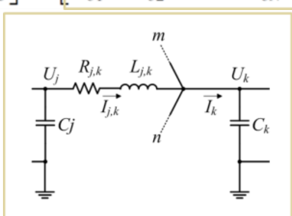
Multi-Terminal DC Controls

Out state space modeling method is generalizable to arbitrary MTDC configurations



n

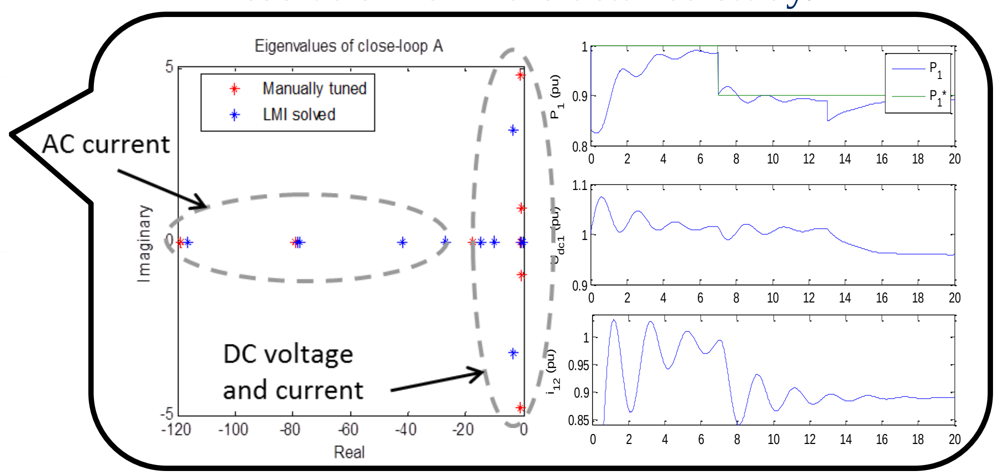
$$\begin{bmatrix} \dot{\mathbf{x}}_1 \\ \dot{\mathbf{x}}_2 \\ \vdots \\ \dot{\mathbf{x}}_N \\ \dot{\mathbf{x}}_c \end{bmatrix} = \begin{bmatrix} \boxed{\mathbf{A}_{11}} & 0 & \cdots & 0 & \mathbf{A}_{1c} \\ 0 & \mathbf{A}_{22} & \cdots & 0 & \mathbf{A}_{2c} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \cdots & \mathbf{A}_{NN} & \mathbf{A}_{Nc} \\ \mathbf{A}_{c1} & \mathbf{A}_{c2} & \cdots & \mathbf{A}_{cN} & \mathbf{A}_{cc} \end{bmatrix} \begin{bmatrix} \mathbf{x}_1 \\ \mathbf{x}_2 \\ \vdots \\ \mathbf{x}_N \\ \mathbf{x}_c \end{bmatrix} + \begin{bmatrix} \mathbf{B}_1 & 0 & \cdots & 0 \\ 0 & \mathbf{B}_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & B_N \\ 0 & 0 & \cdots & 0 \end{bmatrix} \begin{bmatrix} \mathbf{u}_1 \\ \mathbf{u}_2 \\ \vdots \\ \mathbf{u}_N \end{bmatrix}$$



Coupling

Modal analysis :

- Identify critical modes and which states are contributing to it
- Study how each system or control parameter influences the damping of a mode
- Extract simplified model in desired time resolution for more detailed study.

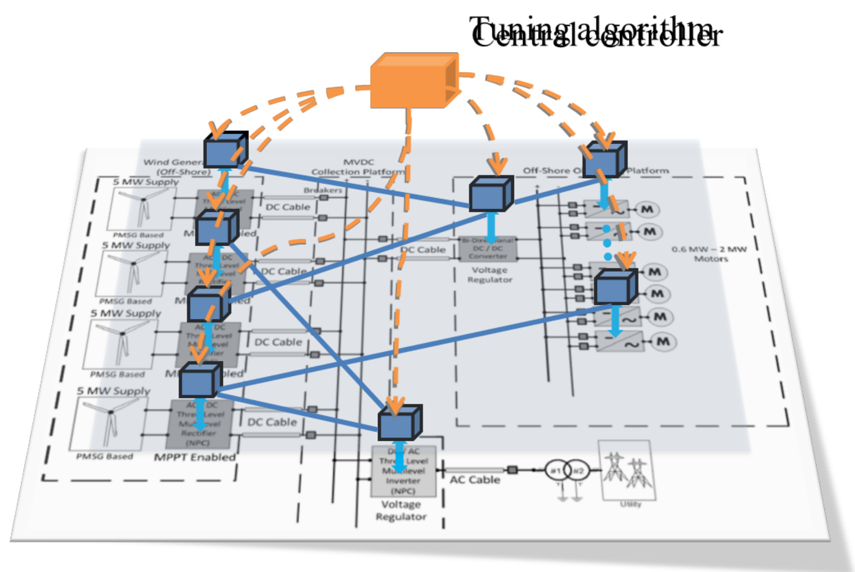


DC and Hybrid Systems Analysis

Multi-Terminal DC Controls

Controller Design Method based on Linear Matrix Inequality (LMI) Optimization

Tune local controllers for system performance → Add communication among controllers and compare different topologies → Control and communication co-design



Features:

1. Tuning control gains to stabilize the grid as a whole
2. Able to set communication structure to fit realistic infrastructure condition.
3. More flexibility on cost function

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DC Data Center Design

Prepared by: Augustin Cremer, Masters Student, Emmanuel Taylor, PhD Student

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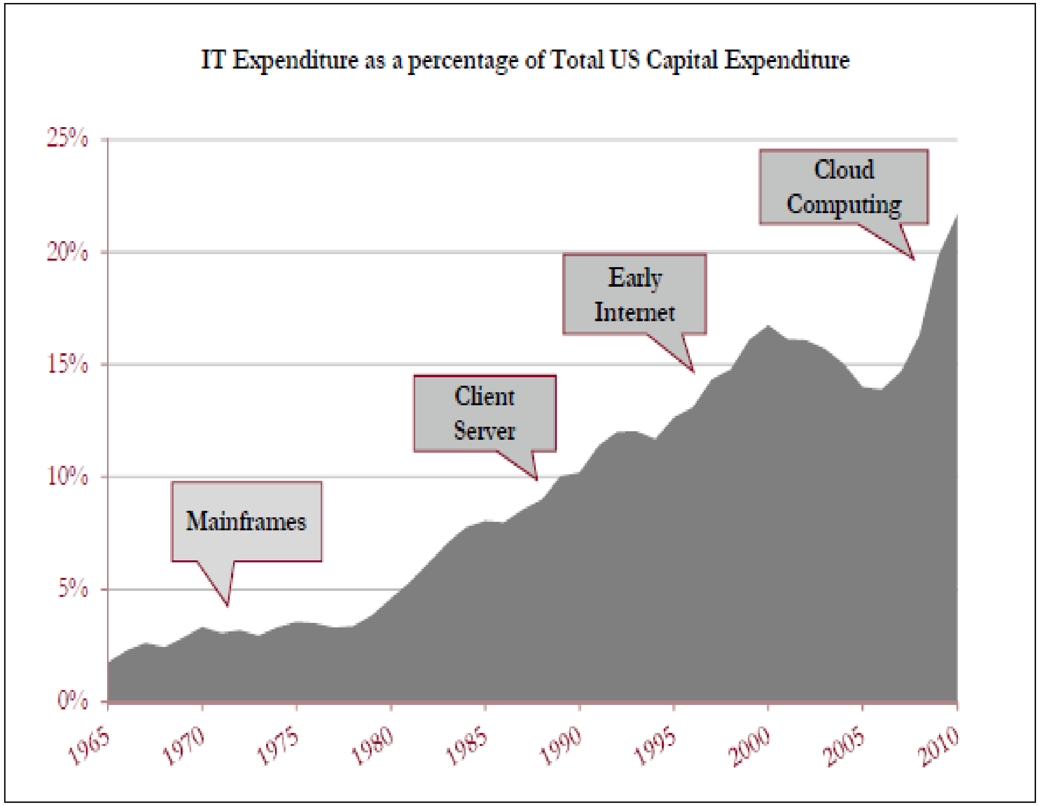
DC and Hybrid Systems Analysis

DC Data Center Design

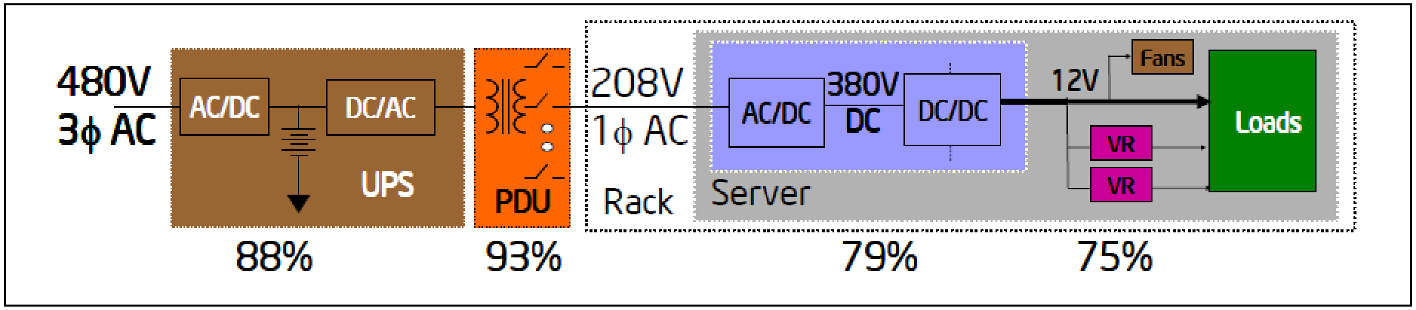
The need for computing power continues to increase.

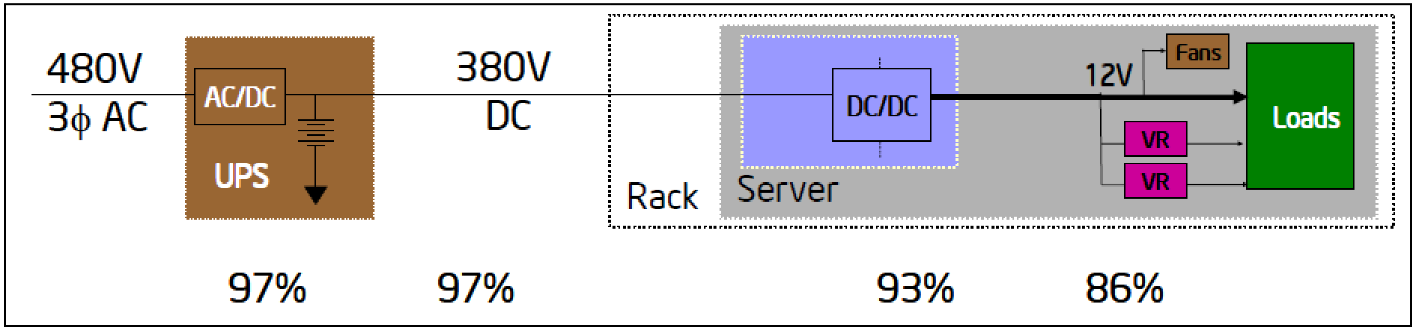


DC and Hybrid Systems Analysis

DC Data Center Design

DC load growth has made DC distribution affordable.





DC and Hybrid Systems Analysis

DC Data Center Design

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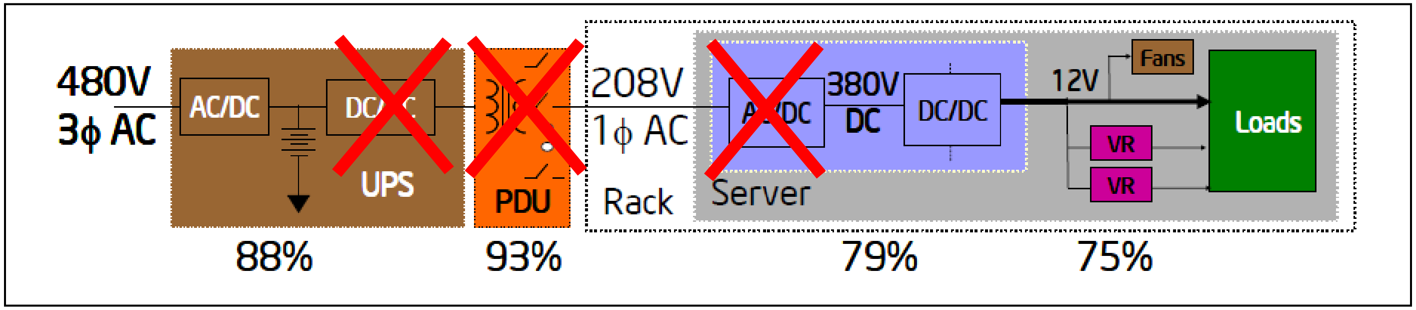
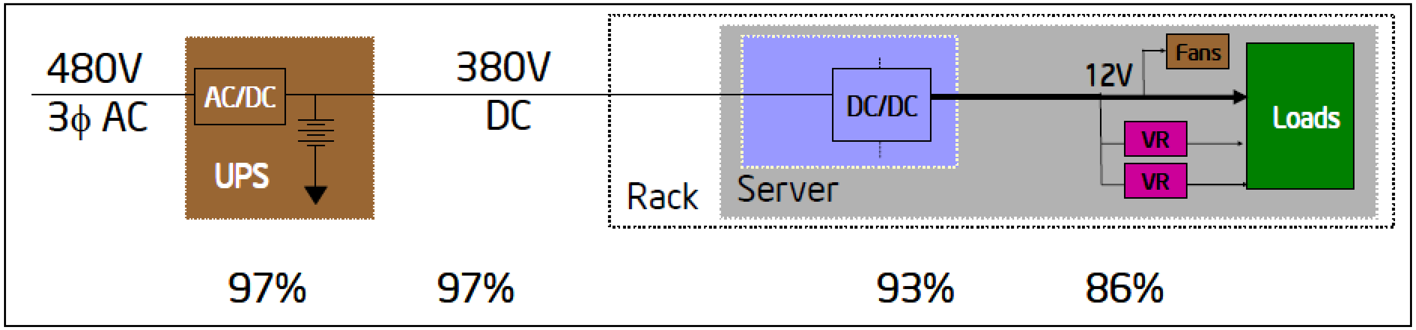
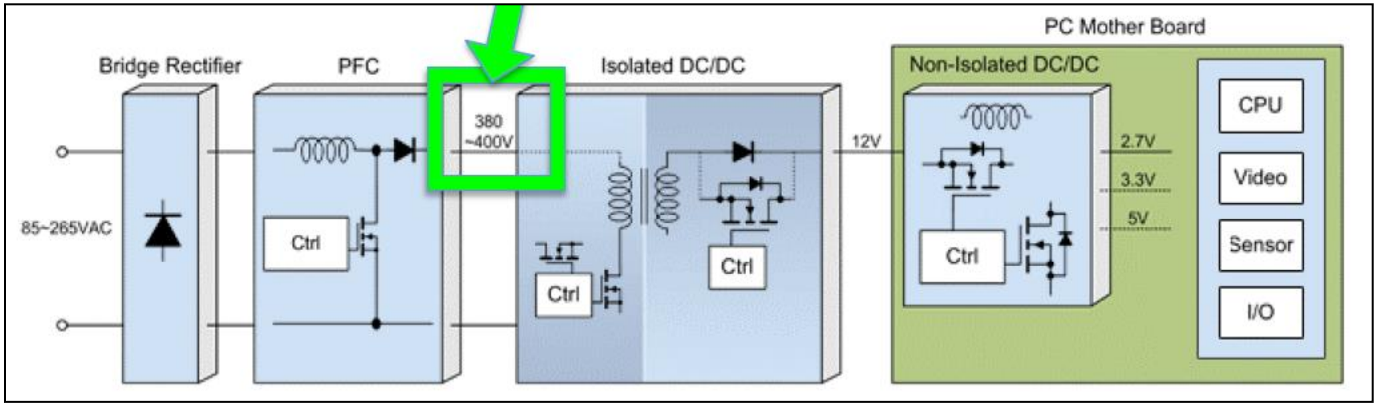




DC and Hybrid Systems Analysis

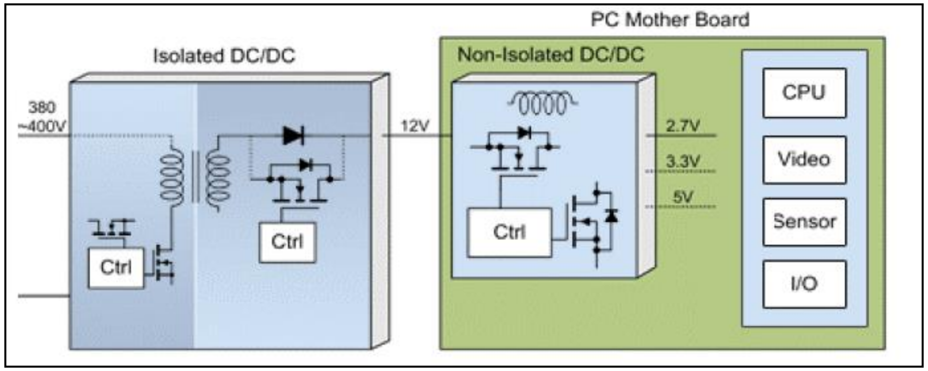
DC Data Center Design

380V DC is already used in datacenter design.



^ AC PSU

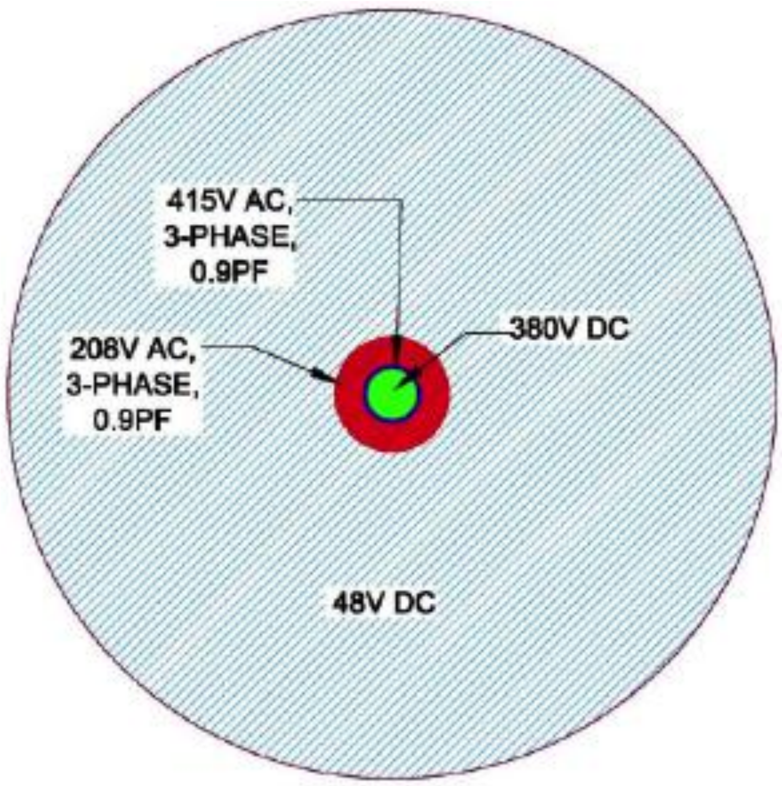
DC PSU >



DC and Hybrid Systems Analysis

DC Data Center Design

380V DC allows substantial savings on copper.



» Emerge, shift to 380 V, why it makes sense, pdf dropbox

DC and Hybrid Systems Analysis

DC Data Center Design

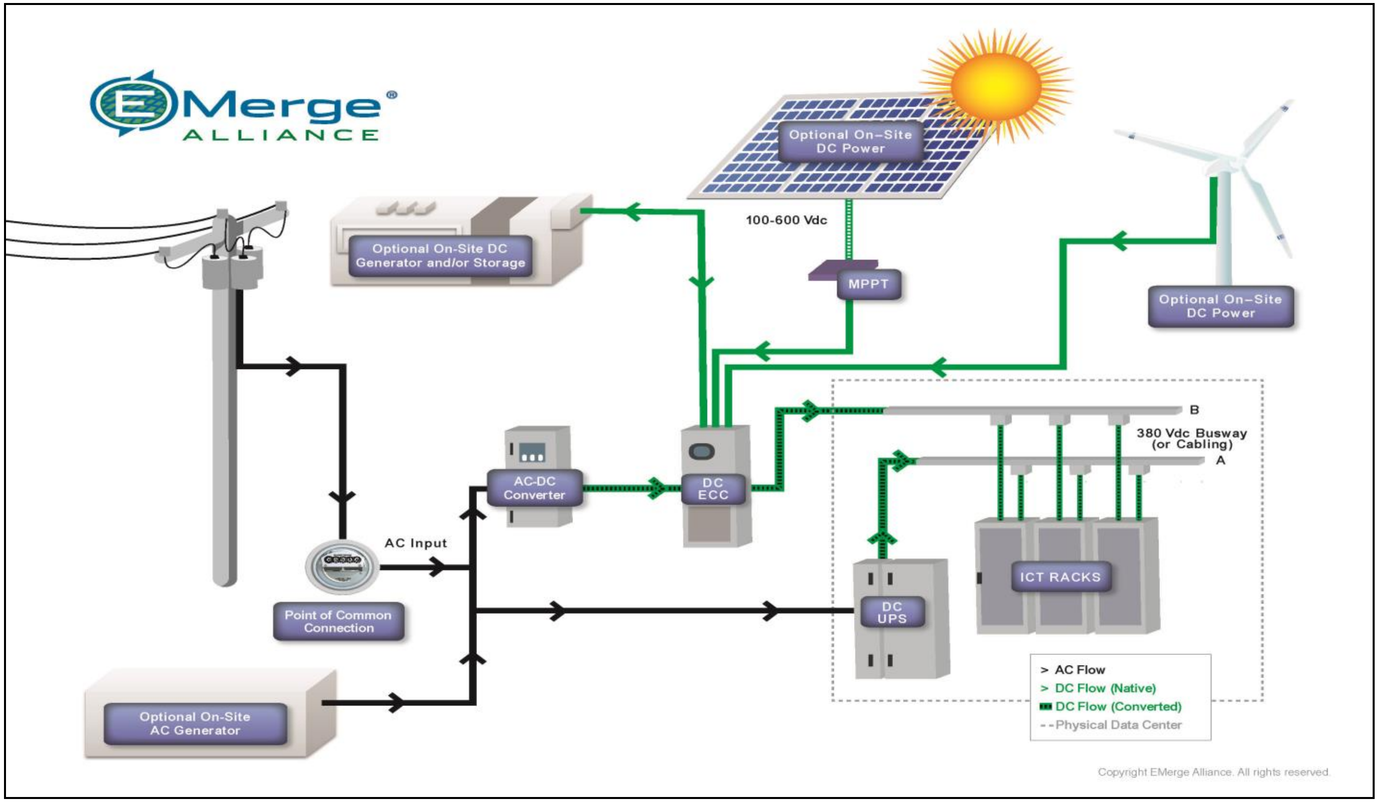
Full DC facilities are becoming more prevalent, with higher power capacities

	DC DATACENTER PROJECT LISTING						
	SYSTEM / PROJECT	POWER RATING(kW)	Voltage (V)	Servers	DC UPS/Rectifier	Year	LOCATION
1	Gnesta Municipality	9	350/380			2006	Gnesta, Sweden
2	Elicom	4.5	350			2006	Toreboda, Sweden
3	NTT NEDO Project	20	380			2007	Sendai, Japan
4	NTT University Microgrid	50	380			2007	Aichi, Japan
5	France Telecom	31.5	350/380			2007	Lannion, France
6	Ericsson	4.5				2008	Stockholm, Sweden
7	Soderhamm Teknikpark	6	350/380			2008	Soderhamn, Sweden
8	NTT Data Corp.	100	380			2009	Tokyo, Japan
9	NTT Lab.	100	380			2009	Tokyo, Japan
10	NTT Facilities	100	380	Intel		2009	Tokyo, Japan
11	Compare Test Lab	4.5				2009	Hammaro Karlstad, Sweden
12	Korea Telecom		300/380			2009	Seoul, Korea
13	UCSD	20	380	Oracle Sun Fire X4270, Intel 2600s	Emerson	2009	San Diego, California
14	Syracuse University	150	380			2009	Syracuse, New York
15	Swedish Energy Agency	18	350			2010	Eskilstuna, Sweden
16	Compare Test Lab	500	350			2010	Hammaro Karlstad, Sweden
17	Duke Energy	30	380	HP DL 385 G7, IBM Power 795	Delta Products	2010	Charlotte, North Carolina
18	NTT East	100	380			2010	Tokyo, Japan
19	NTT	100	380			2011	Atsuigy City, Japan
20	Intel		400				
21	Validus		550				
22	China Telecom		240/380				
23	China Mobile		380				
24	ABB - Green	1000	380	HP DL 385	ABB	2012	Zurich, Switzerland

DC and Hybrid Systems Analysis

DC Data Center Design

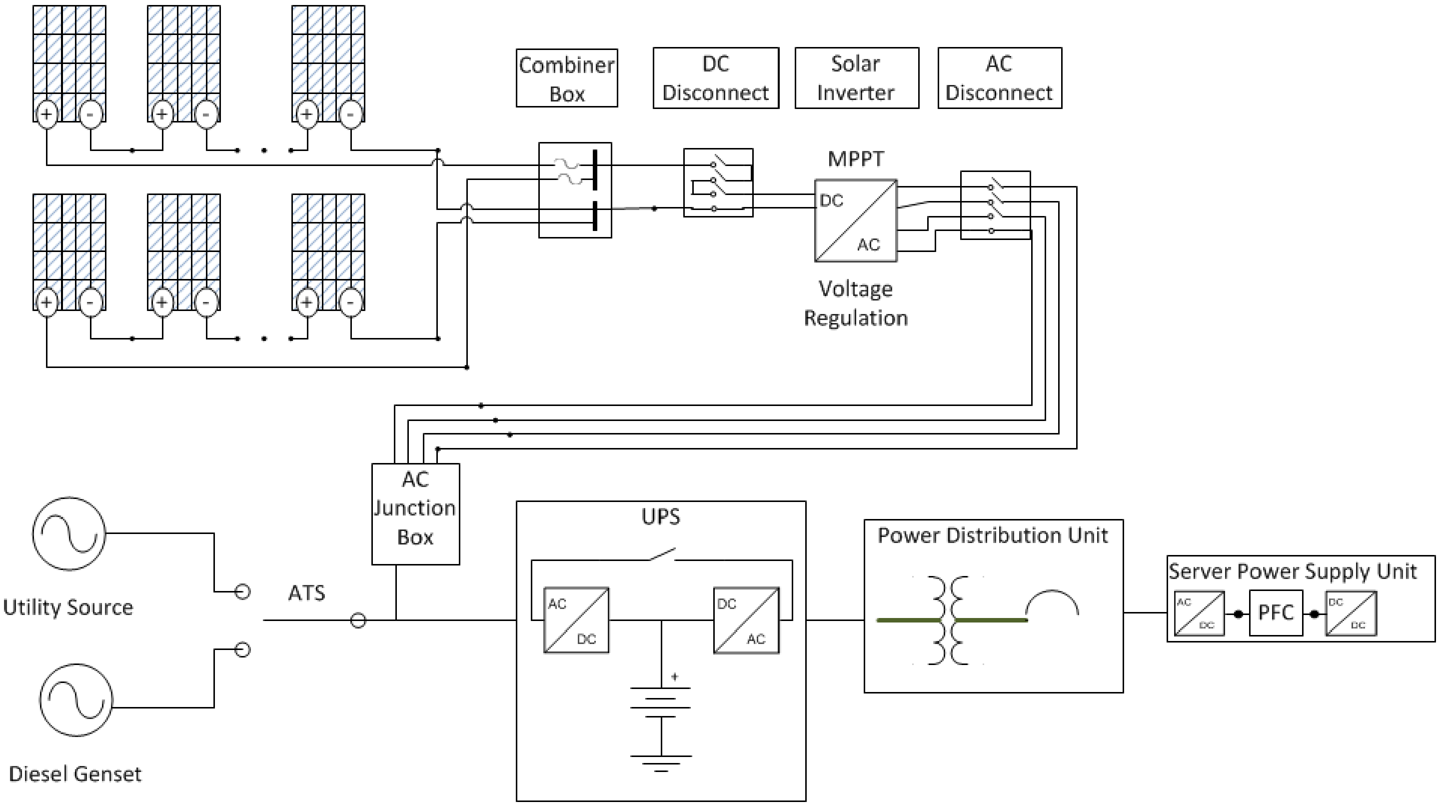
DC distribution allows for easier and lower cost solar installation:



DC and Hybrid Systems Analysis

DC Data Center Design

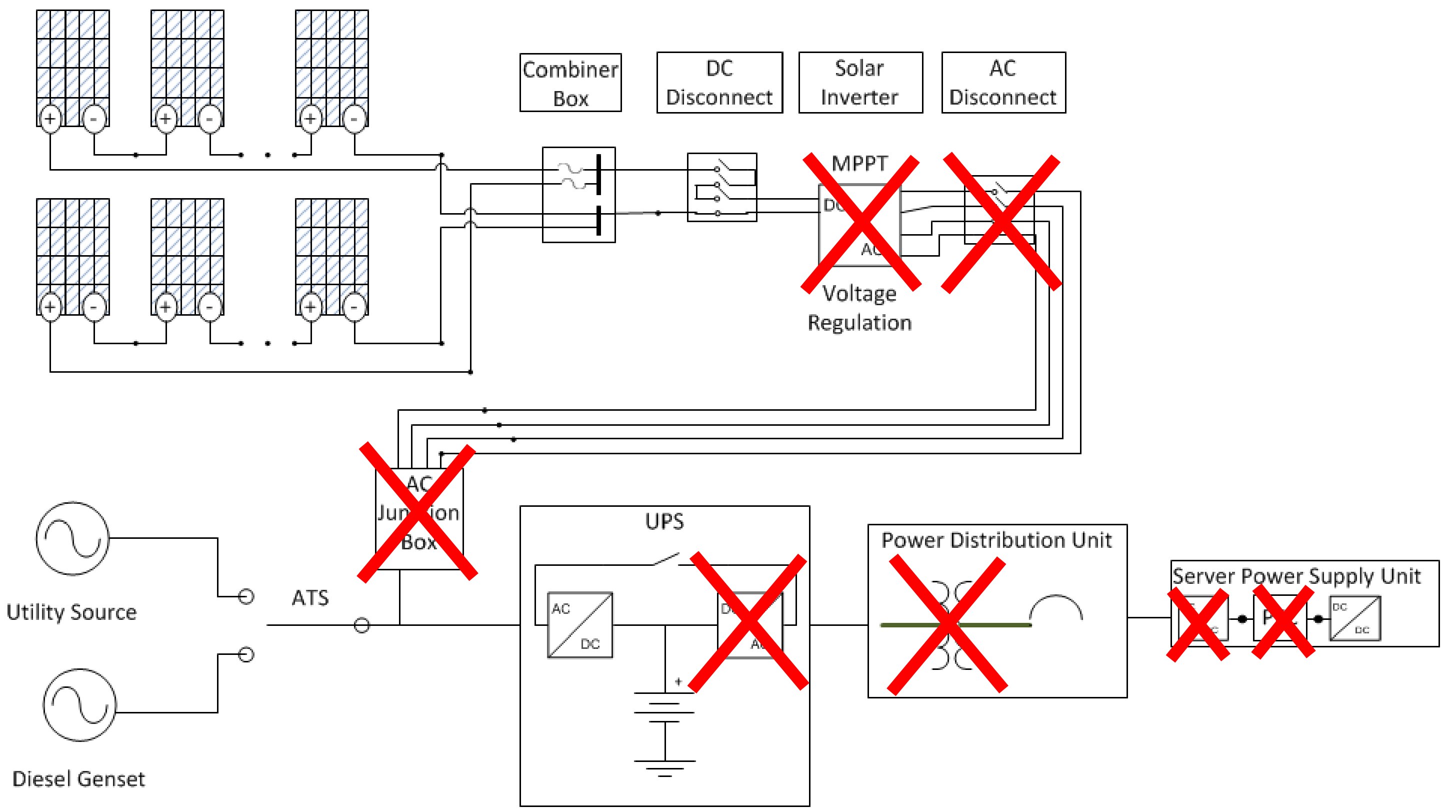
Commercial solar installations typically interconnect to an AC system



DC and Hybrid Systems Analysis

DC Data Center Design

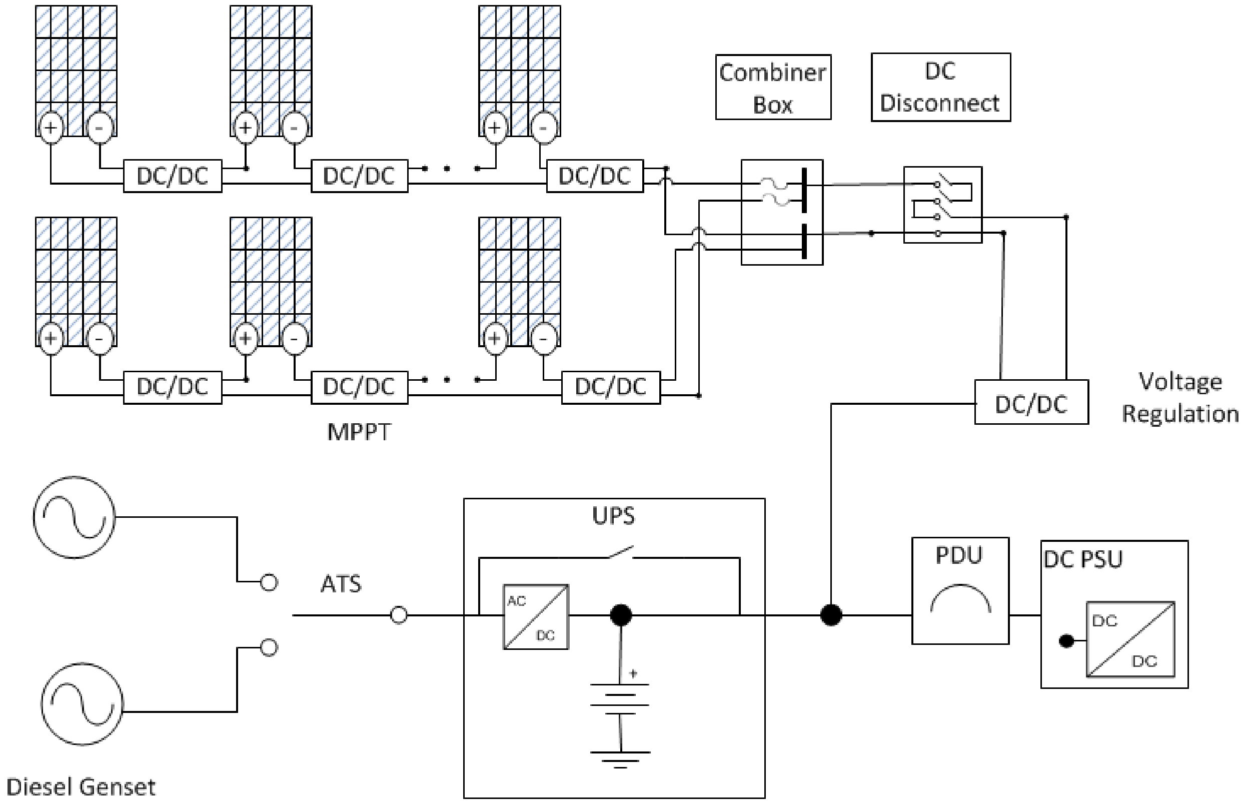
When the AC system is eliminated, the total facility impact is heightened



DC and Hybrid Systems Analysis

DC Data Center Design

This DC design concept will be realized through our partnership with PITT-OHIO



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The Electric Power Systems Lab

Prepared by: Ansel Barchowsky
M.S. Student

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DC Power Systems Research

The Electric Power Systems Laboratory

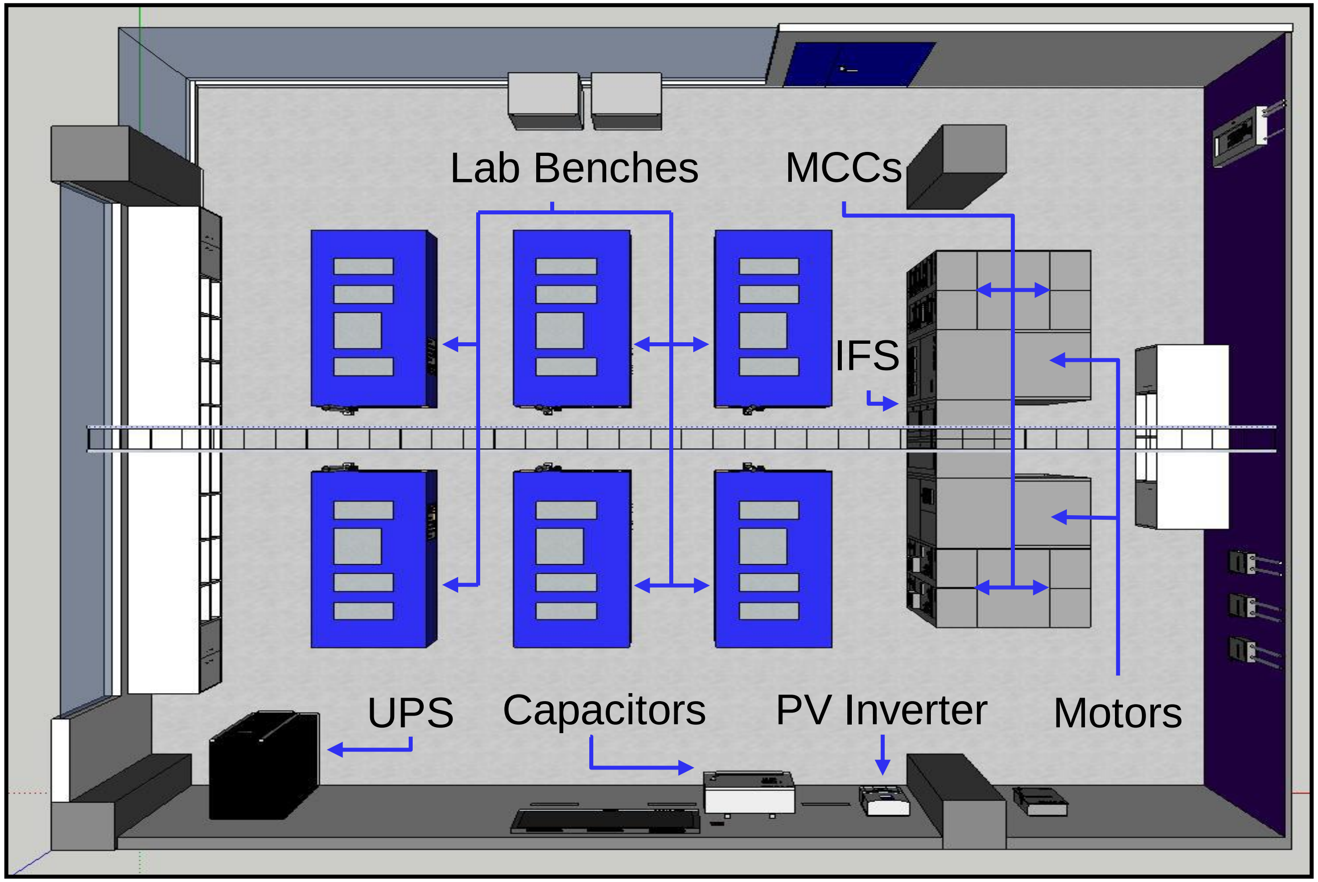
Objective: Create a world class facility for hands-on education and research

- **Train the next generation of power systems engineers**
- **Foster an environment for research at the highest level**

DC Power Systems Research

The Electric Power Systems Laboratory

Layout of the laboratory



- Mix of Generation: Grid, PV, Gas, Wind
- Variable system strength
- Integrated laboratory workbenches
- Motor Control Centers
- Advanced controls
- UPS and Datacenter
- Power factor correction
- 6 MHz metering

DC Power Systems Research

The Electric Power Systems Laboratory

Each bench was designed to incorporate controllable load banks and safety features

Contents:

- 4.5 kVA R, L, and C Loads
- 0.5 kVA Harmonic Load
- Touchscreen HMI PLC
- Motor Control Center
  - 15-HP ATL or RVSS control
  - 5-HP VFD control
- Auxiliary outlets (1 and 3 phase)
- Integrated Safety Features

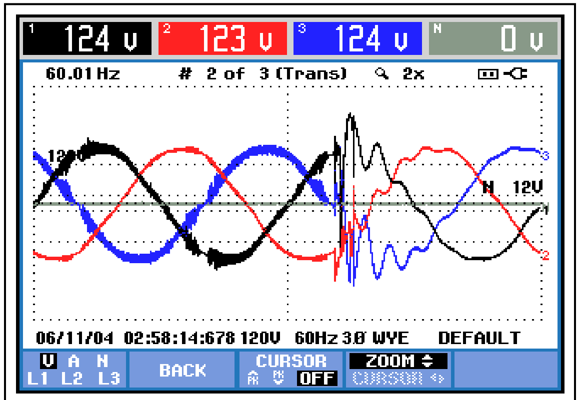
DC Power Systems Research

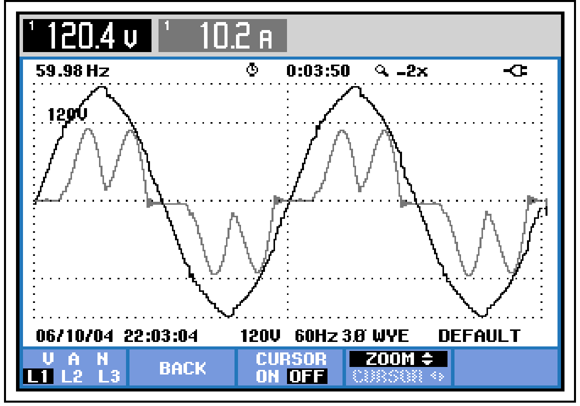
The Electric Power Systems Laboratory

The power systems laboratory can be used for a wide variety of applications:

Complex topics can be explored, including:

- **Distribution systems**
- **Power electronics**
- **Smart grids**
- **Energy storage**
- **Renewable energy**
- **Power quality**
- **Microgrids**





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Developing HVDC and FACTS Transmission Technologies

Patrick Lewis

Hashim Al Hassan

Alvaro Cardoza

8^{th} Annual Electric Power Industry Conference

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MITSUBISHI ELECTRIC
Changes for the Better

Modeling and Protection Design Supporting HVDC Technology Development

Patrick Lewis and Hashim Al Hassan

SIEMENS

Investigating FACTS Technologies in Weak AC Grid Environments

Alvaro Cardoza

University of Pittsburgh

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Prepared by: Patrick Lewis
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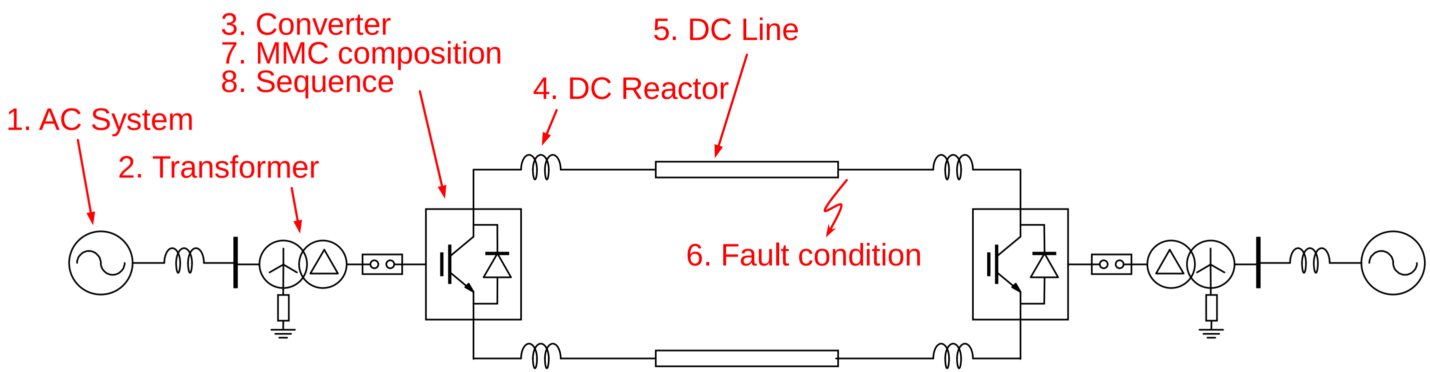
HVDC and FACTS Transmission Technologies

Modular Multilevel HVDC Model Development

Role of the University of Pittsburgh within HVDC technology development project with Mitsubishi Electric Corporation

1. HVDC System Modeling
2. DC Fault Analysis
3. DC Protection System Design
4. DC Protective Relaying Schemes

System Ratings	
Rated AC RMS Voltage	500 kV
Rated DC Voltage	± 500 kV
Rated Power of Converter	1000 MW

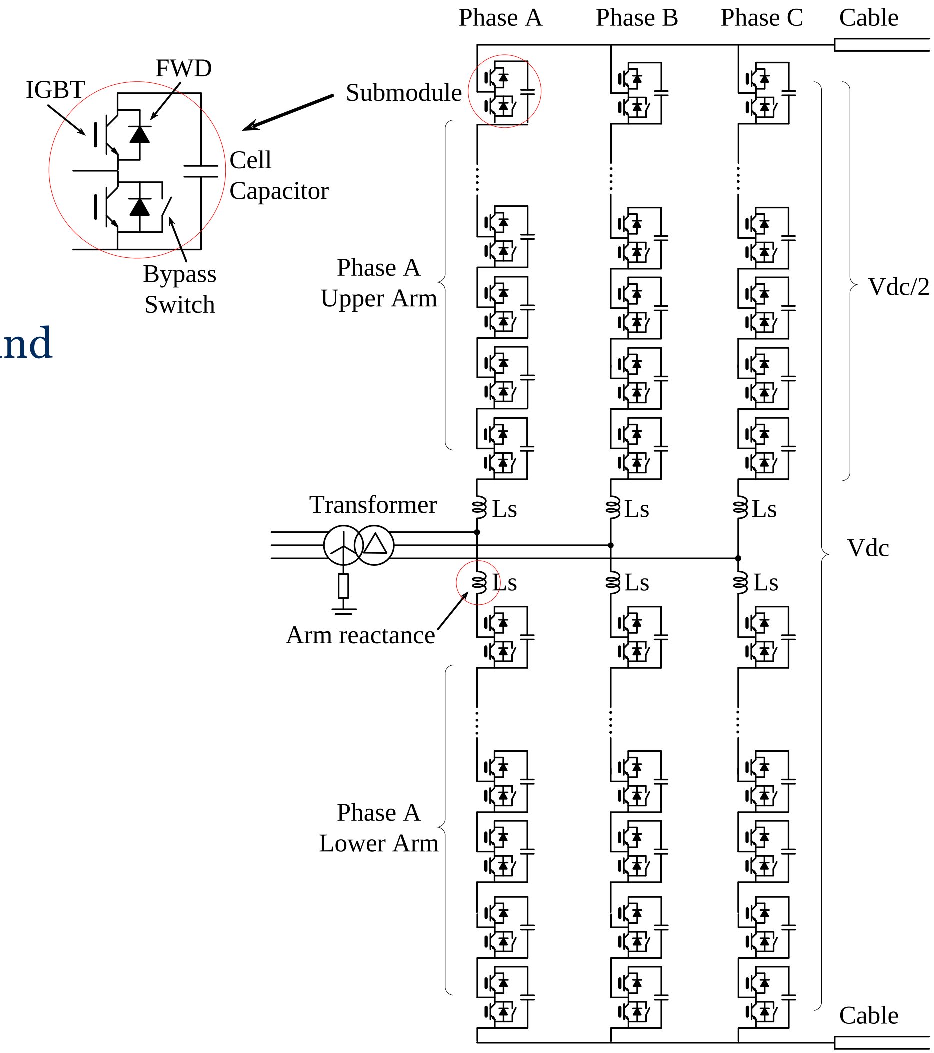


HVDC and FACTS Transmission Technologies

Modular Multilevel HVDC Model Development

MMC Topology Design

- Advantages over traditional multilevel designs:
  - Stronger approximation of a sinusoidal output
  - High modularity in hardware and software
  - Low generation of harmonics
  - Lower switching frequency of semiconductor devices
  - Easily scalable with increasing submodules

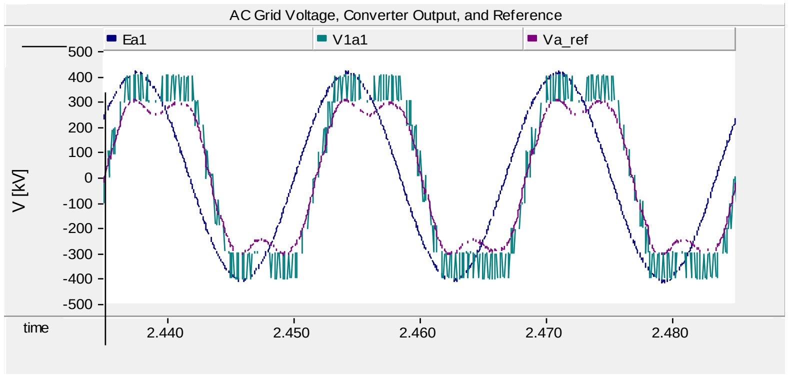


HVDC and FACTS Transmission Technologies

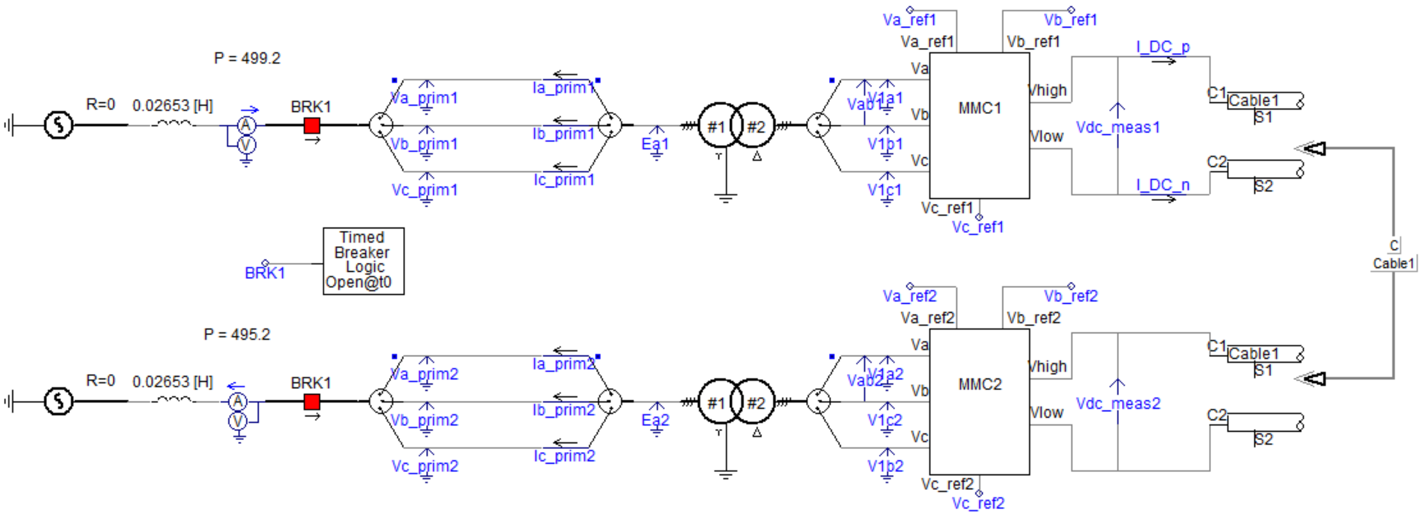
Modular Multilevel HVDC Model Development

Model Implementation in PSCAD

- Goal: Demonstrate expected system functionality of the PSCAD model during both steady state operation and system events



AC Grid Voltage, Converter Output and Reference

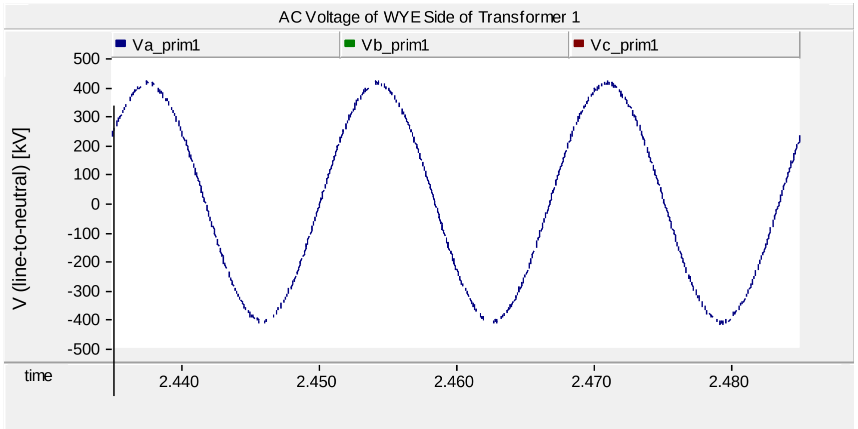


HVDC and FACTS Transmission Technologies

Modular Multilevel HVDC Model Development

Model Approximations and Considerations

- Simulation run time is of concern when modeling power electronic switching events making model approximations a necessity.
- System Model Simplified to 10 Cells Per Arm for Approximate Modeling
  - IEEE 519-1992, a standard focused on harmonic limits and maximum THD levels, was used to determine the number of submodules to model.
  - Standard Requirement: Maximum of 1.5% THD on the wye-side of transformer (AC grid side)



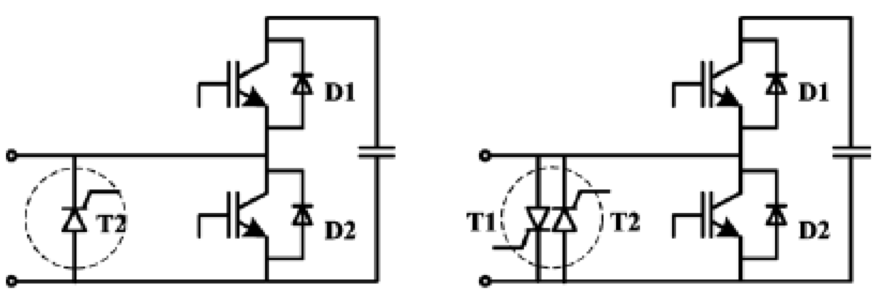
0.8% THD Level on Wye-Side (AC Side) of Transformer

HVDC and FACTS Transmission Technologies

Modular Multilevel HVDC Model Development

Future Work

- Task 2: DC Fault Analysis
  - Running DC fault case scenarios for the purpose of identifying worst case events to protect against
- Task 3: DC Protection System Design
  - Problem: HVDC-MMC is vulnerable to DC faults
  - Objective: Design a protection scheme that includes protection coordination and a strategy to address fault currents that cause stress on the converter devices



Single and Double Thyristor Design for Submodule Protection

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Developing HVDC and FACTS Transmission Technologies

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HVDC and FACTS Transmission Technologies

Section Identification & Location Identification of HVDC Faults

HVDC Protection Research

- Looking into methods of locating faults on hybrid DC systems including submarine cables and OH lines.
- **Application System**
  - Offshore wind using HVDC VSC MMC
- **Current fault location identification technology**
  - Fault locators
- **Limitations of fault locators**
  - Potential Damage
  - Unreliability on hybrid systems
  - Cannot find location of temporary faults

HVDC and FACTS Transmission Technologies

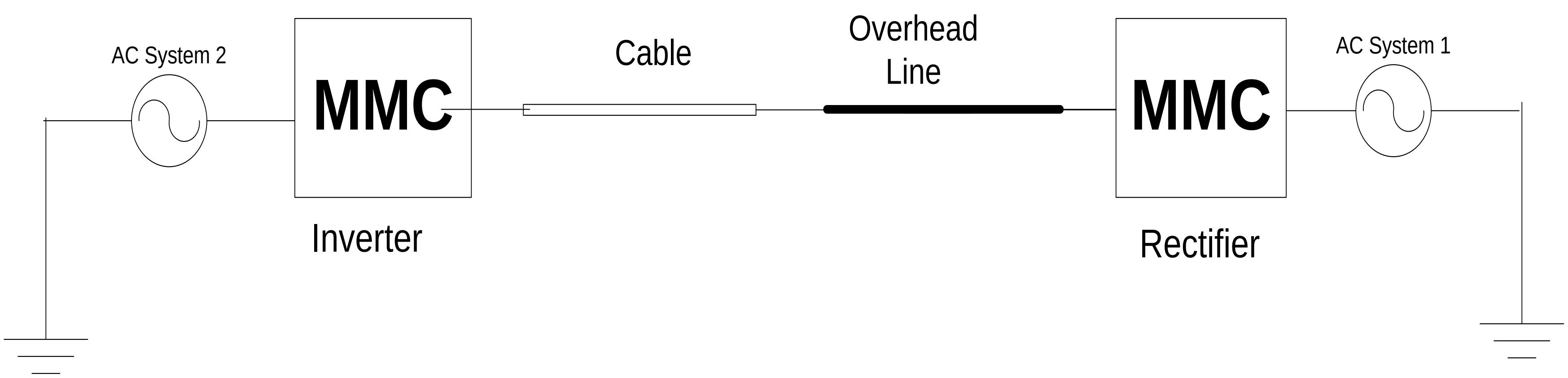
Section Identification & Location Identification of HVDC Faults

Protection Coordination:

1. Fault section identification: instantly identify if the fault is on the cable or on the OH line

Locating Faults without Fault Locator Technology:

2. Fault location identification: use transient data recorded at the converter station terminal to identify exact location on hybrid system



HVDC and FACTS Transmission Technologies

Section Identification & Location Identification of HVDC Faults

Motivation of Research

1. Fault Location Identification:
   - Reduce maintenance time and cost.
   - Prevent damage that may be caused by fault locators.
   - Identify weak points in the system.(preventative maintenance)

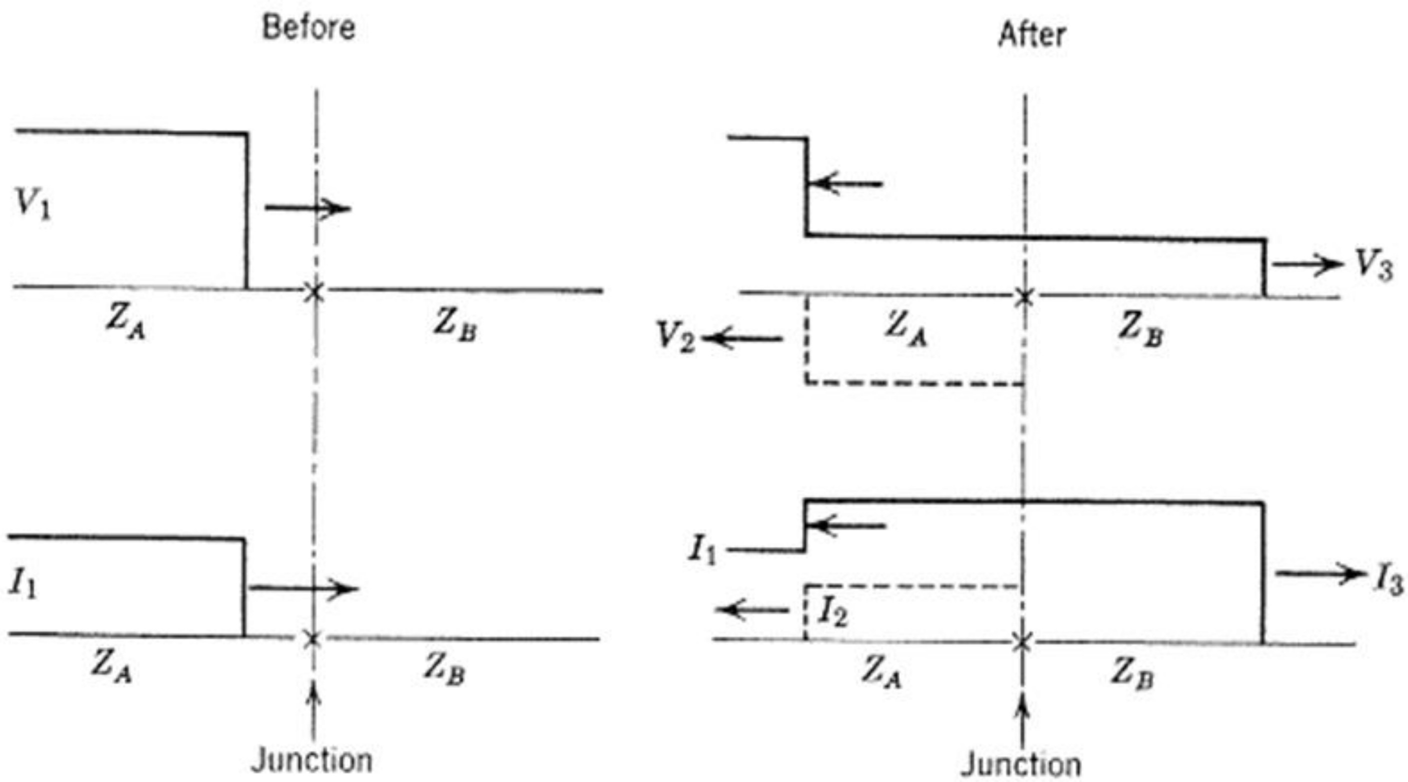
2. Fault Section Identification:
   - Increase Reliability by:
     - Operating reclosers for OH line faults.
     - Shutting down the system for cable faults.

HVDC and FACTS Transmission Technologies

Section Identification & Location Identification of HVDC Faults

Travelling Wave Theory: The method applied to research topic

- The wave is reflected and refracted at a junction



Source: Allan Greenwood, Electrical Transients in Power Systems, Second edition, John Wiley & Sons, Inc. 1991

HVDC and FACTS Transmission Technologies

Section Identification & Location Identification of HVDC Faults

Using Travelling Wave Theory

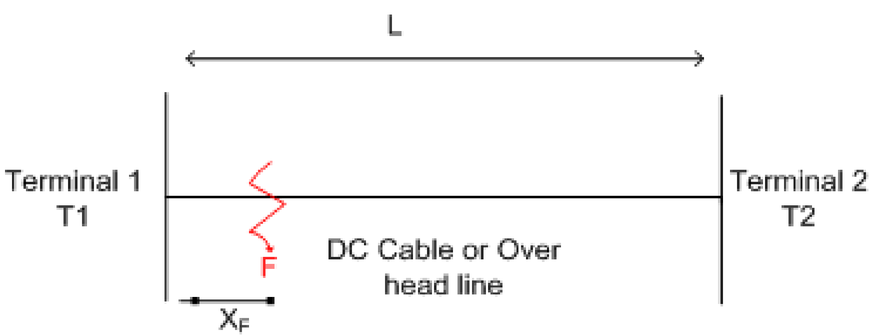
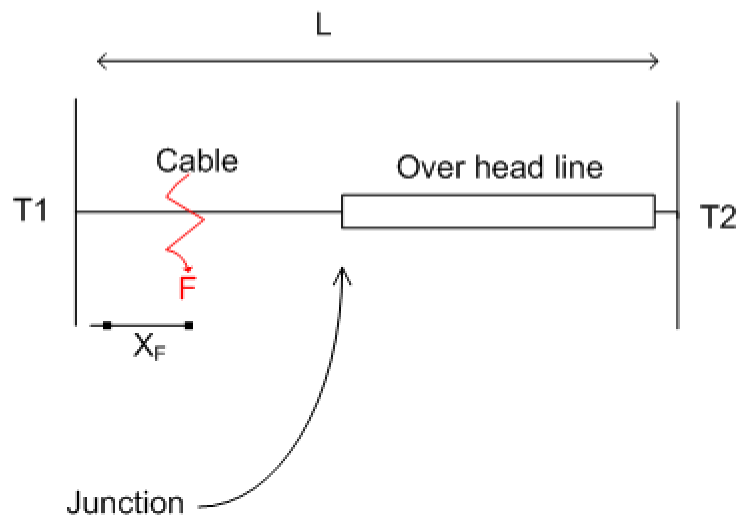


Fig.1

$$x_F = \frac{[L - (\Delta t) \times v]}{2}$$



- Find a Surge Detection Method.
- Deal with complexity of the hybrid case
- Deal with uncertainty in wave velocity

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Developing HVDC and FACTS Transmission Technologies

Prepared by: Alvaro Cardoza
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HVDC and FACTS Transmission Technologies

Investigating FACTS in Weak AC Grid Environments

Project Description

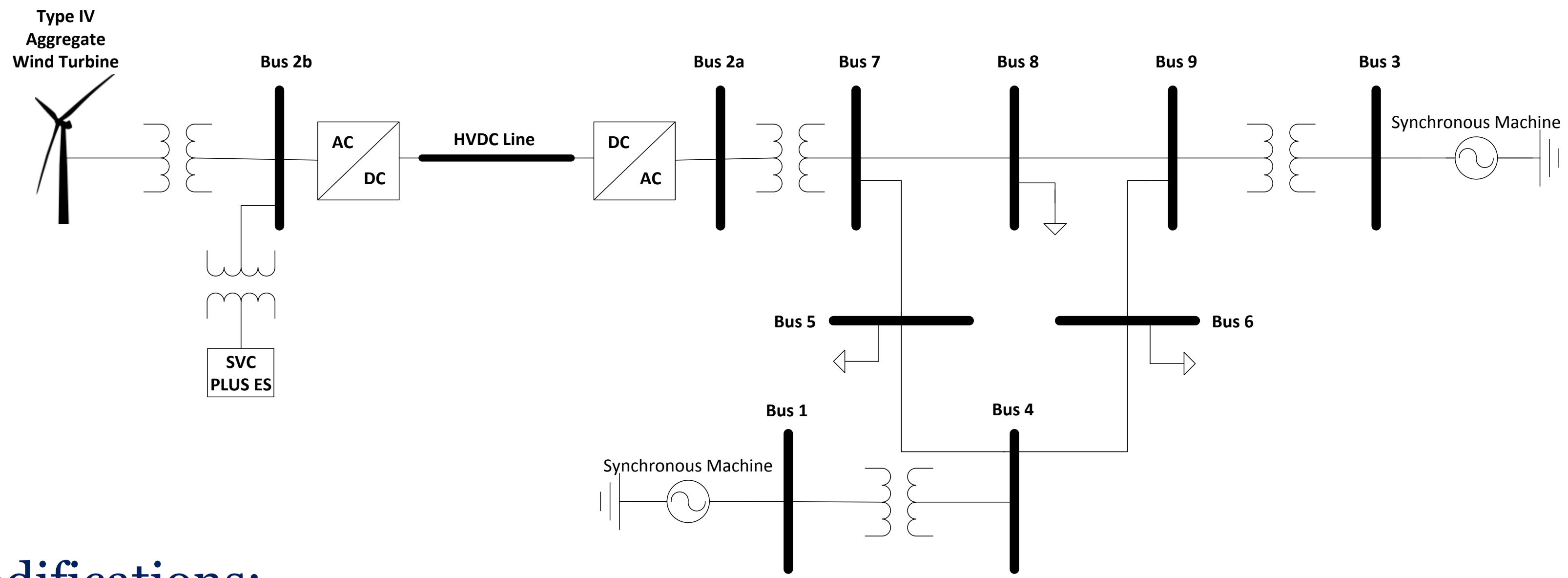
- Exploration of Siemens' new SVC PLUS ES
- Used to help alleviate a system's weak grid conditions
  - Weak grids occur when a system's impedance is too high which does not allow for adequate current to flow
- PSS®E Simulation Software
  - Main simulation tool for analysis
  - Donated to the university by Siemens

SIEMENS

HVDC and FACTS Transmission Technologies

Investigating FACTS in Weak AC Grid Environments

Modified WECC 9-Bus Model



<u>Modifications:</u>

- HVDC Interconnecting Line
- Type IV Aggregate Wind Turbine
- SVC PLUS ES

HVDC and FACTS Transmission Technologies

Investigating FACTS in Weak AC Grid Environments

SVC PLUS ES Technology

- SVC PLUS ES uses a full-bridge topology
- Energy storage is incorporated at every level
  - Ultra capacitors
  - Lithium ion batteries
- Tackles the issue of system inertia

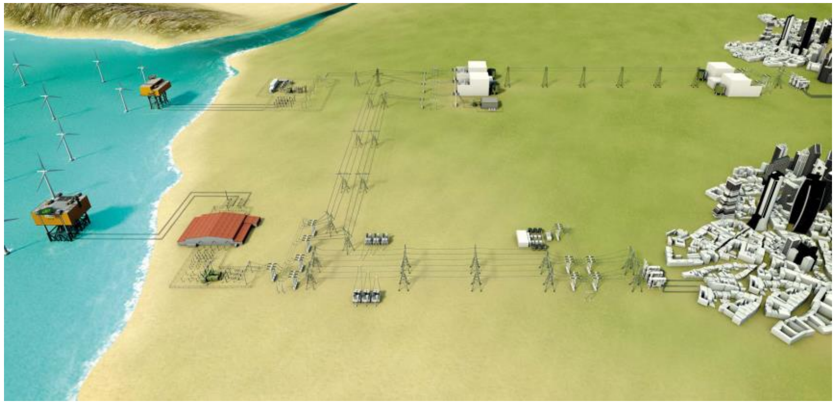
Modularized Ultra Capacitor Example

HVDC and FACTS Transmission Technologies

Investigating FACTS in Weak AC Grid Environments

Main Project Objectives

- How well does the SVC PLUS ES perform close to HVDC and/or weak grid conditions?
- How does the SVC PLUS ES design compare to alternative solutions?
- Identify applicable test cases within the United States for SVC PLUS ES technology.



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Merits of High Frequency in Next Generation Power Electronics and Electric Machinery

Raghav Khanna

Qinhao Zhang

Oreste Scioscia

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Ben Franklin Technology PArtners

Wide Bandgap Semiconductors and Maximum Power Point Tracking

Raghav Khanna and Qinhao Zhang

arpa·e
Advanced Research Projects Agency • ENERGY

Novel Magnetic Materials Utilized in Transformers and Electric Machinery

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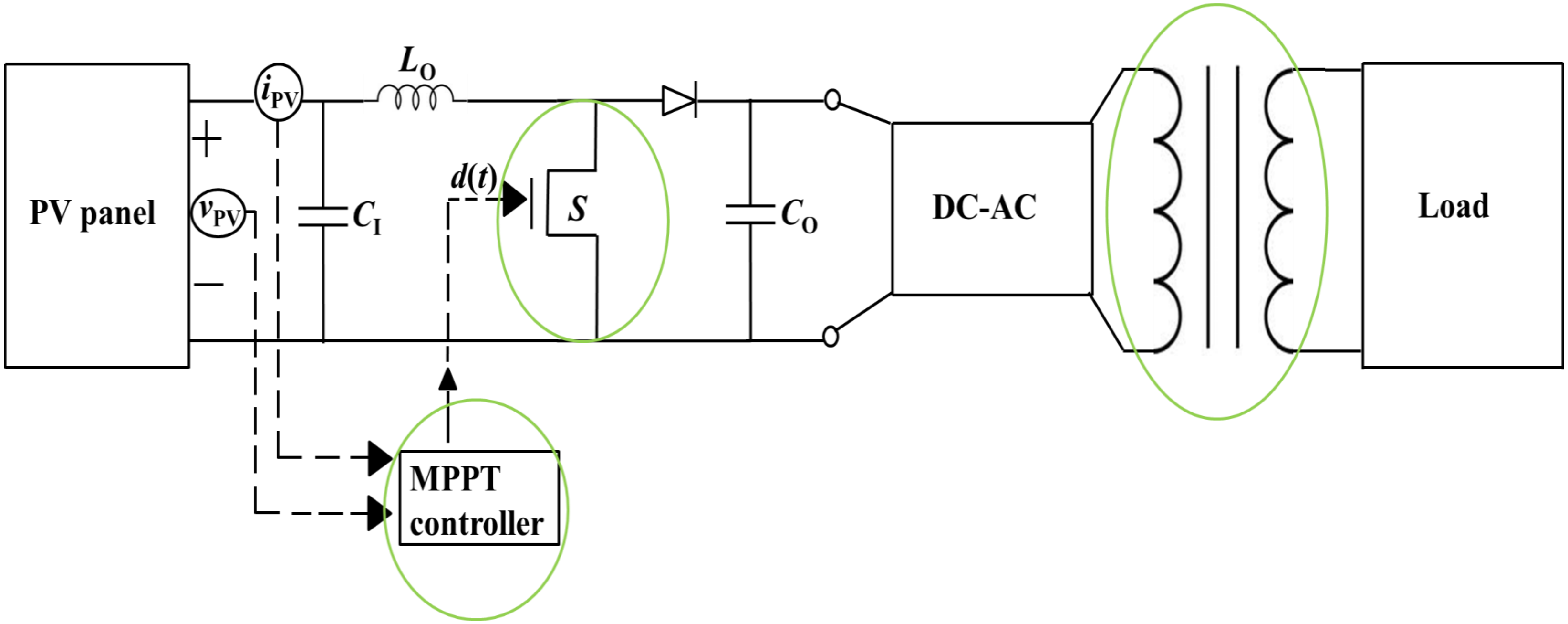
Merits of High Switching Frequency

Enhancements in Semiconductor Technology

- **High frequency operation in power converters will reduce the size and cost of renewable energy integrations.**
  - **Transistor / MPPT Controller / Transformer**



Merits of High Switching Frequency

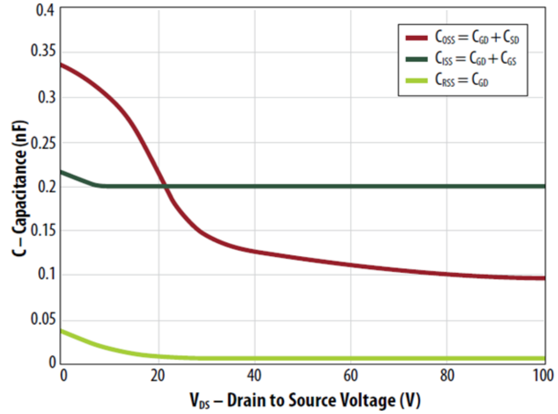
Enhancements in Semiconductor Technology

- **Desired objectives for using GaN or SiC (WBGs) to replace Si:**
  - Reduce the size and potentially cost of power converter
    - Higher operating switching frequency capability
    - Faster turn-on and turn-off enables high switching frequency capability
  - Increase operating efficiency
    - Lower on-resistance
    - Lower switching losses
  - Eliminate mechanical support systems
    - High temperature operation
    - Ideal for renewable energy integrations.

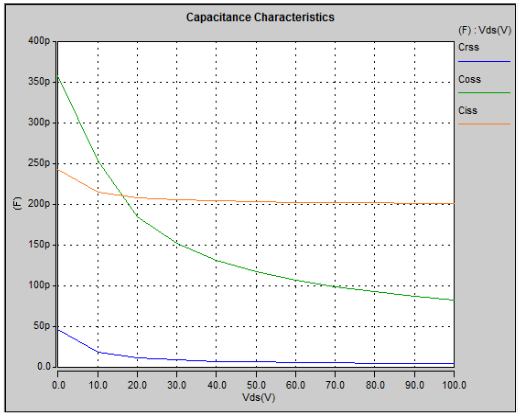
Merits of High Switching Frequency
Enhancements in Semiconductor Technology

- **Lower parasitic capacitances for wide bandgap semiconductors enable faster switching.**

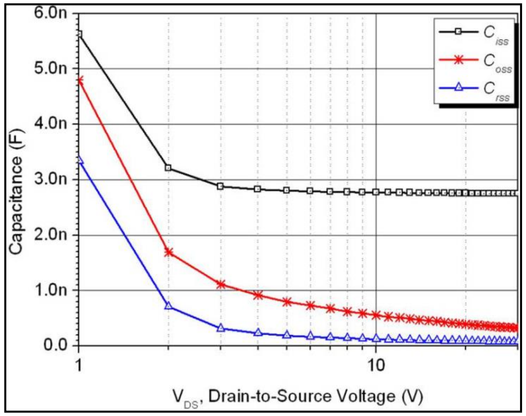
Reported GaN FET



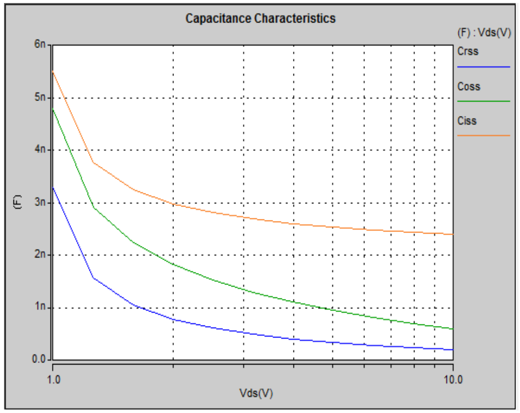
Development of GaN Device Model



Reported Si FET



Development of Si Device Model

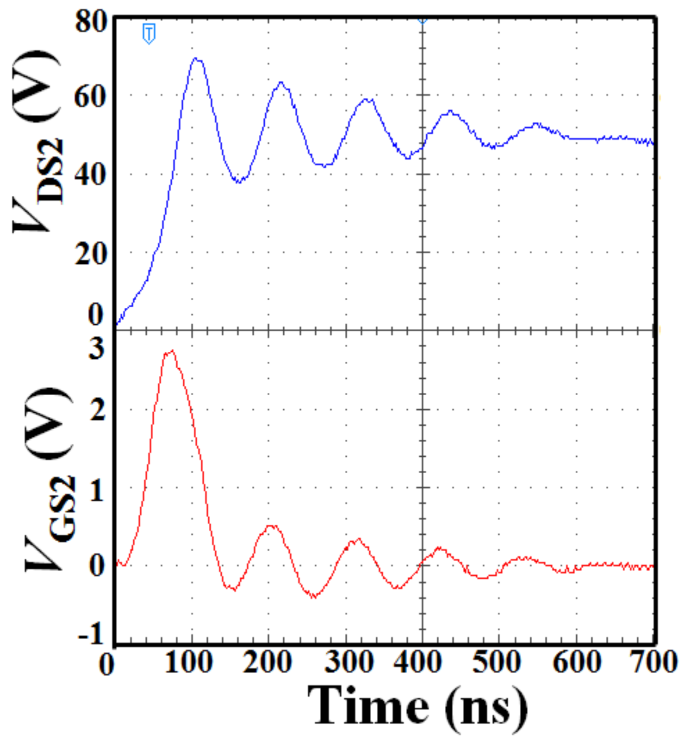


Merits of High Switching Frequency

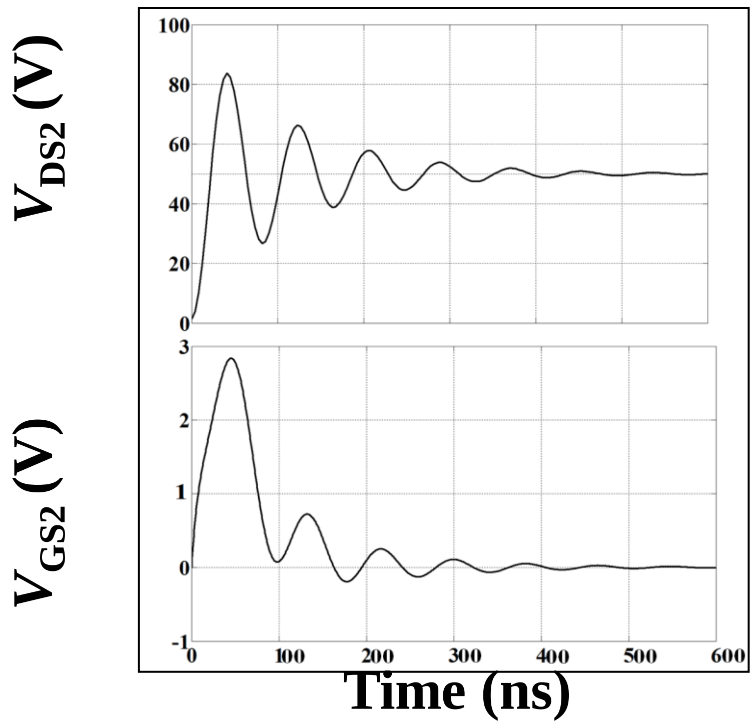
Enhancements in Semiconductor Technology

- **Faster switching however can also lead to certain detrimental “dv/dt” effects.**

Experimental



Modeled



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8TH ANNUAL PITT ELECTRIC POWER INDUSTRY CONFERENCE

Presented by the Swanson School of Engineering & the Center for Energy

Merits of High Frequency in Next Generation Power Electronics and Electric Machinery

Prepared by: Qinhao Zhang

Ph.D. Student

8th Annual Electric Power Industry Conference

Swanson School of Engineering

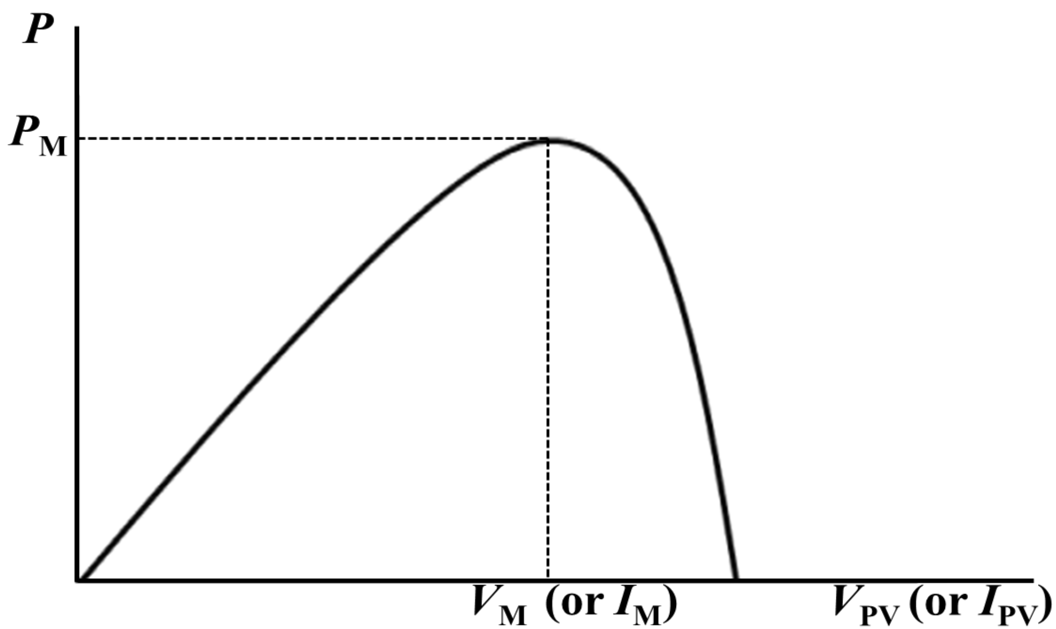
Graduate Student Symposium

November 11th, 2013

Merits of High Switching Frequency

Adaptive Control Design for Photovoltaic Systems

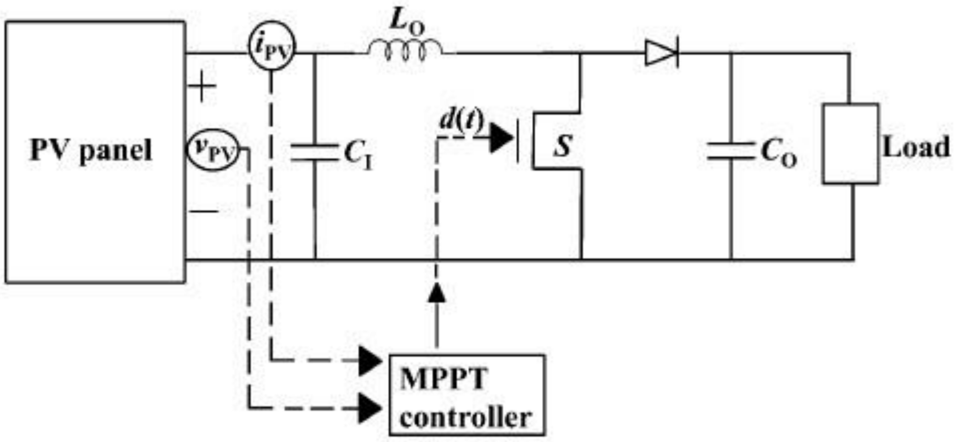
- **One application of utilizing high frequency is in maximum power point tracking.**
  - Utilizes the I-V and P-V profiles to track the maximum power point.



Merits of High Switching Frequency

Adaptive Control Design for Photovoltaic Systems

Topology of the circuit design: MPPT generates duty cycle

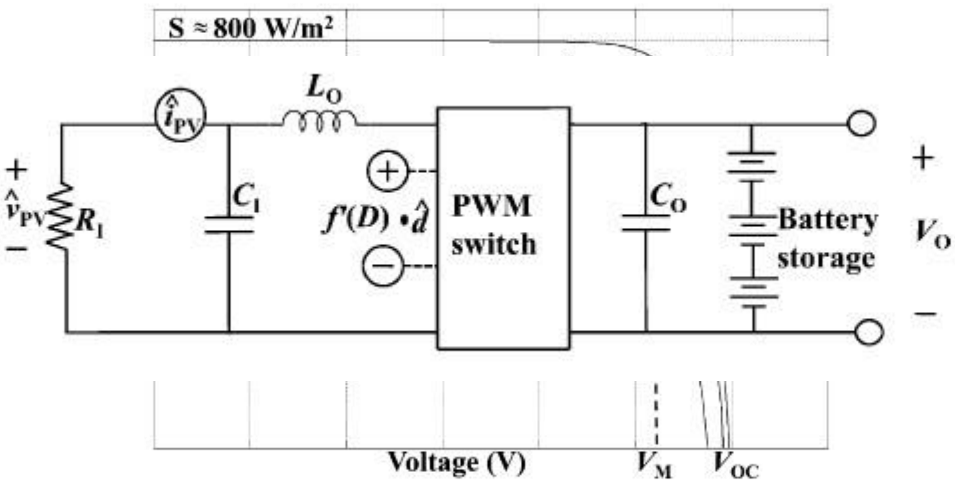


Circuit Design

Merits of High Switching Frequency

Adaptive Control Design for Photovoltaic Systems

- **Constantly changing operating point leads to an under-damped system in equivalent small signal circuit.**



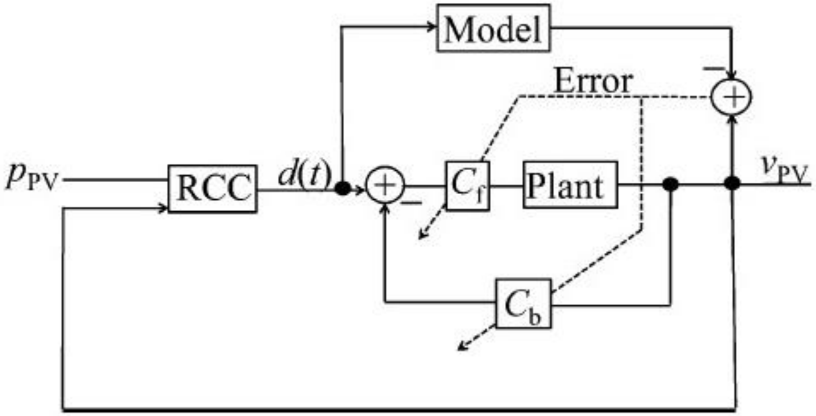
$$\frac{\hat{v}_{PV}(s)}{\hat{d}(s)} = \frac{-\frac{V_O}{L_O C_I}}{s^2 + \frac{1}{R_I C_I}s + \frac{1}{L_O C_I}}$$

$$\zeta = \frac{1}{2R_1}\sqrt{\frac{L_o}{C_I}}$$

Merits of High Switching Frequency

Adaptive Control Design for Photovoltaic Systems

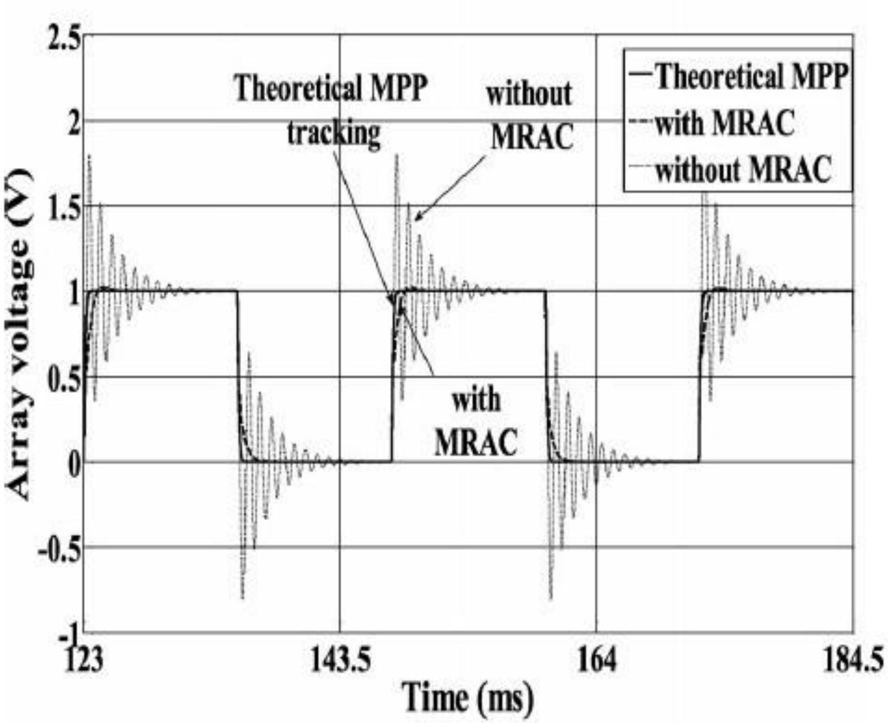
- **Our proposed adaptive control algorithm will enable the system to converge to the MPP at high switching frequencies.**

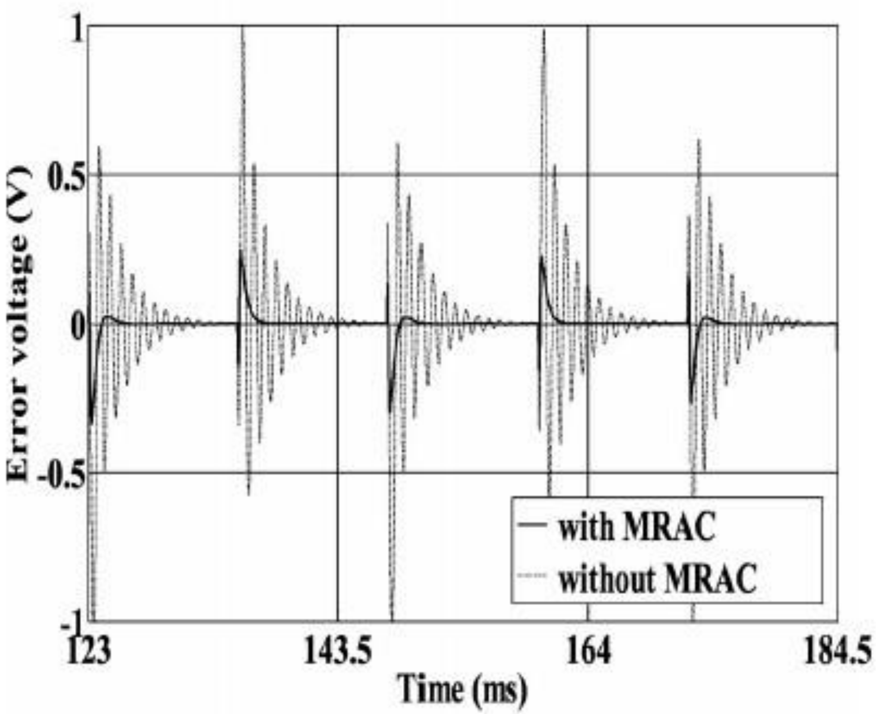


Adaptive Control Representation

Merits of High Switching Frequency
Adaptive Control Design for Photovoltaic Systems

- **Improved MPPT exhibits critically damped characteristic and smaller error**





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Merits of High Frequency in Next Generation Power Electronics and Electric Machinery

Prepared by: Rusty Scioscia
M.S. Student

8th Annual Electric Power Industry Conference
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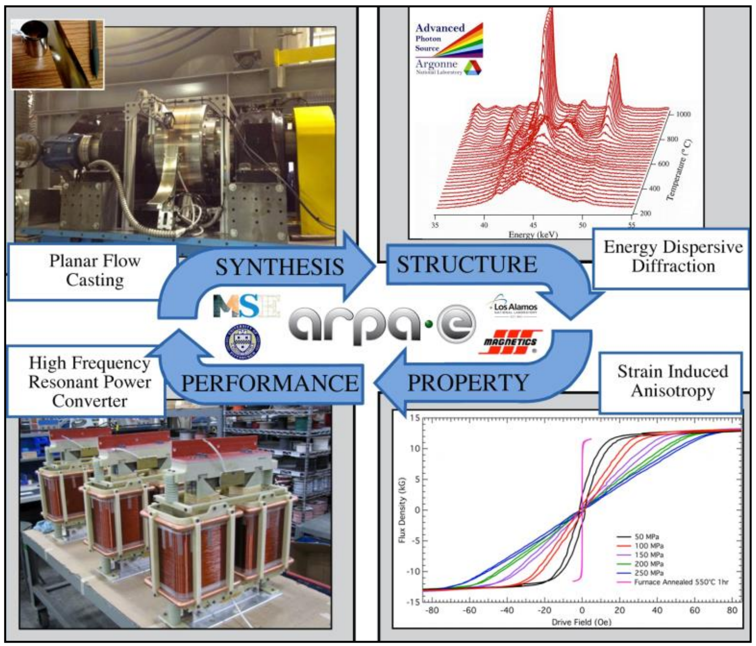
November 11th, 2013

Merits of High Switching Frequency

Novel Magnetic Materials Utilized in Machine Design

- **Novel nanocrystalline material developed that has been proven to reduce magnetic cores of transformers by 60%.**



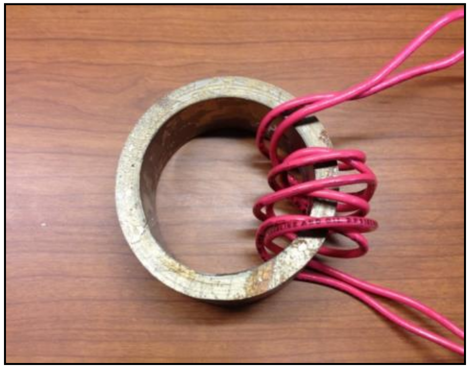
Partners

Size Reduction Observed

Merits of High Switching Frequency

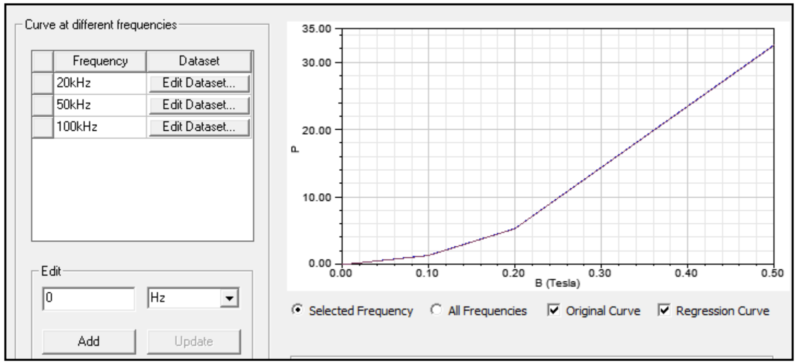
Novel Magnetic Materials Utilized in Machine Design

- **ANSYS Maxwell utilized to predict Steinmetz coefficients of magnetic materials.**

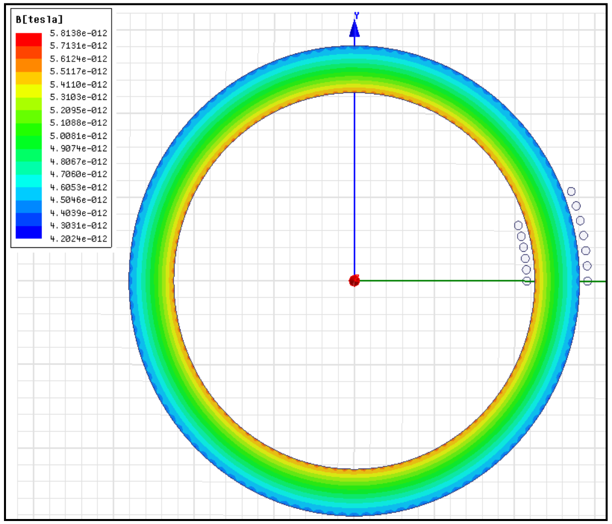


Modeled Core

ANSYS



Core Loss vs. Frequency Characteristics



Simulated Core

Merits of High Switching Frequency

Novel Magnetic Materials Utilized in Machine Design

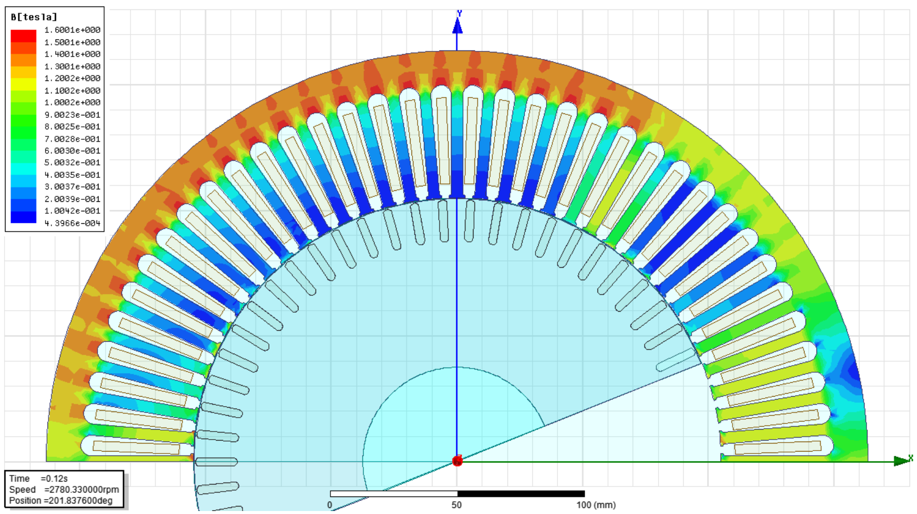
- **Modeling to Predict Steinmetz Coefficients:**
  - Below 5% error for experimental and simulated results

			Experimental Steinmetz Coefficients		Simulated Steinmetz Coefficients			
Core #	Dimensions	Remarks	α	β	α	β	α error	β error
1	1.25"x1.0"x1.0"	Impregnated	1.5467	2.0281	1.56	1.96	1%	3%
2	1.25"x1.0"x1.0"	Impregnated, cut	1.6945	1.8964	1.617	1.956	5%	3%
3	2.81"x2.25"x1.0"	Impregnated	1.4548	1.9877	1.494	1.992	3%	0%
4	2.81"x2.25"x1.0"	Impregnated, cut	1.5314	1.9004	1.563	1.968	2%	3%
5	6.25"x5.0"x1.0"	Impregnated	1.5967	1.9689	1.579	1.987	1%	1%
6	6.25"x5.0"x1.0"	Impregnated, cut	1.6059	1.9630	1.578	1.987	2%	1%

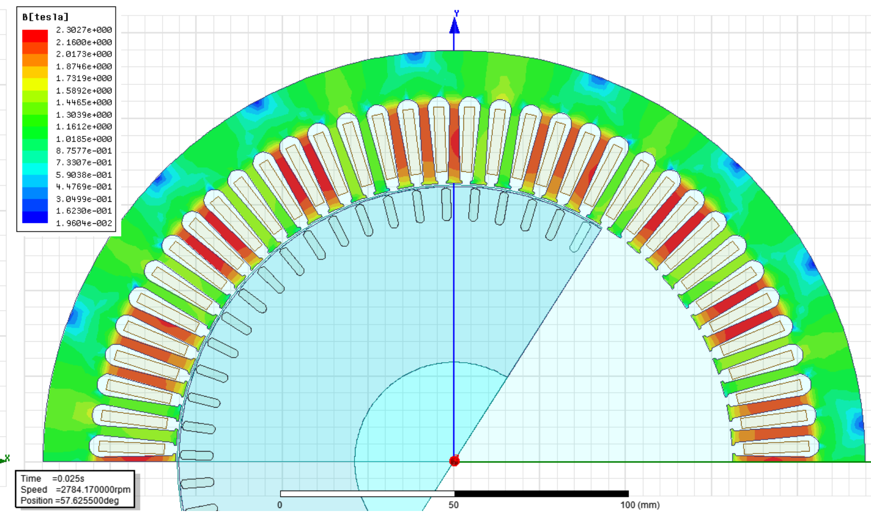
Merits of High Switching Frequency

Novel Magnetic Materials Utilized in Machine Design

- **Varying the driving frequency and the number of pole pairs while keeping the mechanical speed constant results in a 55 to 70% size reduction on motor geometry.**



Field Strength for a 2 Pole Motor Design



Field Strength for a 16 Pole Optimized Motor Design

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8TH ANNUAL PITT ELECTRIC POWER INDUSTRY CONFERENCE

Presented by the Swanson School of Engineering & the Center for Energy

Methods and Approaches for Integrating Renewable Energy to an Evolving Grid

Matthew Korytowski

Laura Wieserman

Stephen Abate and Andrew Reiman

8^{th} Annual Electric Power Industry Conference

Swanson School of Engineering

Graduate Student Symposium

November 11^{th}, 2013

Integration of Offshore Wind Power to the U.S. Grid

Matthew Korytowski

PV Inverter Grounding

Laura Wieserman

Distribution Modeling for Feeder Analytics and Distributed Energy Resource (DER) Integration

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University of Pittsburgh

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Integration of Offshore Wind Power to the U.S. Grid

Prepared by: Matthew Korytowski
Ph.D. Student

8th Annual Electric Power Industry Conference
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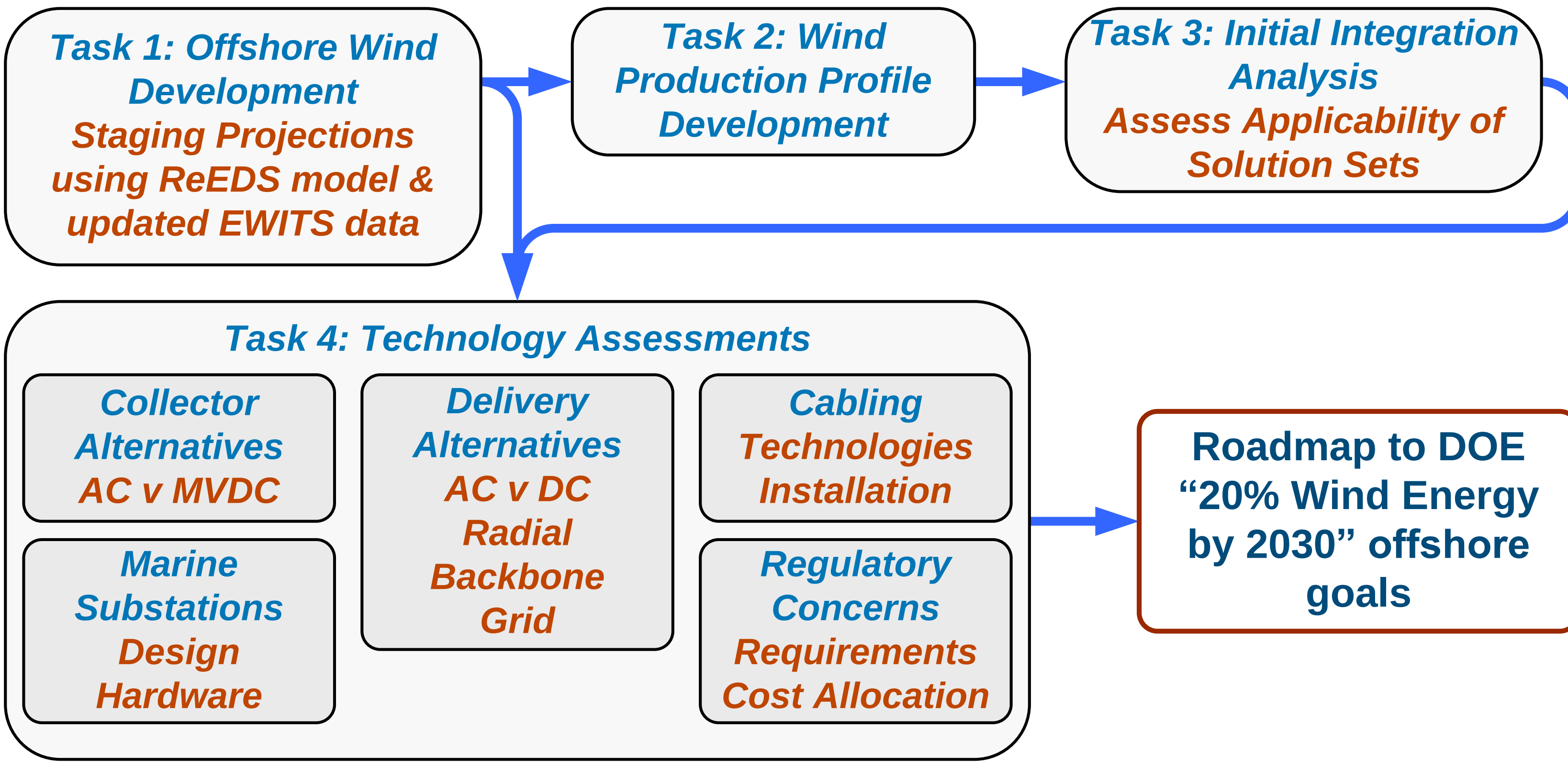
Methods and Approaches for Integration

Integration of Offshore Wind Power

Develop the technical and economic viability data necessary to produce a roadmap to the "20% Wind Energy by 2030" offshore goals



Methods and Approaches for Integration

Integration of Offshore Wind Power

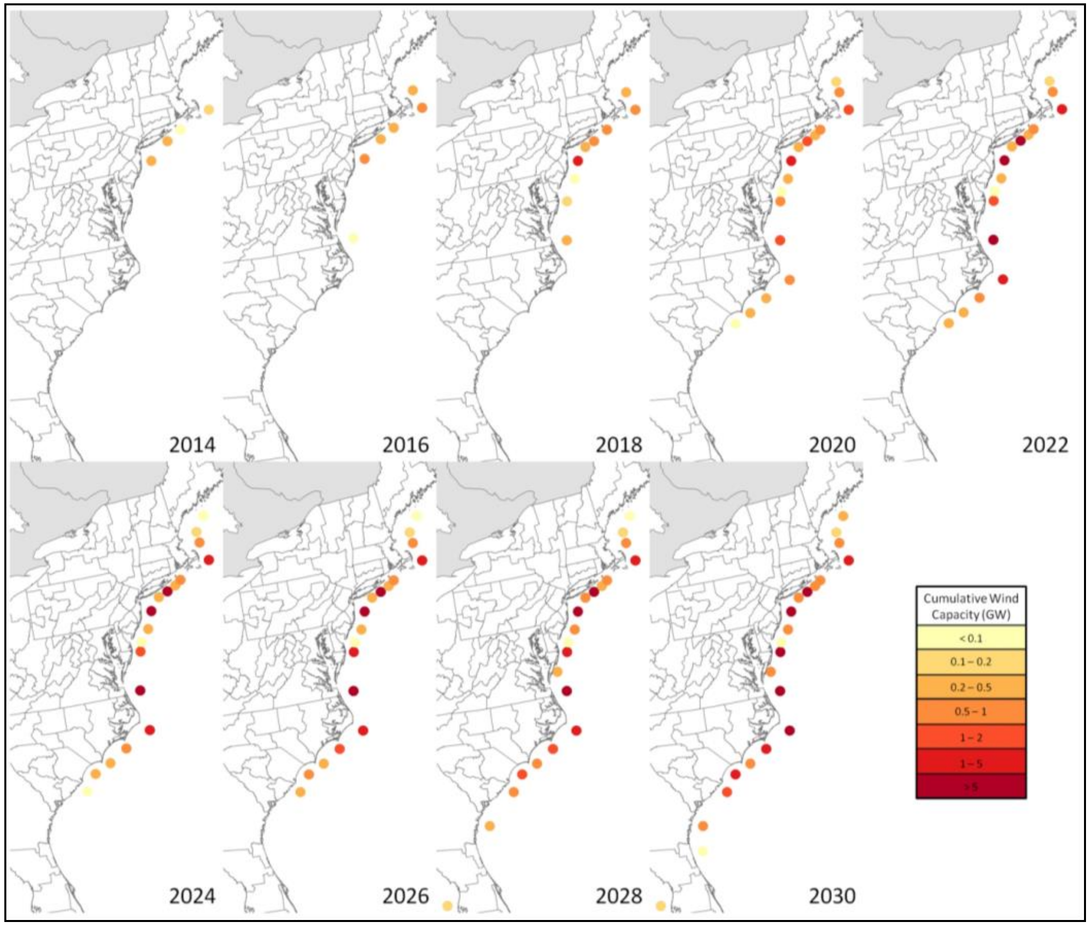
There are six other companies involved to achieve the desired goals

- **ABB Power Systems Consulting**
  - Power systems studies, market analysis, power equipment
  - Project lead and technology assessments
- **University of Pittsburgh**
  - Electric Power Initiative, Department of Electrical Engineering
  - Technology assessments and cost trends
- **Xero Energy Limited**
  - Grid connection engineering consultant for renewable energy projects
  - Technology assessments and cost trends
- **AWS Truepower**
  - Renewable energy consulting and wind farm siting
  - Wind resources, power production profiles
- **National Renewable Energy Laboratory (NREL)**
  - Laboratory for renewables research and development
  - Wind development staging, study method assessment
- **Duke Energy**
  - Generation and transmission owner
  - Regulatory issues assessment

Methods and Approaches for Integration

Integration of Offshore Wind Power

Task 1: Determine the expected offshore wind development staging

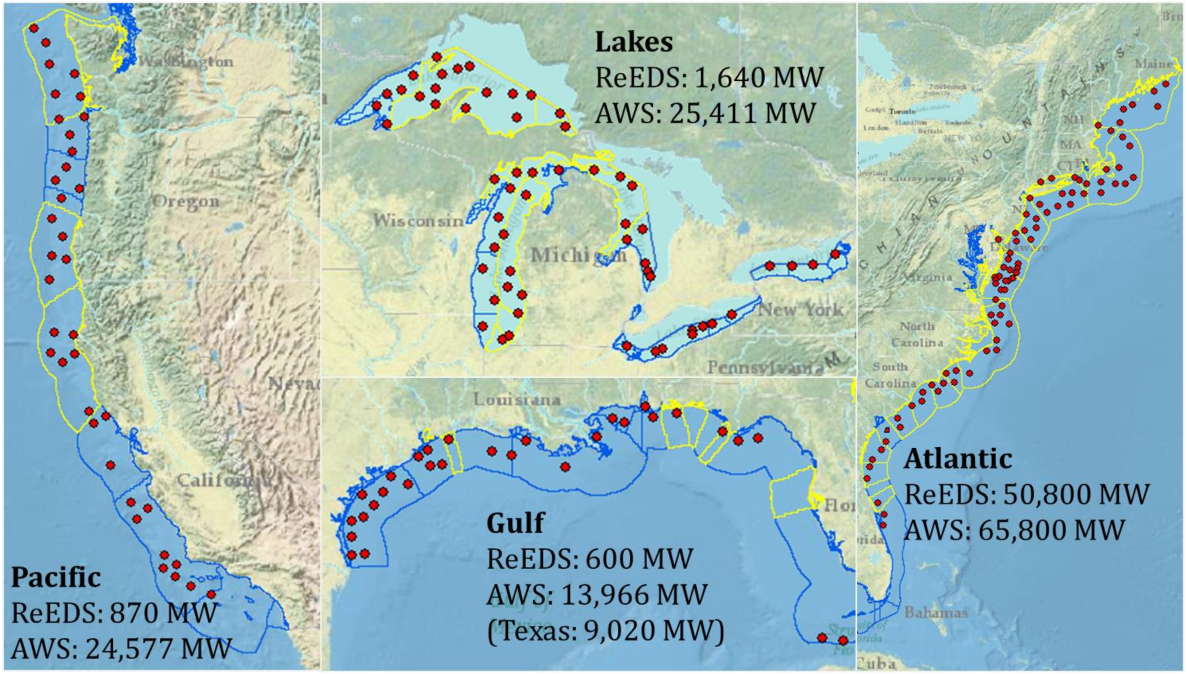


ReEDS 2030 Build-out progression

Methods and Approaches for Integration

Integration of Offshore Wind Power

Task 2: Determine the wind generation production profiles



- Develop synthetic power output profiles for theoretical offshore wind plants
- 209 Sites Totaling 134+ GW
- Site Totals By Region: All ReEDS Targets Met or Exceeded

Methods and Approaches for Integration

Integration of Offshore Wind Power

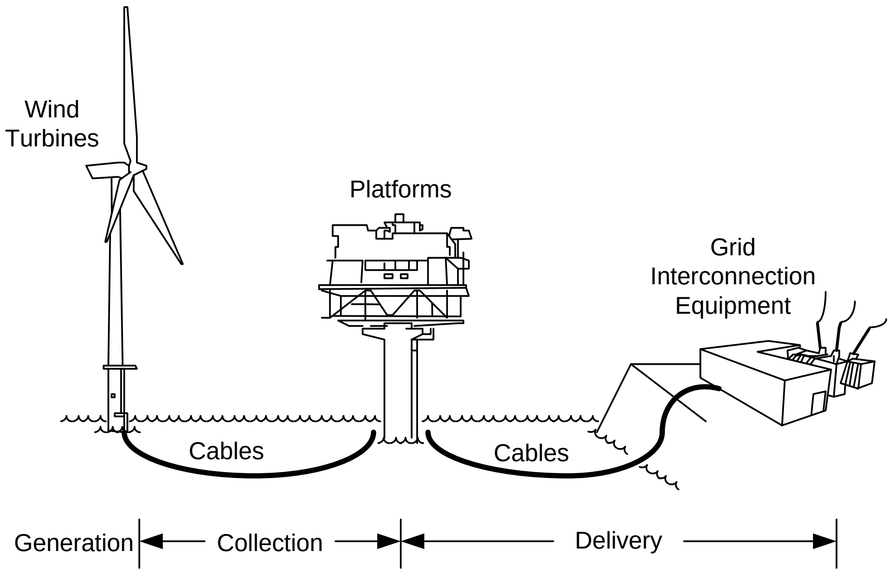
Task 3: Assess the applicability of onshore wind integration study methods to offshore wind studies

Methods to be assessed:	Potential improvements:
Eastern Wind Integration and Transmission Study (EWITS)	Improved offshore wind data sets
Western Wind and Solar Integration Study (WWSIS)	Improved utility system production modeling
Energy Imbalance Market (EIM) analysis	Larger balancing regions provided by offshore grid

Methods and Approaches for Integration

Integration of Offshore Wind Power

Task 4: Assessment of present-day cost trends and technologies



1. What options are currently available?
2. What new options are possible (but not implemented) with current technology?
3. What options could be made available with foreseeable technological advancements (and what advancements are needed)?
4. What are the benefits and drawbacks of each possible technology option?
5. What are the economics of each option?

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Photovoltaic Inverter Grounding

Prepared by: Laura Wieserman
M.S. Student

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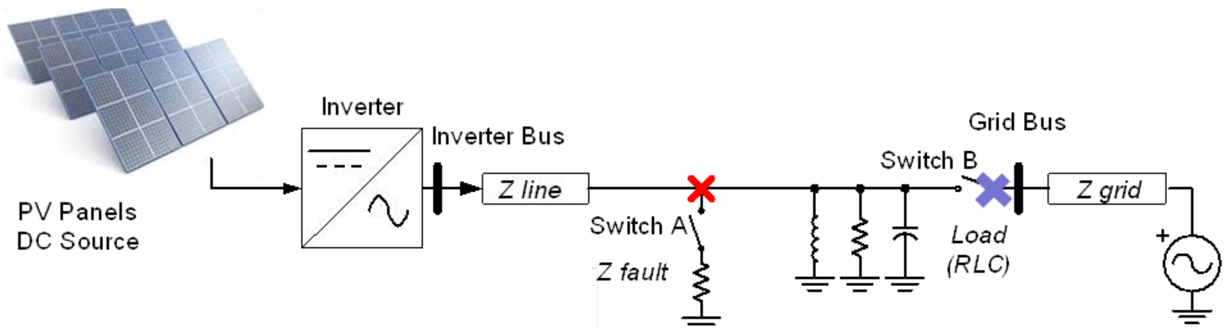
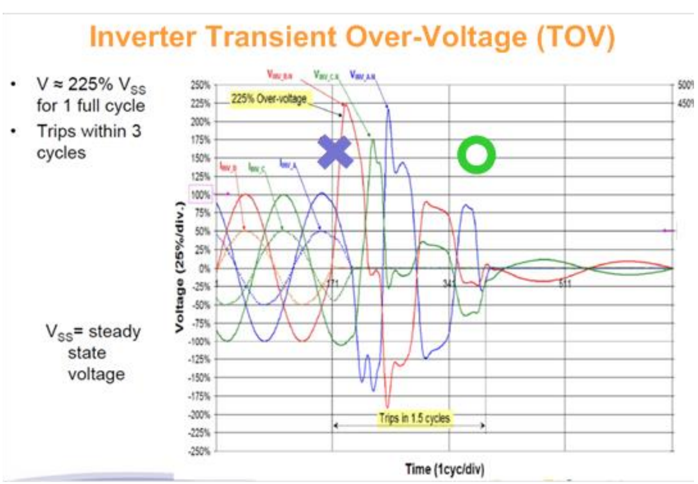
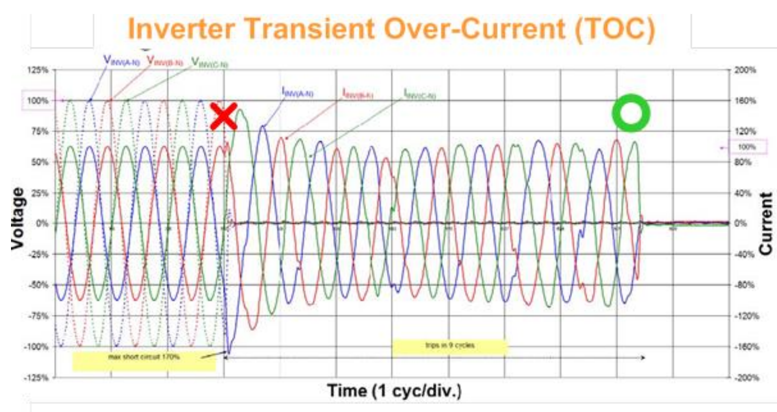
Methods and Approaches for Integration

PV Inverter Grounding

Inverter Testing







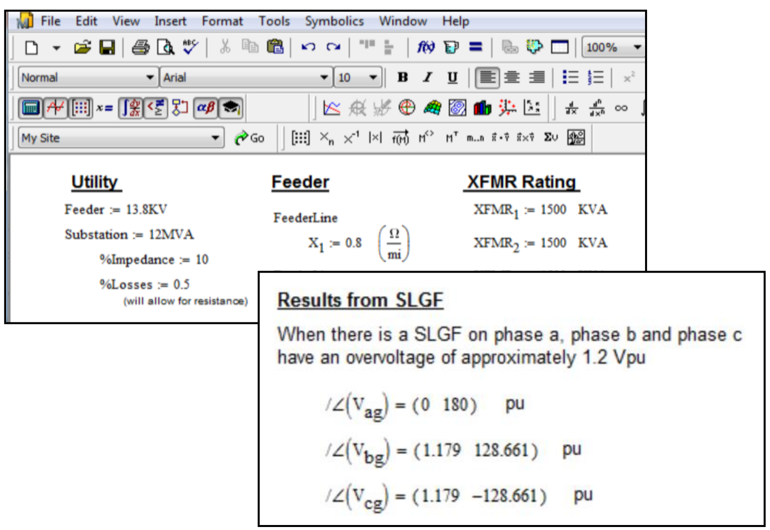
R. Bravo, R. Yinger, S. Robles, W. Tamae, “Solar PV Inverter Testing for Model Validation”, IEEE PES General Meeting, Detroit, MI, July 25, 2011.

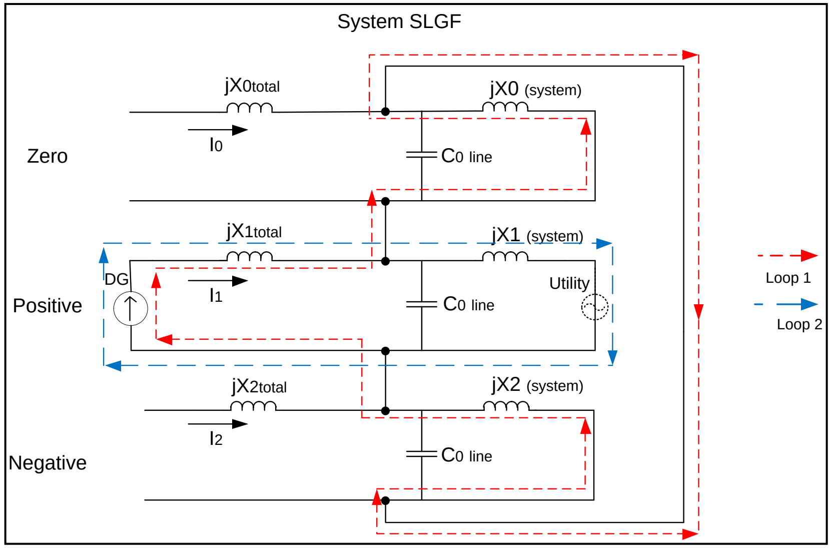
Methods and Approaches for Integration

PV Inverter Grounding

Inverter Modeling

- Starting with superposition to show contribution of the PV inverter to the fault current and overvoltage using symmetrical components



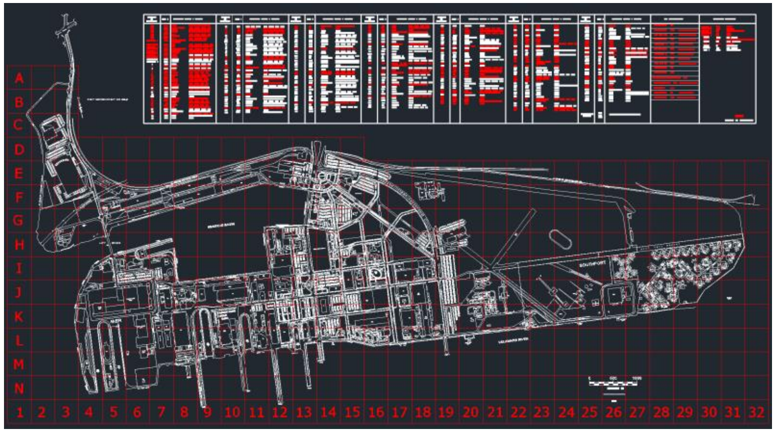


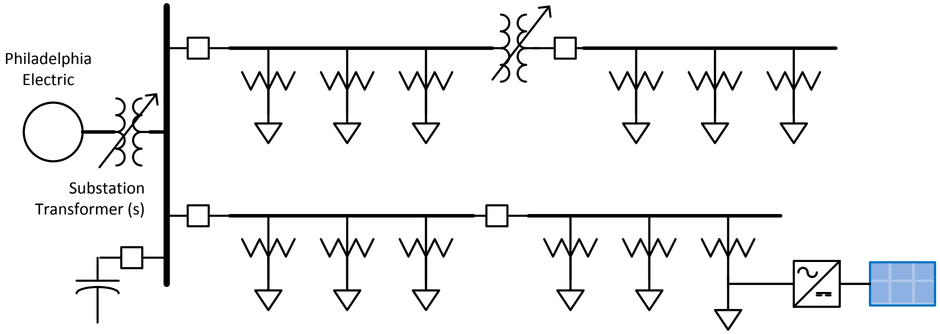
Methods and Approaches for Integration

PV Inverter Grounding

System Modeling

– **Modeling Navy Yard facility in PSCAD and MATLAB**





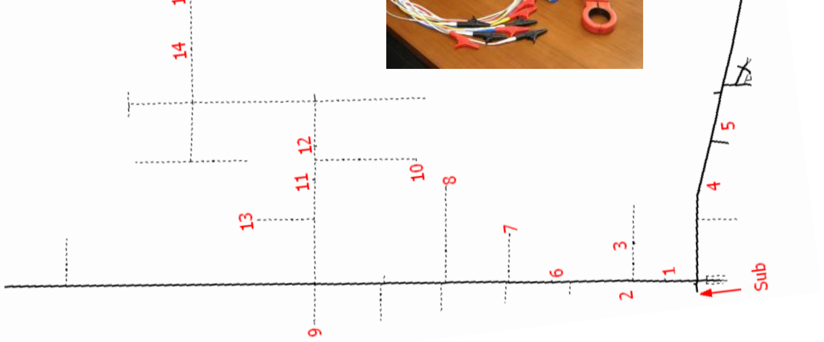
Methods and Approaches for Integration

PV Inverter Grounding

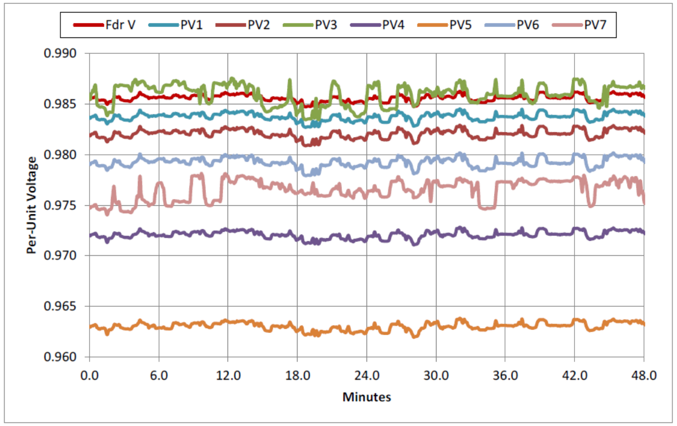
System Testing

- Aggregating PV sources

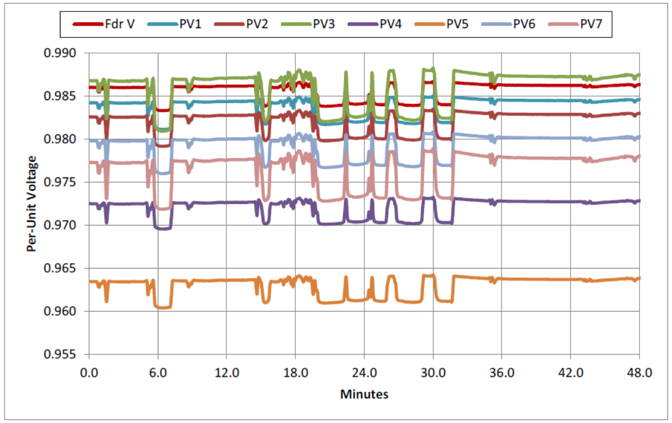
Duquesne Light
Our Energy...Your Power



Distribution Feeder



Uncorrelated Voltage Variations

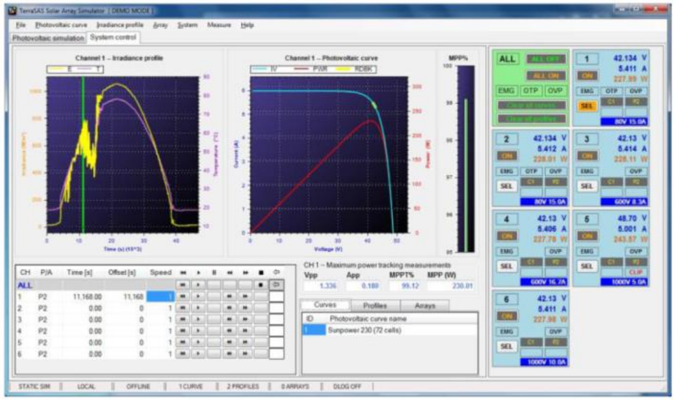


Correlated Voltage Variations

Methods and Approaches for Integration
PV Inverter Grounding

New Lab Instrumentation

4kW PV Panels on the roof of Benedum Hall

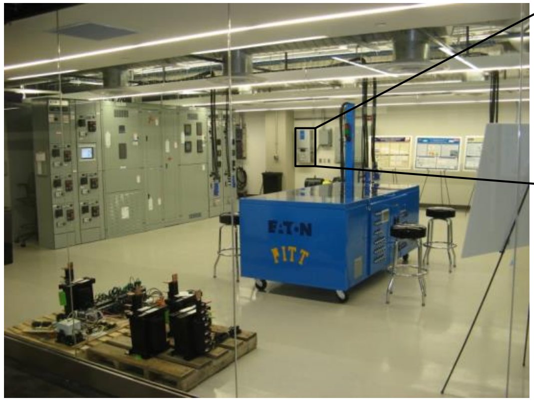


PV Simulator Software

Access to DC and AC inverter terminals

Type 1: 5/10/15 KW, 600Vdc

PV Simulator



Electric Power Systems Lab

University of Pittsburgh

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Distribution Modeling for Feeder Analytics and Distributed Energy Resource (DER) Integration

Prepared by: Stephen Abate
Andrew Reiman

M.S. Students

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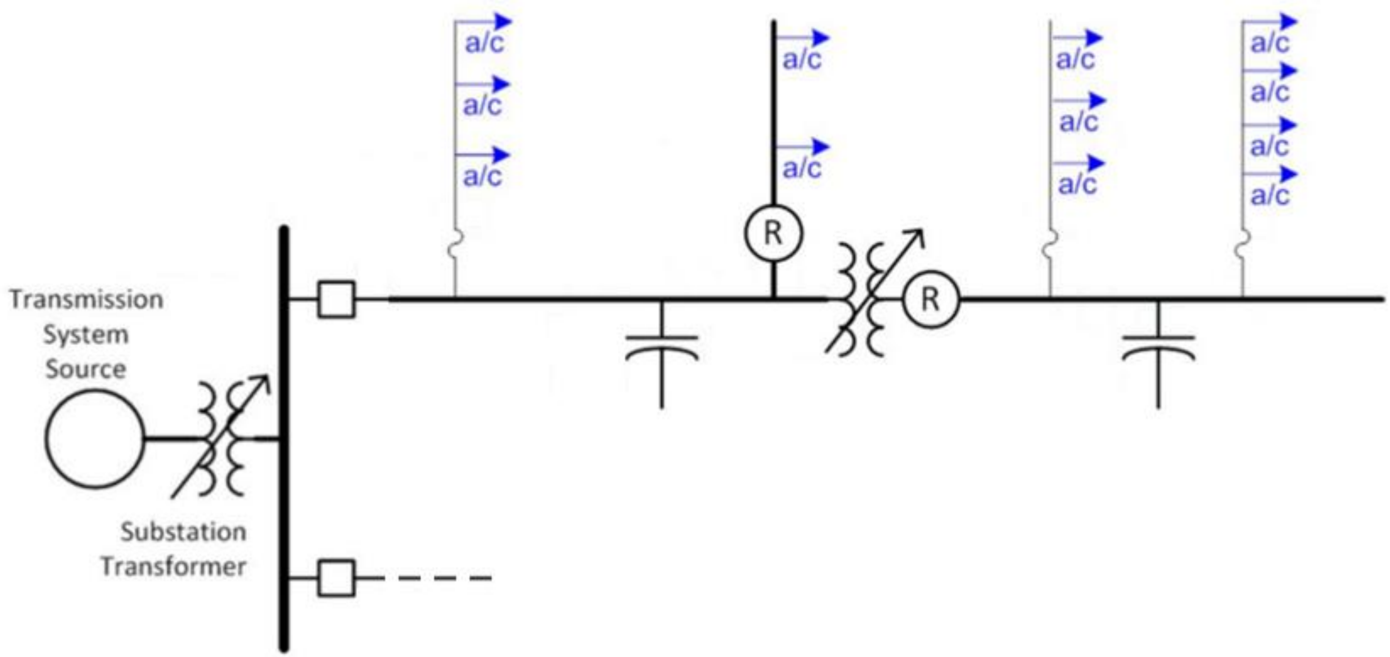
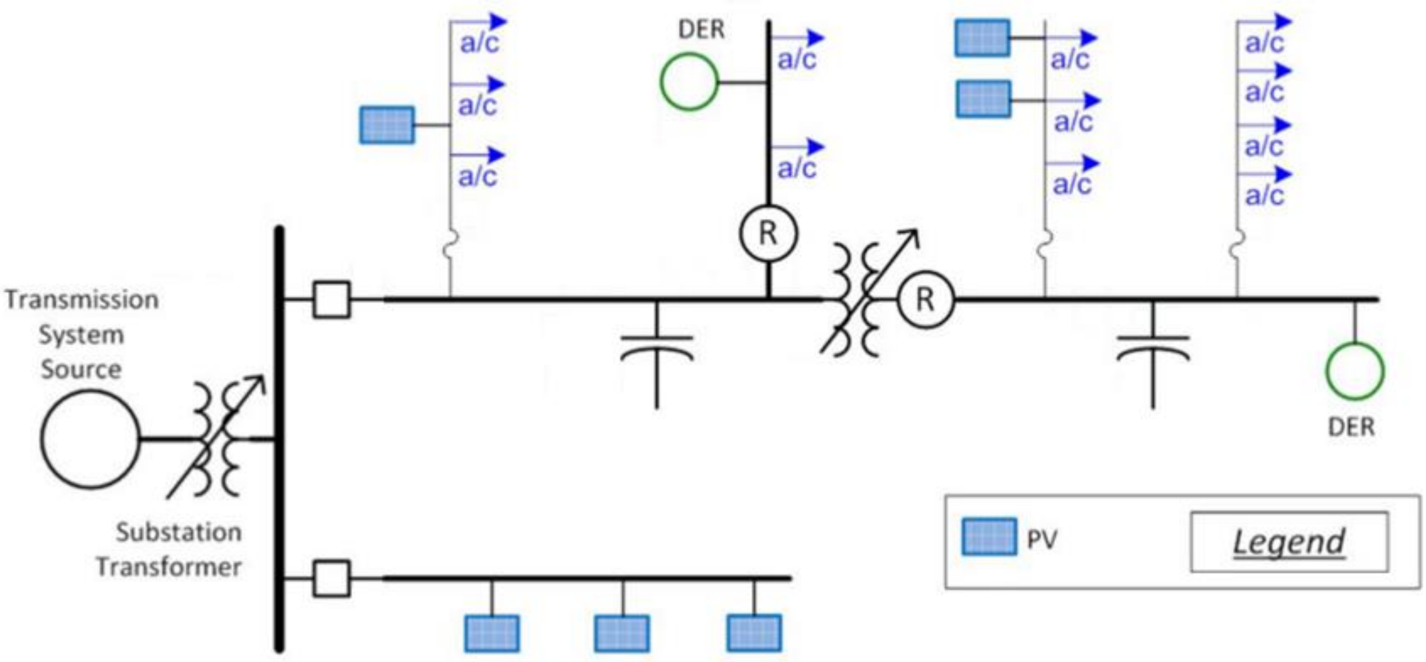
Methods and Approaches for Integration
Distribution Modeling for Feeder Analytics

Basic systems can be modeled using traditional methods



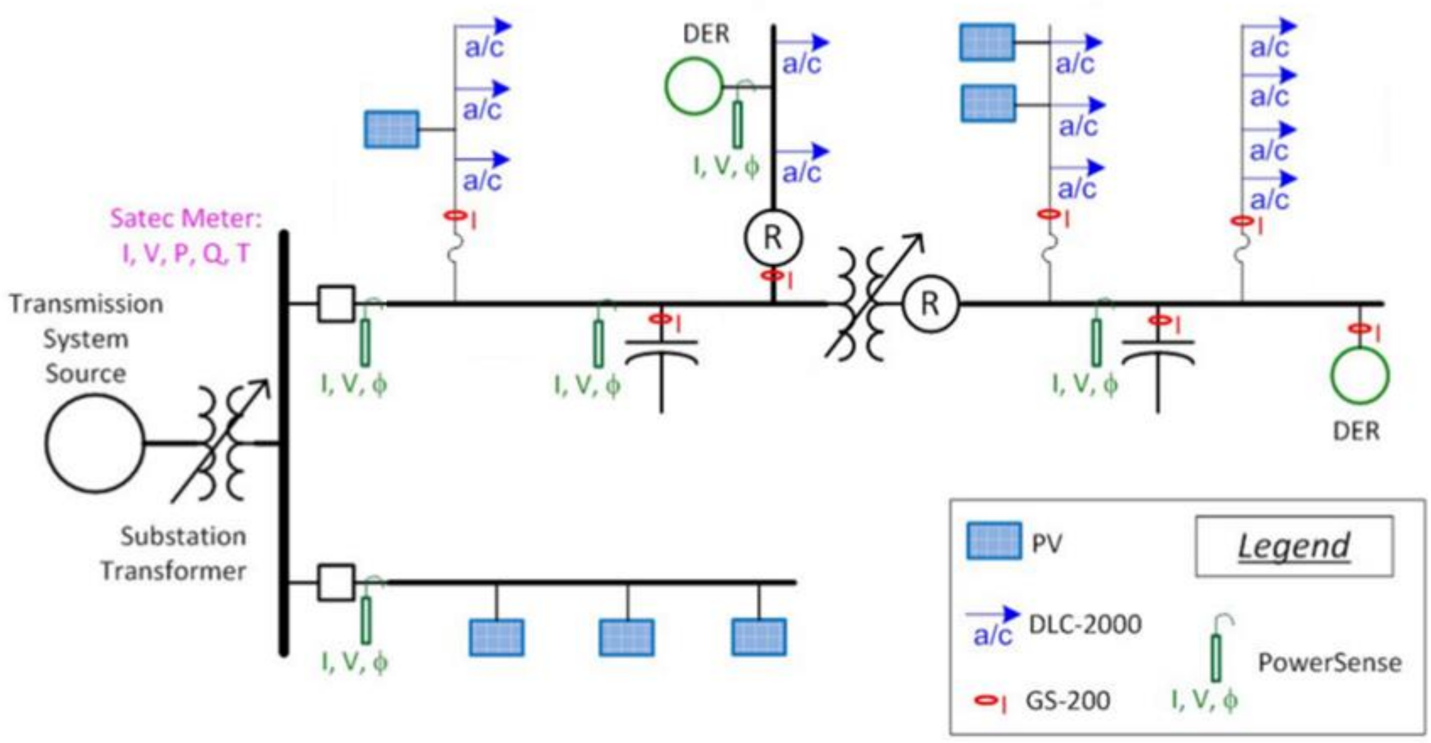
Methods and Approaches for Integration
Distribution Modeling for Feeder Analytics

Systems with DER require advanced modeling techniques



Methods and Approaches for Integration
Distribution Modeling for Feeder Analytics

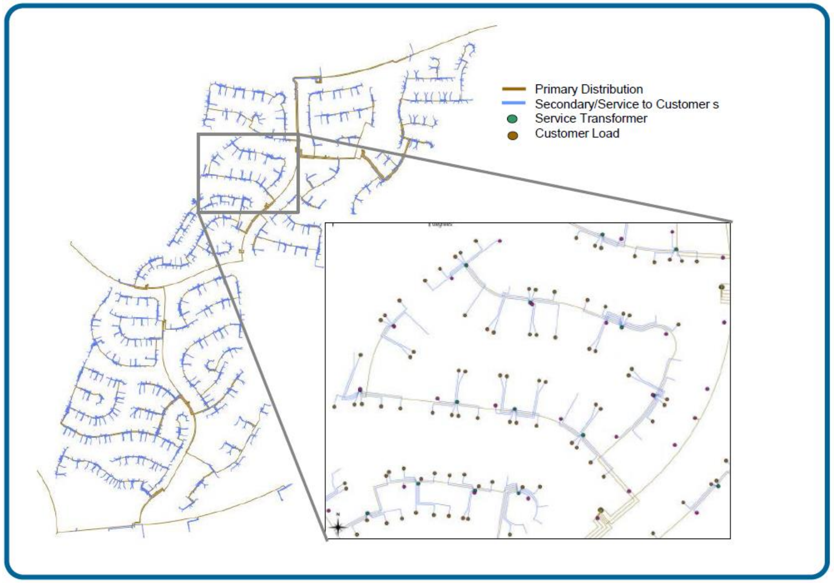
Sensors are used to validate advanced modeling techniques



Methods and Approaches for Integration
Distribution Modeling for Feeder Analytics

Open Distribution System Simulator (OpenDSS)

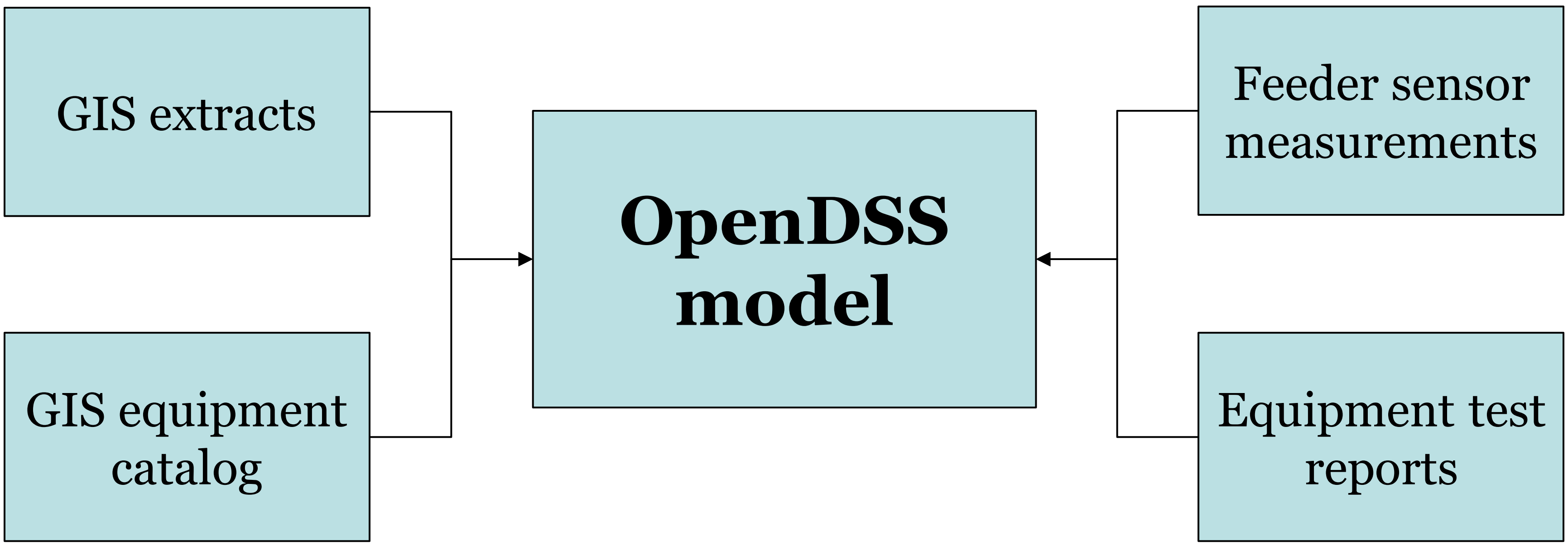
- Flexible open source software
- Time domain analysis
  (yearly, daily, duty cycle simulations)
- COM Interface
  (MATLAB, Excel, VBA, Python, etc)
- Ideal for importing data
- Repetitive scripted solutions
- Models smart grid components
  (DER, Storage, AMI)



Methods and Approaches for Integration

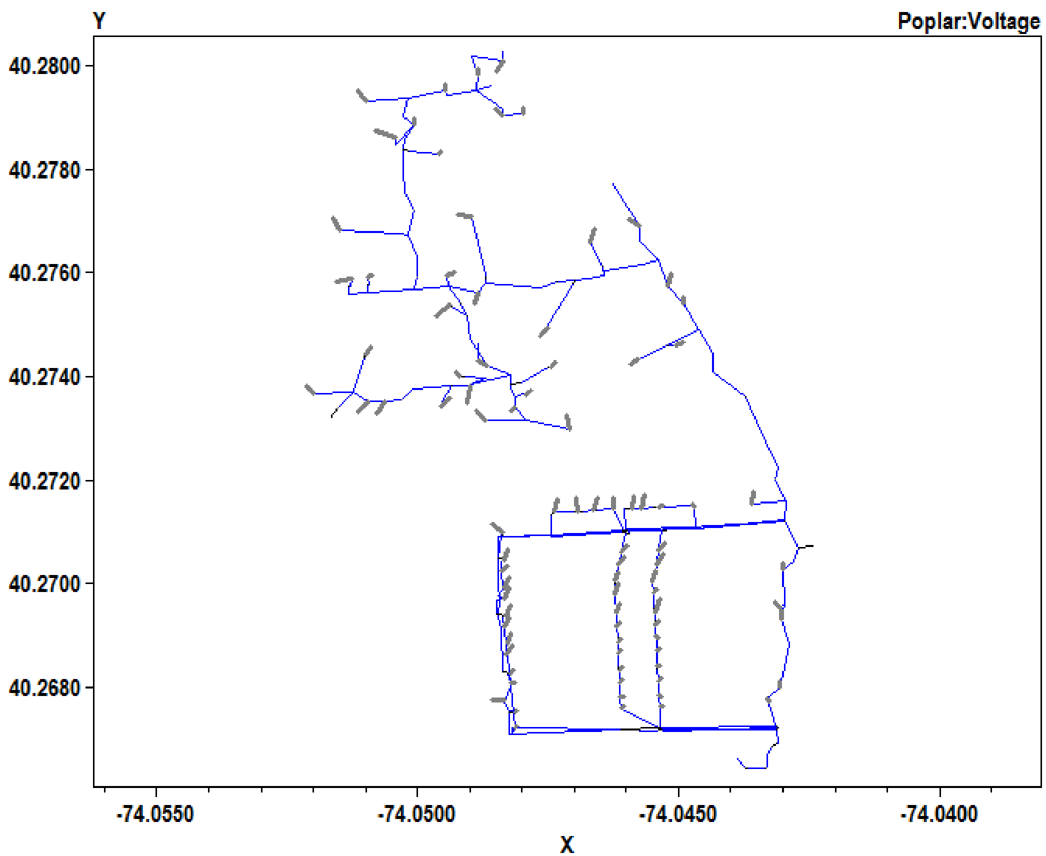
Distribution Modeling for Feeder Analytics

OpenDSS models can be created from a variety of different data sources with scripted methods



Methods and Approaches for Integration
Distribution Modeling for Feeder Analytics

OpenDSS - Poplar Feeder Model



Methods and Approaches for Integration

Distribution Modeling for Feeder Analytics

Research Goals

- Create detailed visualizations
- Use non-linear interpolation techniques to analyze non-synchronous data samples
- Estimate states of grid devices including switches and capacitor banks
- Perform real-time acquisition of data and metrics

Thank You