




Control and Interoperability Challenges in New Energy & eMobility Systems

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New Mexico SMART Grid Center webinar series

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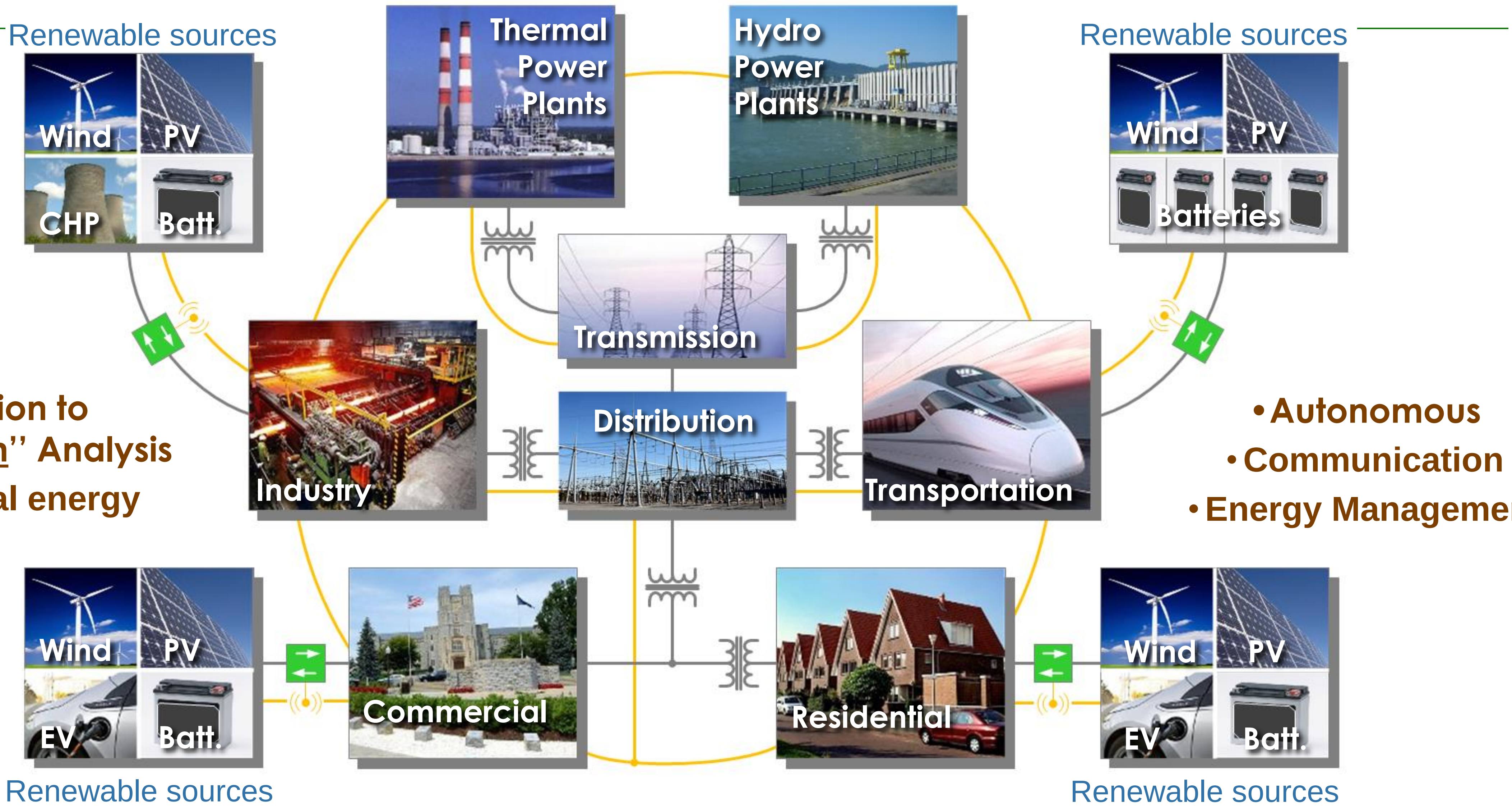
Outline

An overview on my research and teaching accomplishments
and
outline general directions for open gaps and challenges

- **<u>Open Gaps and Challenges</u>**
- Research Framework and Approach
- Research Laboratory Experience
- Sample Research Projects
- Future Ambitions

"Smart Grid" Concepts: Integration of two infrastructures



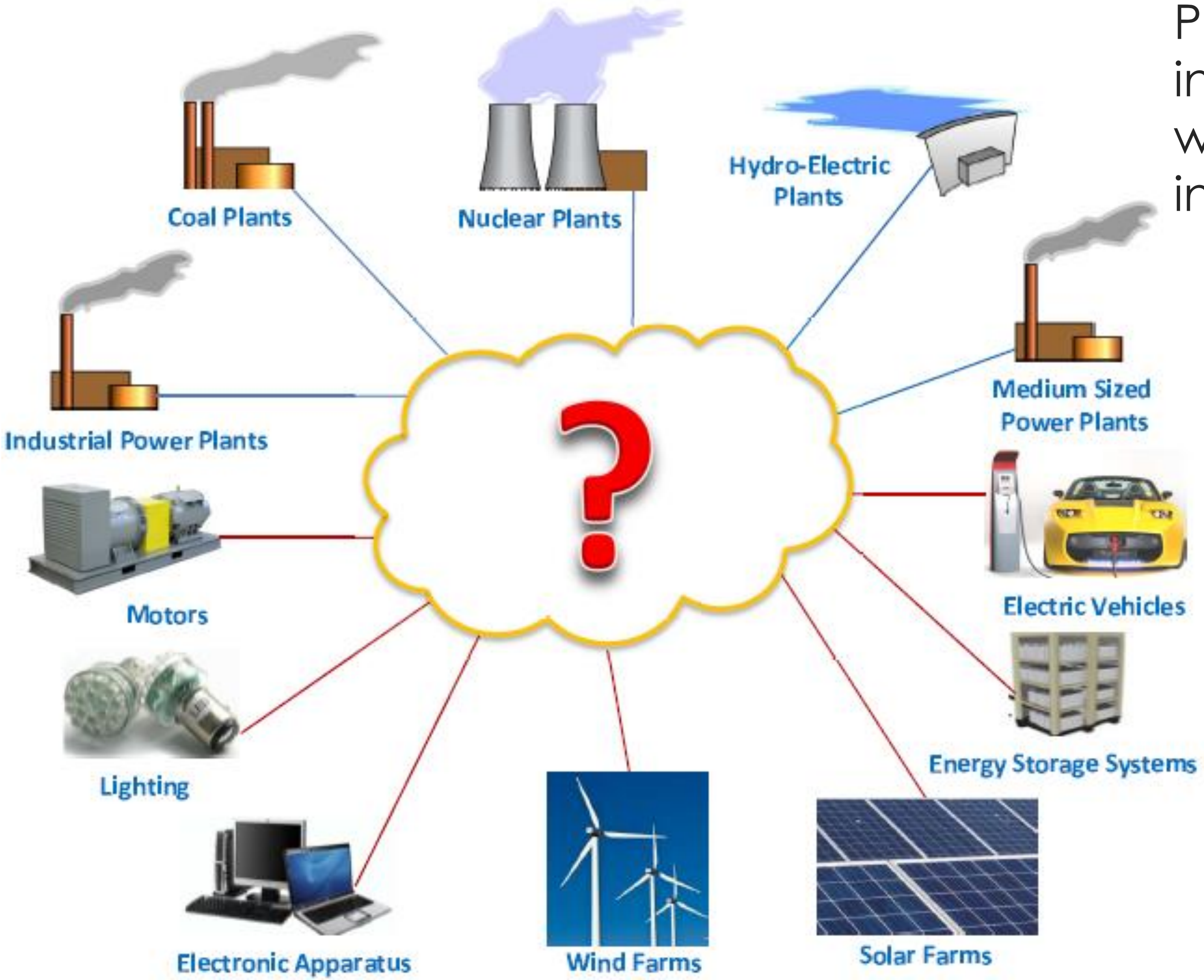
- **Inner Function to "Interaction" Analysis**
- **Bidirectional energy conversion**

- **Autonomous**
- **Communication**
- **Energy Management**

Integrated Information Infrastructure

More Electricity is Supplied by Electronic Sources: "Integrated"

How does power system operate with millions of power electronic converters?



Power electronics-based future grids, instead of electric machines-based, with a huge number of non-synchronous incompatible players.

How Does This Change Stability Analysis and Requirements?

more of a systems problem; Good Solutions require whole System Thinking!

Research Framework and Approach

Electrical Energy Faces Challenges ….. But Opportunities are Bigger!

Exponential Technologies → **Disruptive Impact**

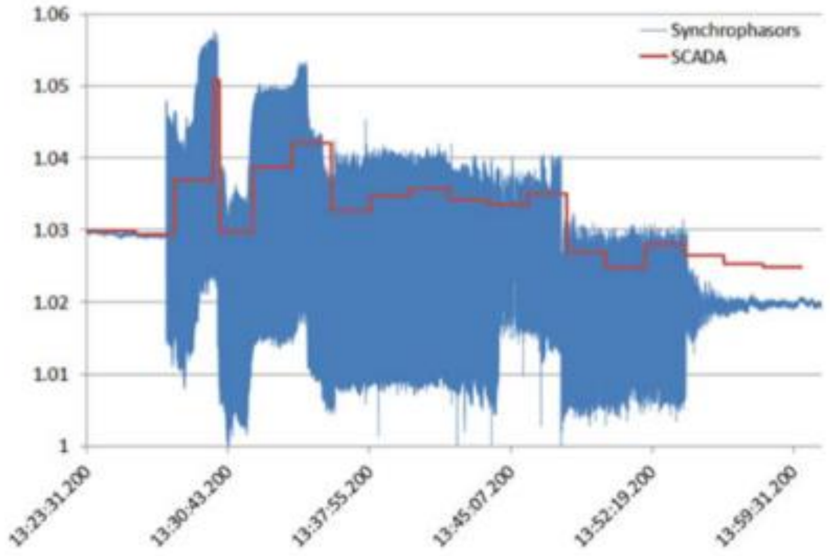
PV, Wind, Batteries, IT, Comms

Power Electronics, Storage, Analytics

Operations, Planning, Regulatory

Stability, Resiliency, Cost

- **Challenges**
  - Rapid advancement in equipment manufacturing/engineering capabilities
  - A lag in control system development and integration theories
  - Fast control and dynamics
  - Operational risks



Forced oscillation from a wind turbine in Oklahoma

Solar Photovoltaic Event in Southern California

- August 2016 :

Result of one fault: Loss of about **1200MW** of solar generation

Ground Fault Over-voltages

- Protection system perceived under frequency condition resulting from a distorted voltage waveform cause by the fault transients
- The inverters were programmed to cease output when f < 57Hz.

WECC: frequency dropped to 59.86 Hz for this event !!!

Page 1, NERC, 1200 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report, Southern California 8/16/2016 Event, June 2017

Motivation: Need for grid observability and controllability

www.greentechmedia.com

REGULATION & POLICY

Utilities, Grid Operators Tell FERC They Need Real-Time Model to Better Manage DERs

It's unclear how federal regulators will tackle the problem.

LACEY JOHNSON | APRIL 12, 2018

This looks like a big opportunity for **R&Ds and Engineering Students!**

- The **need for real-time information** on distributed energy resources to a Federal Energy Regulatory Commission panel in Washington, D.C. on Wednesday (04/11/2018):

- "The worst thing that could happen for distribution companies is to not have visibility on…that distributed energy resource"

- "We need to know the system dynamics, and how it's being operated on a real-time basis."

Our Approach

Learning via Building Real-time Testbeds

- "New Norm" for Education

Industry Expectations of New Engineers, Technologists

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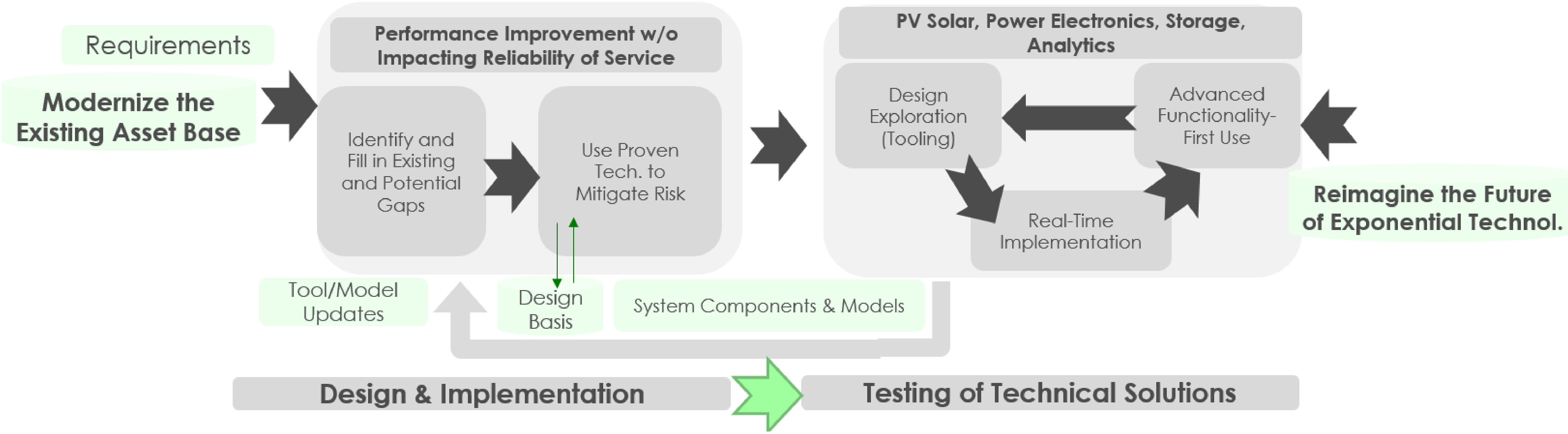
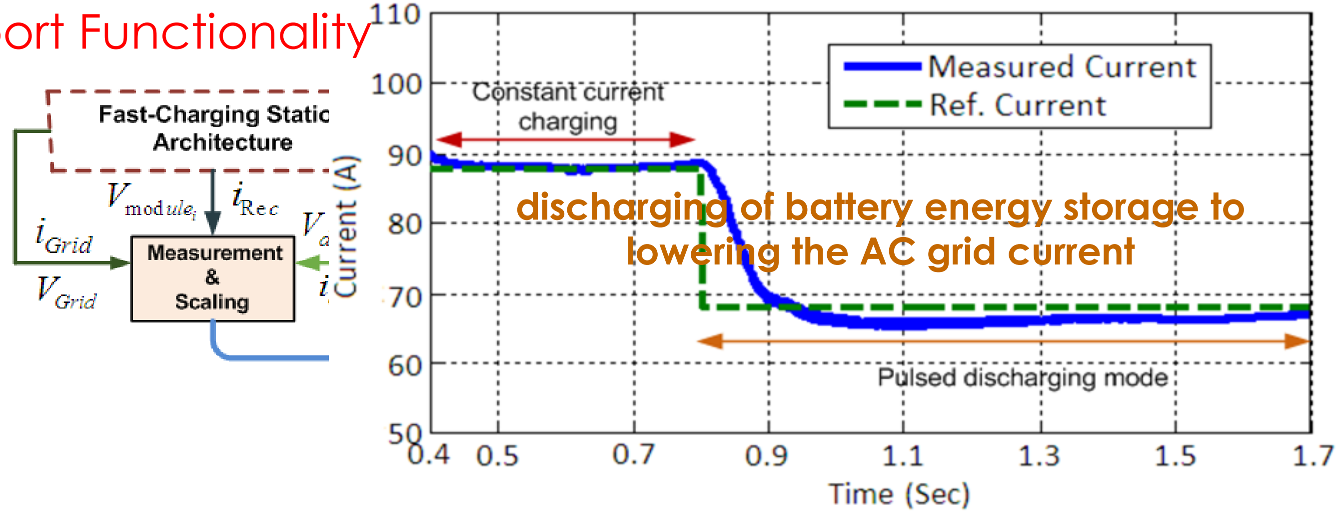
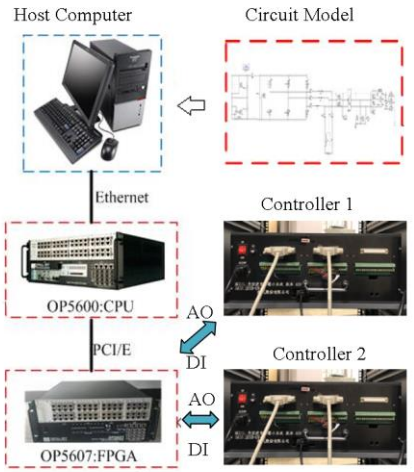
Research Framework and Approach



V2G: Grid Support Functionality



Controller HIL: an effective, and fast solution



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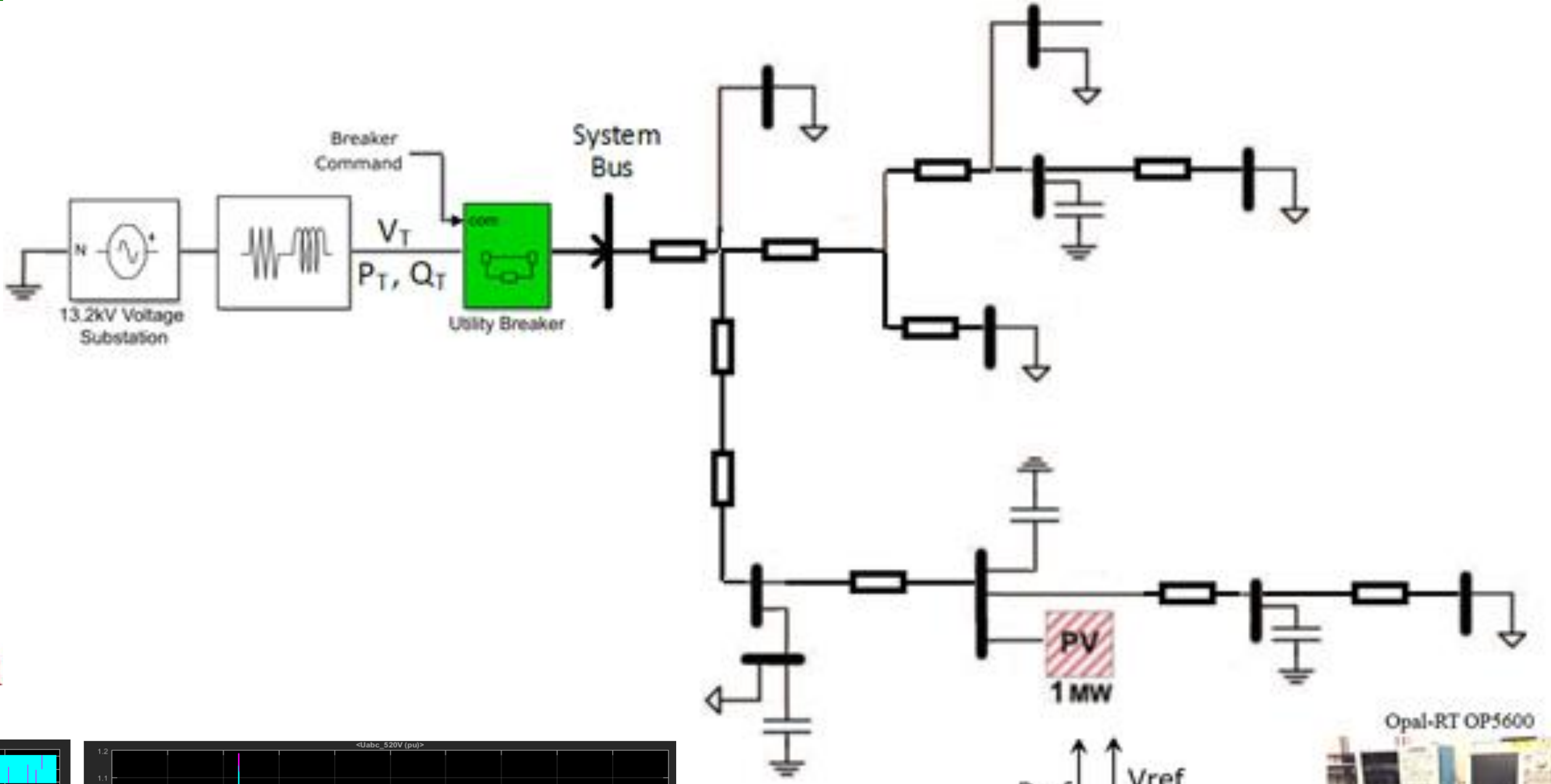
PV Inverter-based DERs: New Challenges

- Several of the issues that have delayed the assessment and approval of interconnection projects of distributed energy resources (DERs)
- Unique to the industry and/or unique to the types of distribution systems in operation, for example in New York State

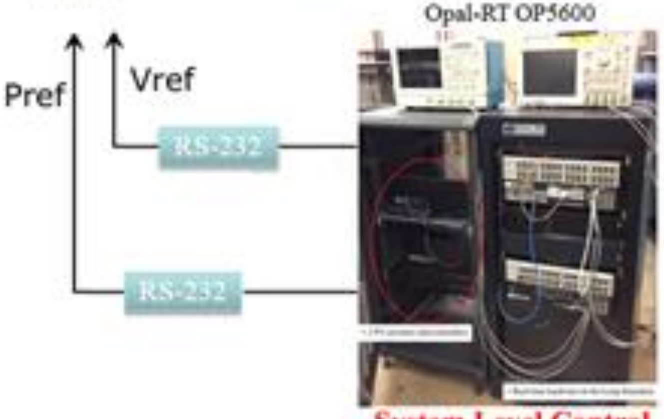
- where instantaneous reclosing, fusing, prevalence of small hydro and other rotating generators

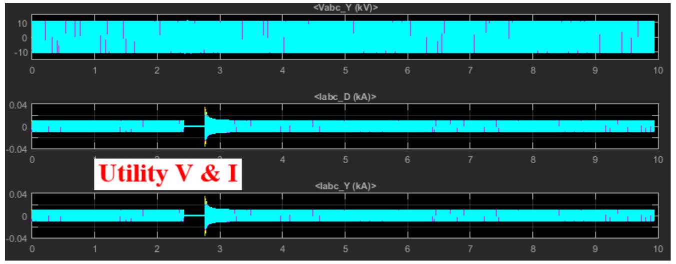
  - *introduce safety / reliability concerns that have not been resolved*
- RTS model presents a fair and accurate method for assessing these issues
- providing clear resolutions to the DER developers, utilities, etc.

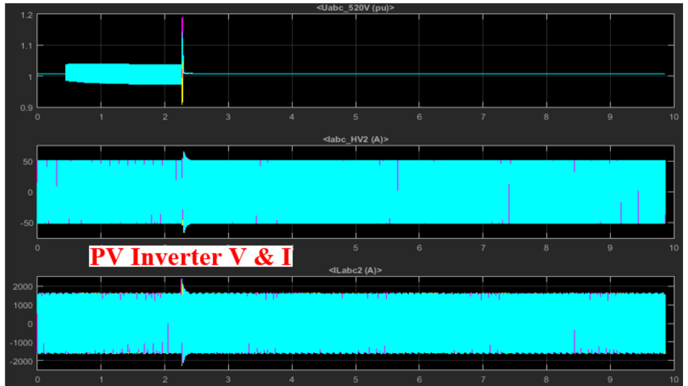
Voltage Protection Scheme in Distribution Systems using RT-HIL



PV-1

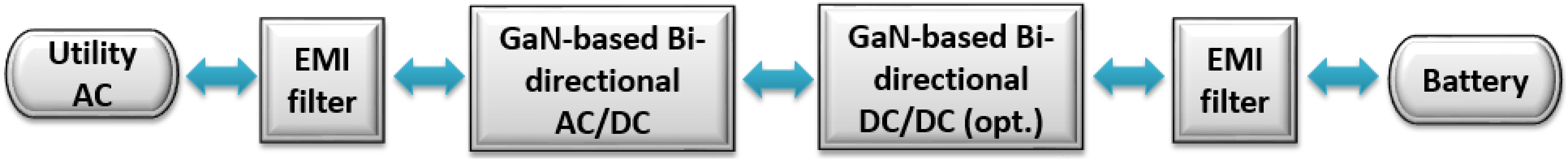






Utility is unable to manage PV injection locations to avoid deteriorating voltage profile.

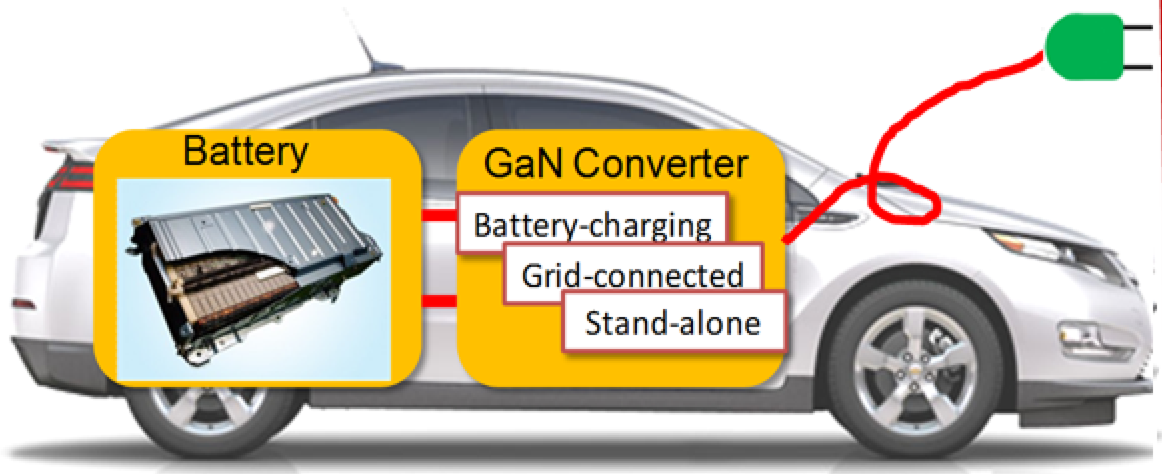
Energy Management for Grid-Connected Battery Charger



Architecture

Functions | **Objective**

Bi-directional Battery-to-Grid Charger Applications



AC voltage (V)	240
Battery voltage (V)	270 ~ 430
Charging current(avg) (A)	0 ~ 24
Switching freq. (MHz)	1
Power (kW)	6.6
Efficiency	>95%
Power density (W/in³)	150

Battery Information from GM.

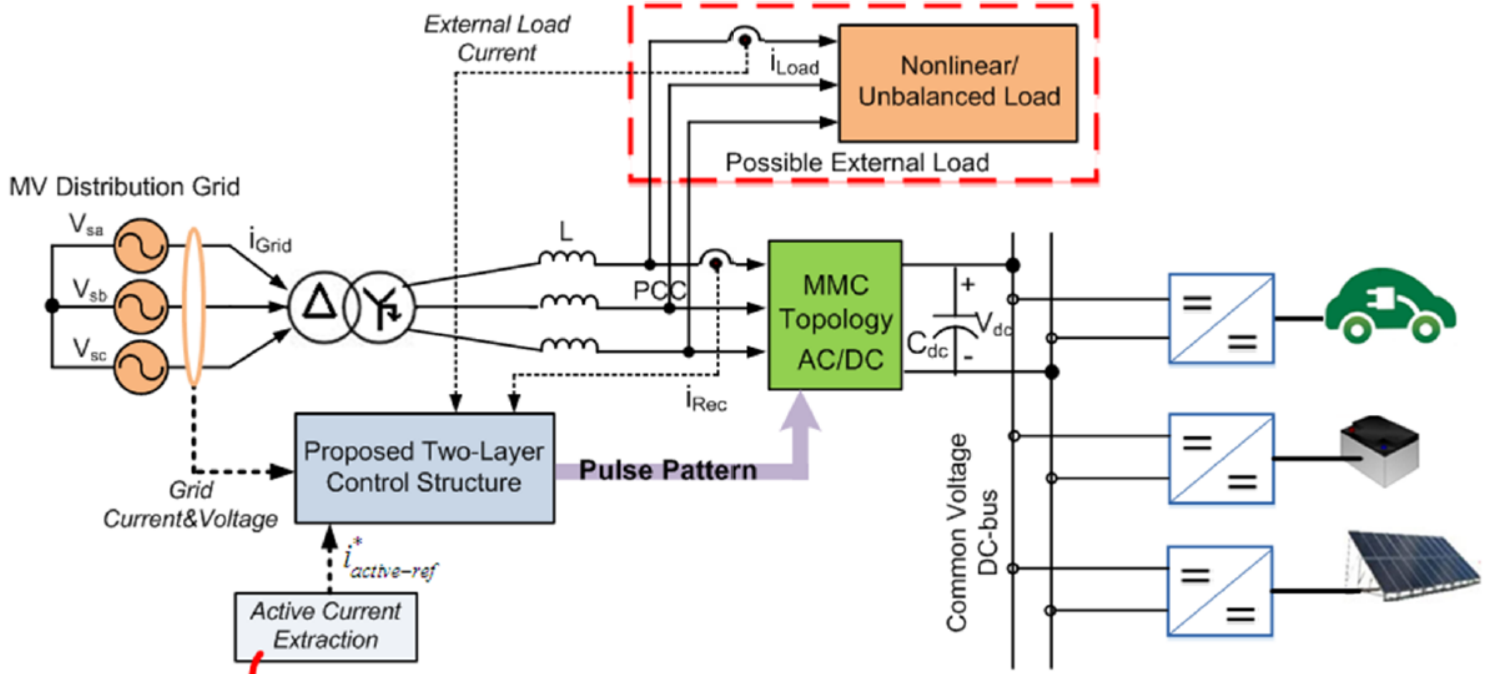
The *US Transportation Electrification* *Scorecard* finds that California is far and away the national leader in enabling the use of Evs. (Source: The American Council for an Energy-Efficient Economy)

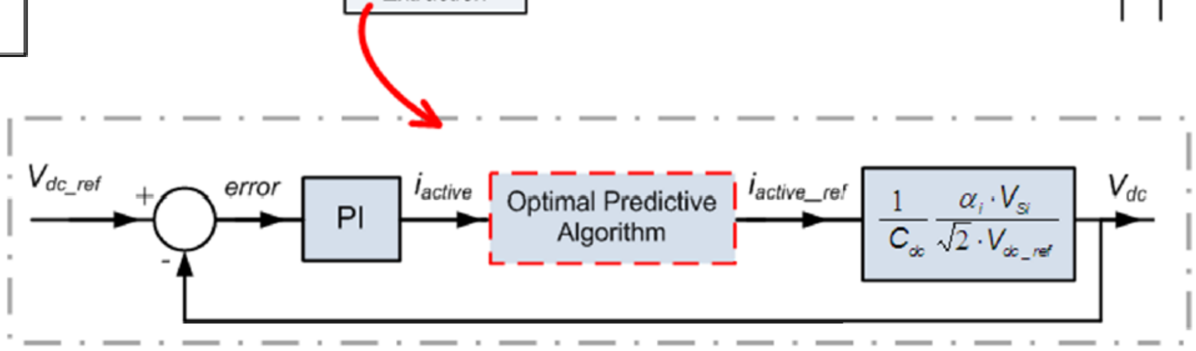
Architecture of typical fast-charging station

- **Charging station connected to the MV distribution grid with proposed control scheme.**

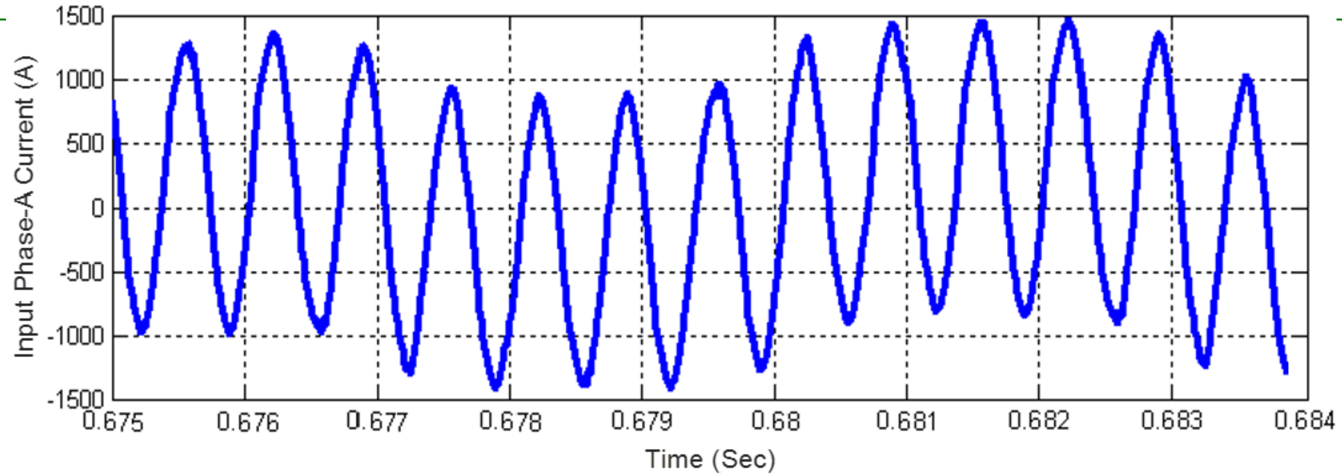
RATING VALUES OF THE SIMULATED SYSTEM

Parameters	Value	Parameters	Value
Full-bridge cell in each module	2	DC-bus voltage	600V
AC voltage	13.8kV	Capacitor voltage setpoint per module	150V
Grid transformer	350kVA, 13.8kV/400V	DC inductor	1.7mH
EV battery capacity	450V, 20kWh	Sampling time	30 µs
DC-DC converter power	80kW	MMC arm inductance	3mH
Leakage inductor	0.22mH	MMC cell capacitance	3.3mF

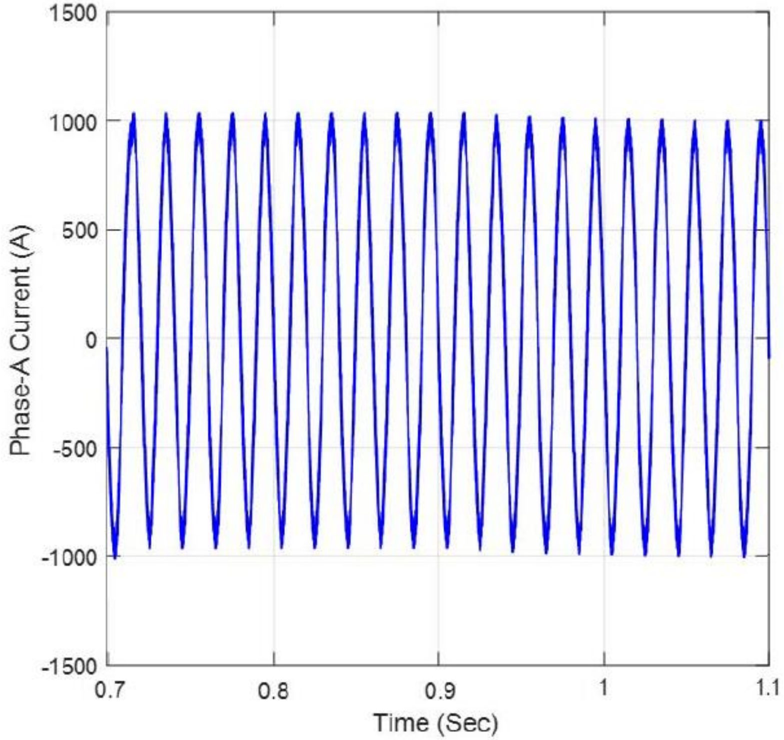




Results with Stability Constraint



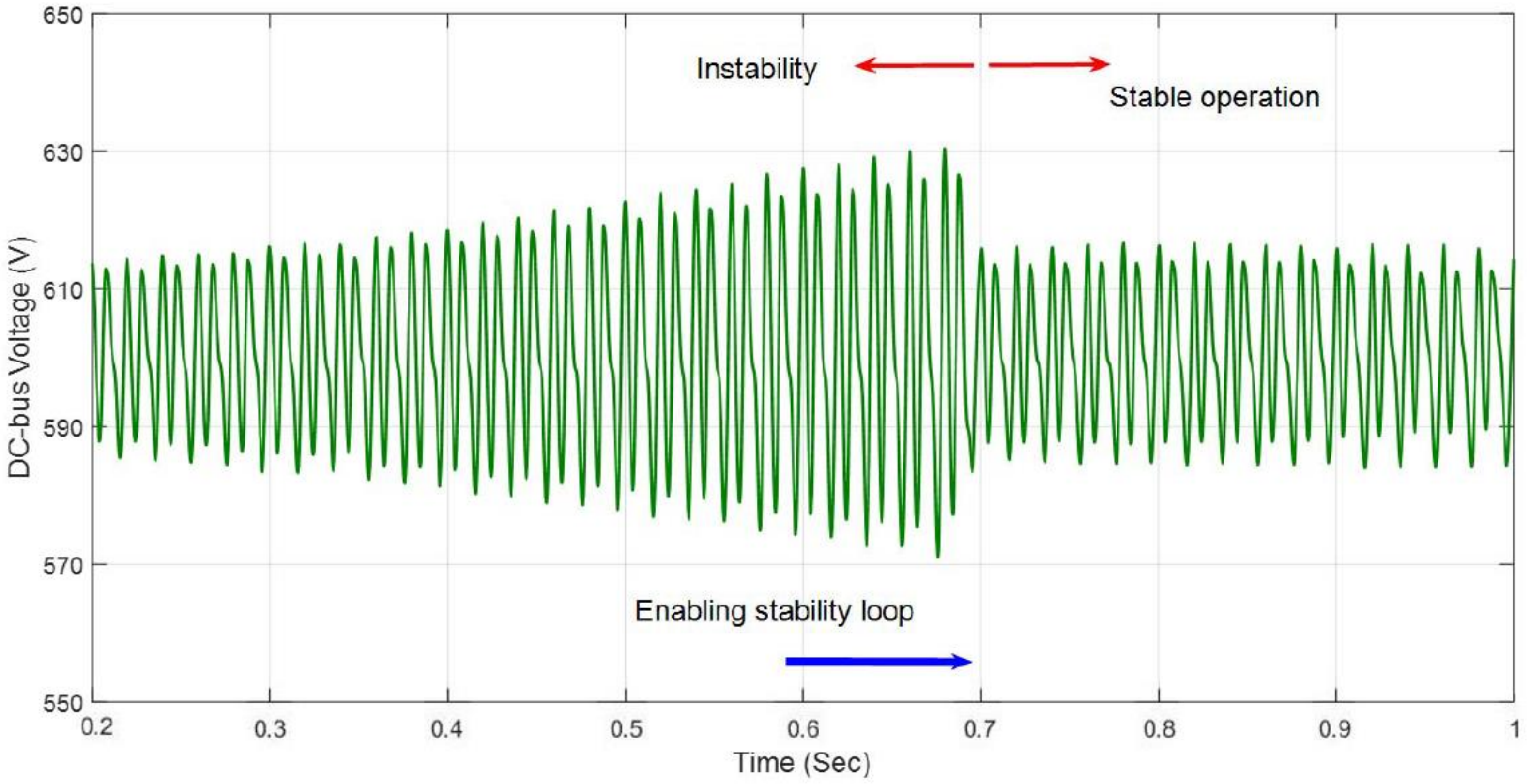
Before Stability Loop Activation



- Current imbalance condition in the AC currents of the EV Charger.
- Oscillations occurred in the common DC bus leading to unstable system.

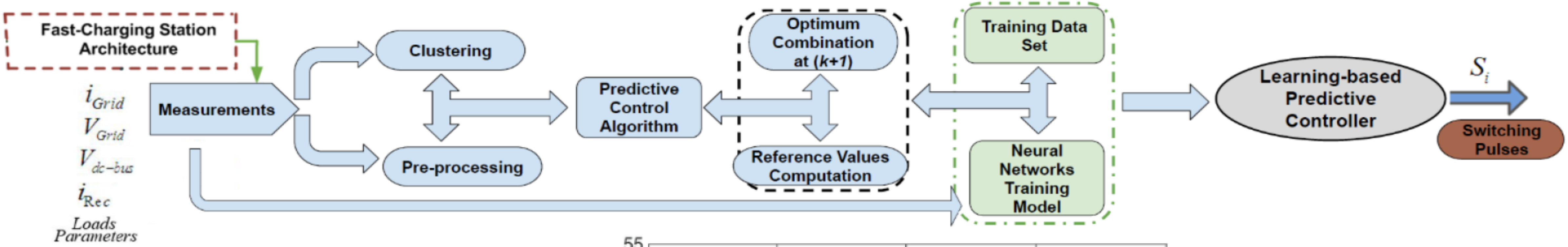
With Stability Loop Activation

Performance with Stability Constraints

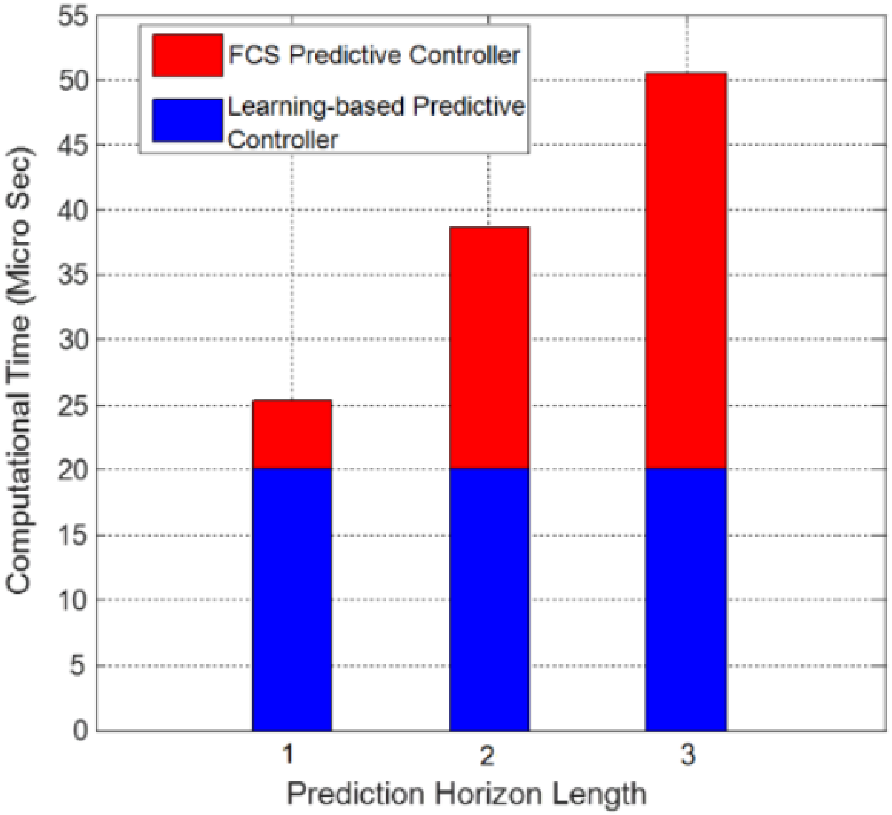


- Common DC-bus waveform with/without Stability Loop enabling at t=0.7sec.
- Distortions are appreciably eliminated without placing an excessive filters (passive) as damping element.

A Learning-based Supervisory Control Architecture

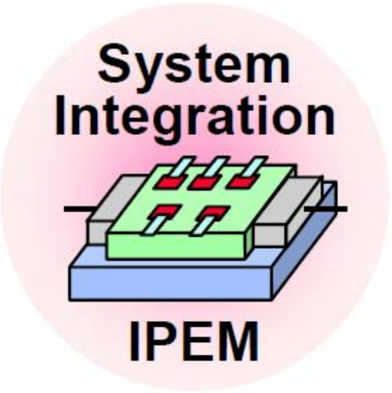


- A Mechine Learning-based co[...]rgy storage system integrated with Electric Vehicle ch[...]
- The model is effectively trained us[...]uccessfully validated via real-time data
- Possibilities for future developm[...]hms with multi-step predictions.
- Integrating multiple DERs into dis[...] huge interest for the utilities and regulatory agencies.



EV Powertrains: Objectives

- A vision for the ability to combine all aspects of the drive:
  - the converter, electrical motor and control system trends



- **Integrated Power Electronics Modules (IPEM)**

to demonstrate 10-fold improvements in quality, reliability and cost effectiveness of power electronics systems in 10 years.

- **Integrated Motor Drive (IMD)**

to offer number of benefit: volume/mass reduction over traditional separately constructed systems

Conventional Motor Drive
Rockwell Automation

SIEMENS 60kW, EV traction drive

Source: Charged Electric Vehicles Magazine, Mar. 17, 2016

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Power Quality and Stability – More-Electric-Aircraft (MEA)

Electrical
- Avionics
- Cabin (lights, galley, in-flight entertainment etc)
- Lights, pumps, fans
- 115V, 400Hz AC

Pneumatic
- Cabin pressurisation
- Air conditioning
- Icing protection

Hydraulic
- Flight control surface actuation
- Landing gear extension/retraction and steering
- Braking
- Doors

Mechanical
- Fuel and oil pumps local to engine

Replacement of some mechanical, hydraulic and pneumatic loads with electrical equivalents e.g. electro-mechanical actuators.

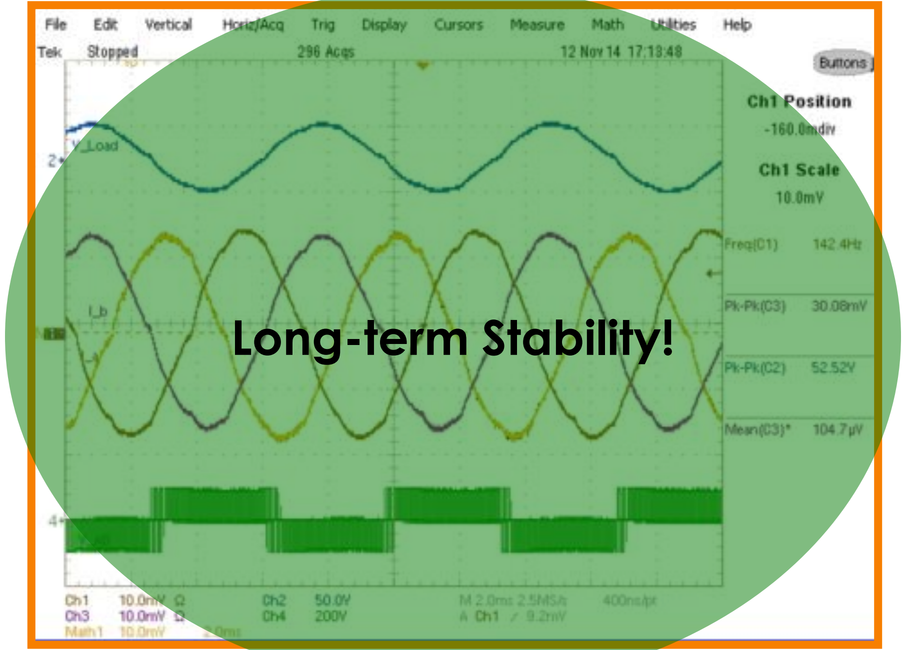
Dependent on the Embedded Power Network

Motivations:
- **Reduced operating costs**
- **Reduced fuel burn**
- **Reduced environmental impact**

Onboard Distribution System:

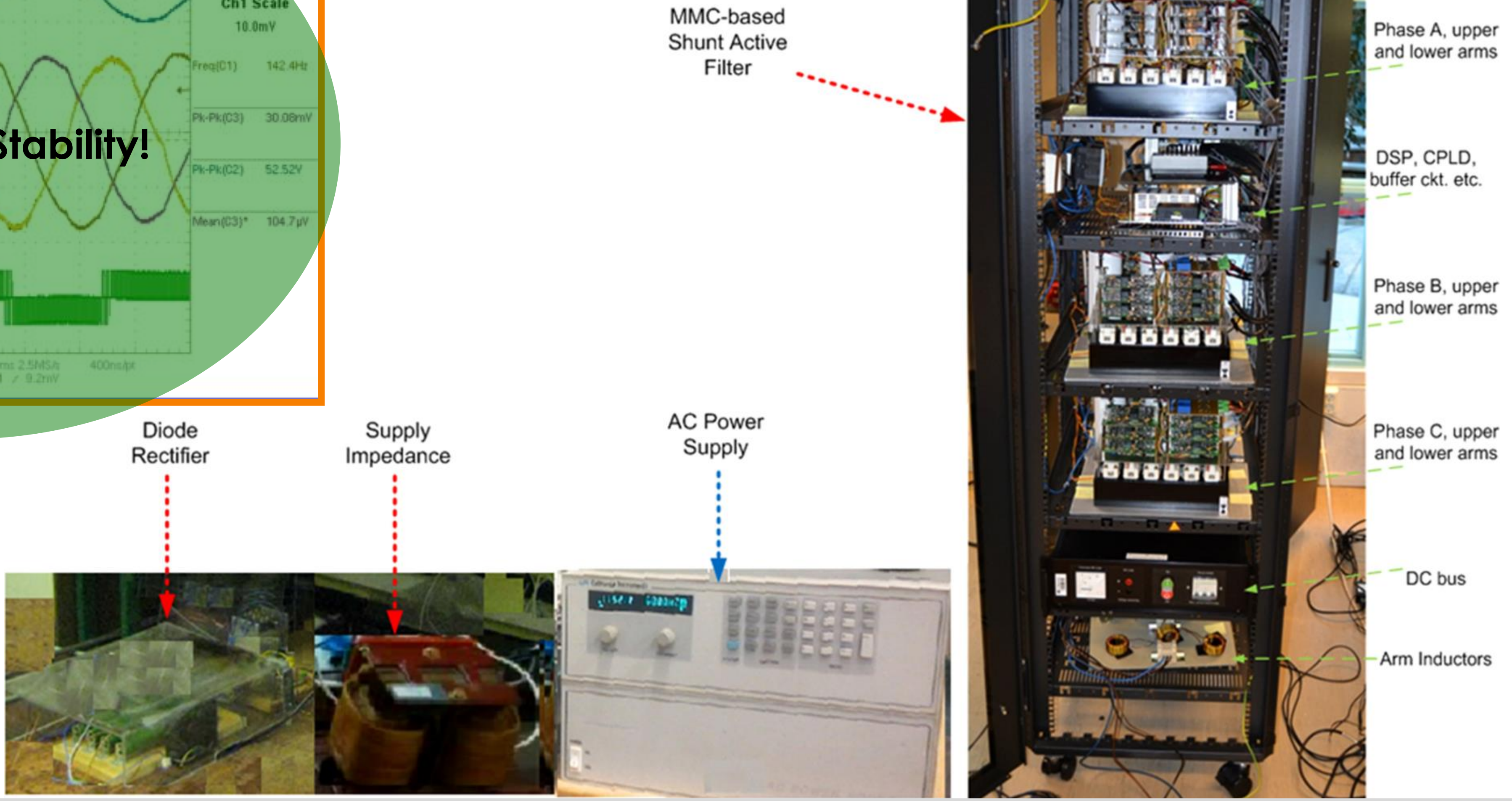
Reliable, high-level of Availability, and Promptly Respond to aircraft's operation change.

Electrified Transport: Past Projects



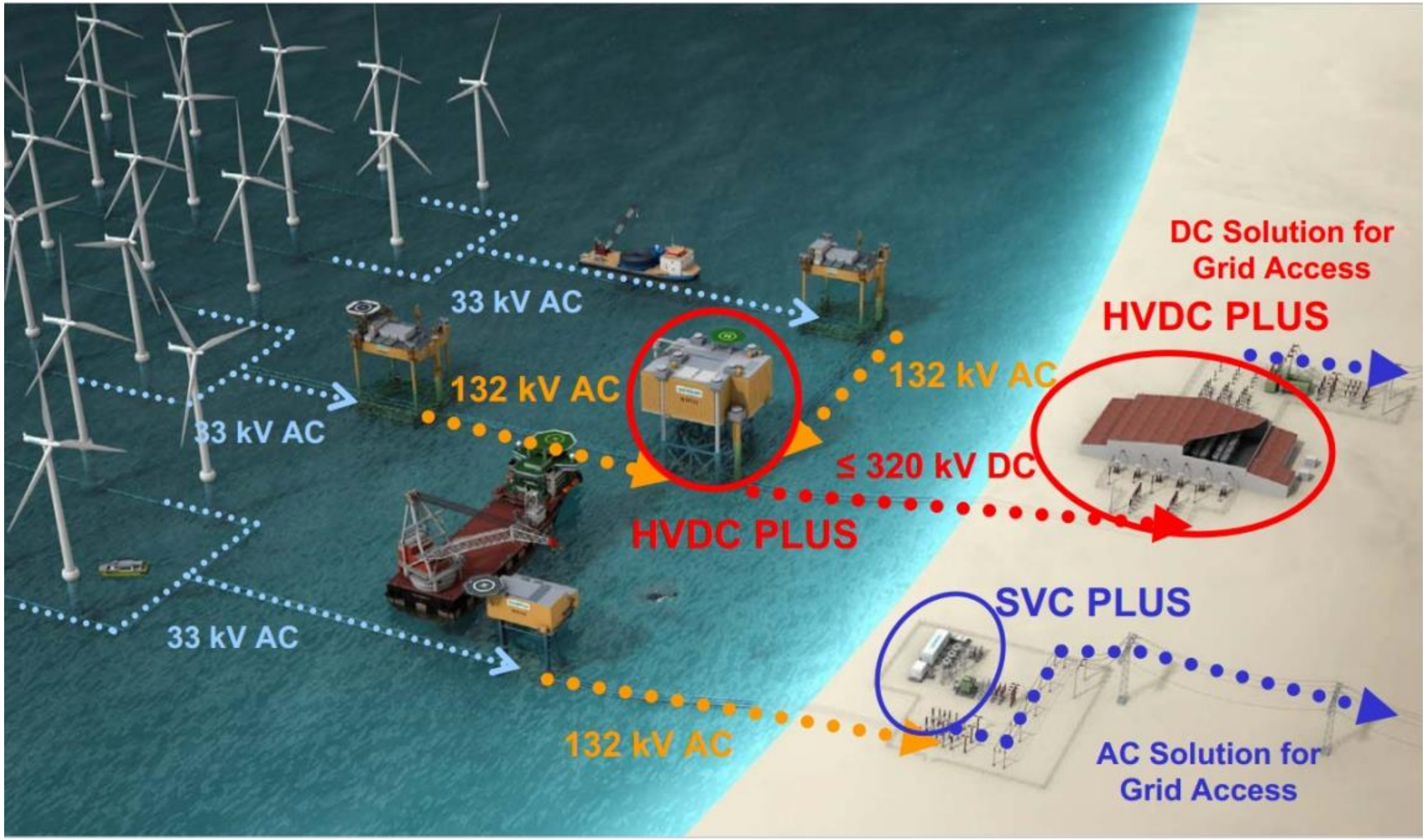
Long-term Stability!

Sample test results:



H. Nademi, R. Burgos, Z. Soghomonian, "Power Quality Characteristics of a Multilevel Current Source with Optimal Predictive Scheme from More-Electric-Aircraft Perspective", *IEEE Transactions on Vehicular Technology*, Vol. 67, No. 1, pp. 160-170, January 2018.

Offshore Wind Power to Grid



http://mydocs.epri.com/docs/publicmeetingmaterials/1108/6XNSUMJE9MT/Siemens_-_Hild_-_HVDC_and_FACTS_make_the_Grid_Smart.pdf

Digital Twins & AI/ML Apps.

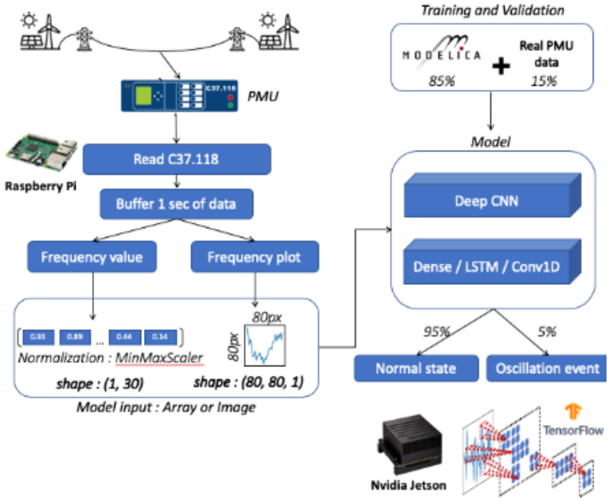
A PMU-Based Machine Learning Application for Fast Detection of Forced Oscillations from Wind Farms

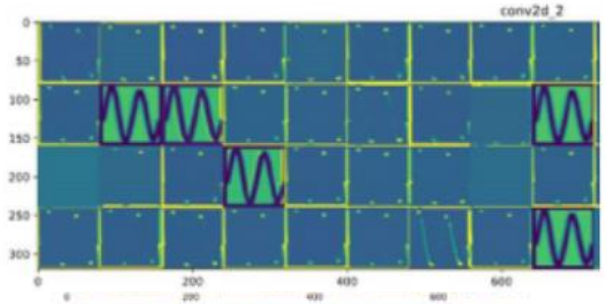
- **AI/ML-Based Design, Prescriptive and Predictive Analytics**

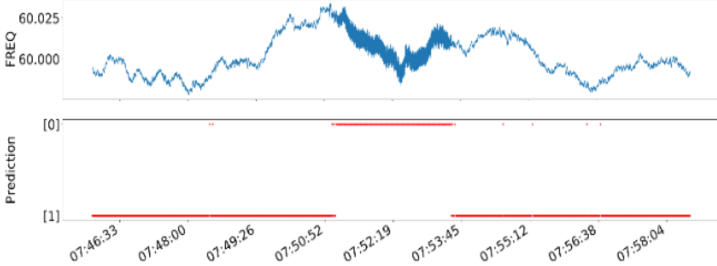
- ***Goal:*** build Machine Learning-based intelligent assistants (e.g. recommender systems) for decision support (from design to operation) considering system dynamics, uncertainties and cyber-security.

  - Exploit traditional simulation models to train ML algorithms, expanding the exploration space and deriving additional value from simulation models.

  - ***Example:*** wind farm oscillation detection using transfer learning and ML, with deployment at the edge.







Model	Accuracy	False-positive	Missed event	Time for 1 prediction (sec)
Proposed CNN	97.41%	2	6	0.0047
Proposed Conv1D	98.06%	0	6	0.0027
MobileNet	97.74%	2	5	0.0074
MobileNet[2]	98.71%	0	4	0.0074
AlexNet	94.51%	12	5	0.0098
ResNet-50	97.42%	4	4	0.0174
Dense	94.19%	6	12	0.0026
Stacked LSTM	94.19%	2	16	0.0054

Hardware	Time for 1 prediction with CNN	Time for 1 prediction with Conv1D
Windows PC Core i7 8700 – Nvidia 1080Ti	0.0049 sec	0.0022 sec
Nvidia Jetson Xavier	0.0357 sec	0.0170 sec
Raspberry Pi 3	0.4698 sec	0.0114 sec

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Future Ambitions – Meeting the Challenges Ahead

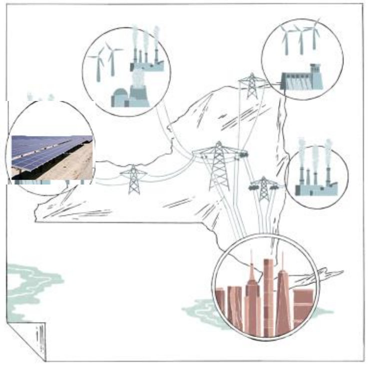
In the context of USA energy goals.

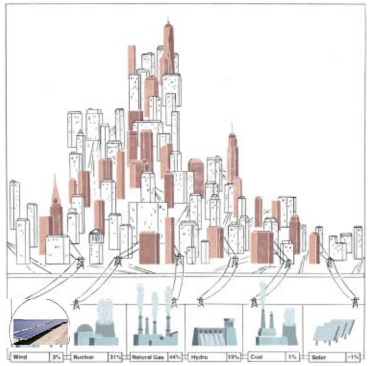
- Advanced Control & Optimization
- Fault Tolerant Control
- Automotive propulsion drive
- Advanced Power Electronic Conversions
- Offshore Wind Power
- Electric Vehicle Charging Stations
- Multilevel Converters and More-Electric-Aircraft
- Control and Stability of Distributed Energy Resources

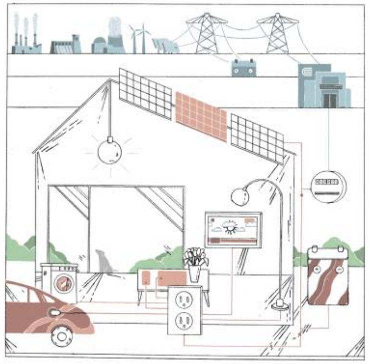
System design and analysis

Real-time operation

- ABB Inverter PVS980
- Real-Time Hardware-in-the-Loop simulation
- Advanced RT-CHIL for Sustainable Grid Integration
- Reliability of Industrial Control Modules







All these challenges and potential solutions *require new scientific & mix of experiential learning with theoretical work* where Universities have a key role to support *State*'s goals.

Sustainable, flexible, and resilient Energy System

Tools for System Design and Analysis

Tools for Real-Time Operation

Gaps and Training Orientation

- Observations:

✓ Gap between Training methods and Industry Needs

✓ In some Areas Industry is Leading the Field and vice versa, Technology Partnership for integration

✓ **Teaching Design (Synthesis not Analysis)**

- Bridge to Energy Systems

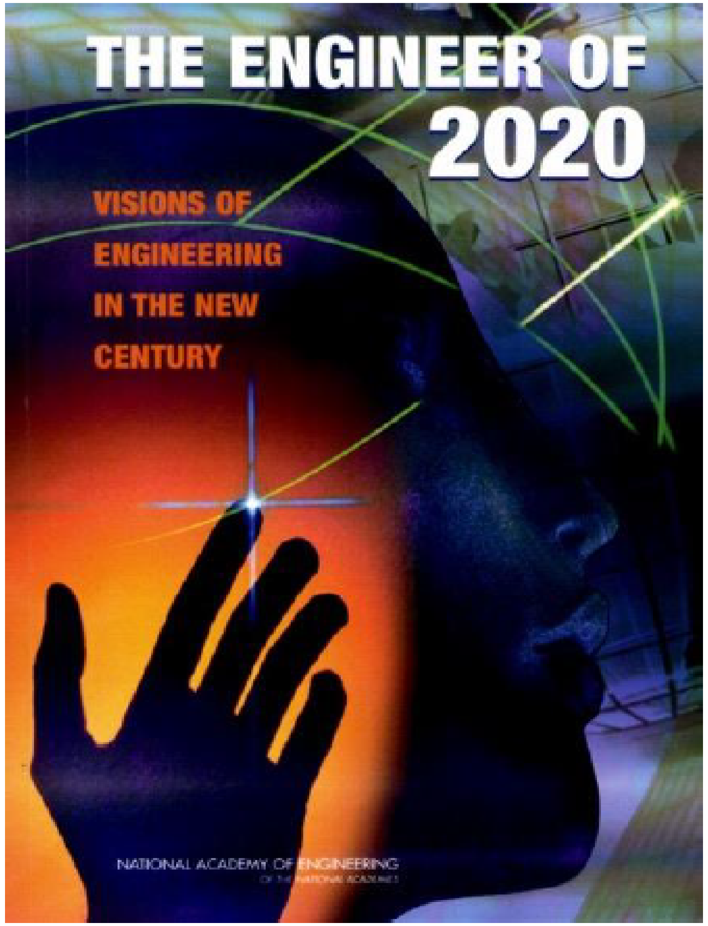
✓ Establish validated Models, whole System Performance

✓ Design with Real-Time simulation

✓ Multi-Domain modeling!

The Engineer of 2020*

There will be growth in areas of simulation and modeling around the creation of new engineering “structures”. **Computer-based design-build engineering ... will become the norm for most product designs,** accelerating the creation of complex structures for which multiple subsystems combine to form a final product.



In the past, steady increases in knowledge have spawned new microdisciplines within engineering (e.g., microelectronics, photonics, biomechanics). However, **contemporary challenges—from biomedical devices to complex manufacturing designs to large systems of networked devices—increasingly require a *systems* perspective.** Systems engineering is based on the principle that structured methodologies can be used to integrate components and technologies. The systems perspective is one that looks to achieve synergy and harmony among diverse components of a larger theme. Hence, there is a need for greater breadth so that broader requirements can be addressed. **Many believe this necessitates new ways of *doing* engineering.**

* National Academy of Engineering, 2004

Together…Shaping the Future of Sustainability

To get there, we must …

"Bridge the Gaps"