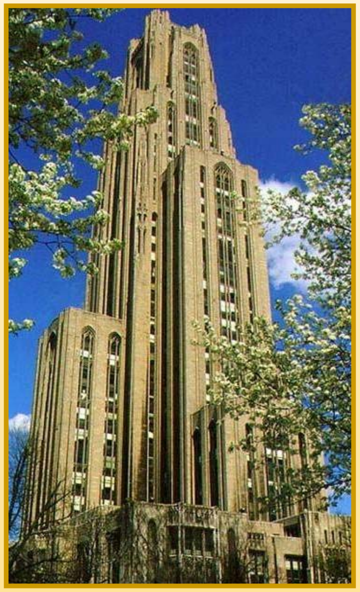
UNIVERSITY OF PITTSBURGH
SWANSON school of engineering
Power & Energy Initiative

7TH ANNUAL PITT ELECTRIC POWER INDUSTRY CONFERENCE
Presented by the Swanson School of Engineering & the Center for Energy

ABB

Ship to Grid:
Medium Voltage DC Concepts in Theory and Practice

7th Annual Electric Power Industry Conference
University of Pittsburgh
November 12th, 2012 – Pittsburgh, PA



Brandon Grainger, Adam Sparacino,
Matthew Korytowski, & Shimeng Huang

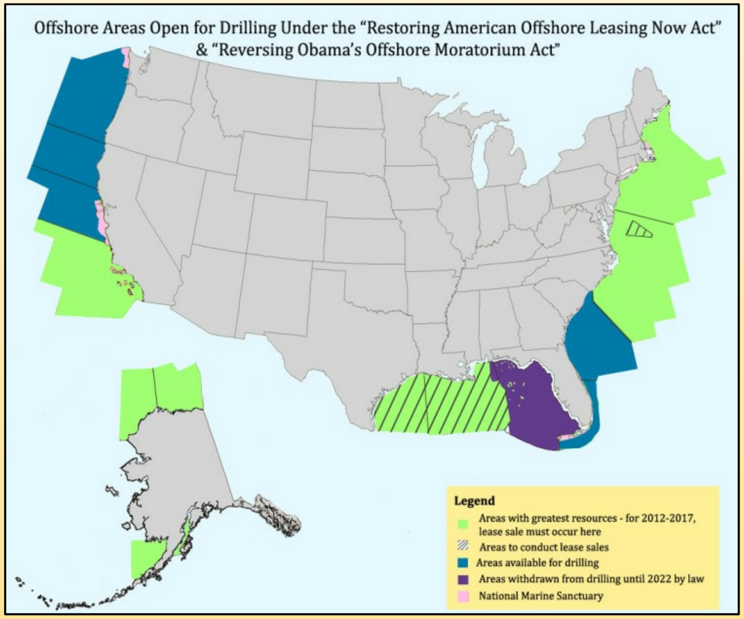
Electric **P**ower & **E**nergy **R**esearch for **G**rid **I**nfrastructure
University of Pittsburgh, Swanson School of Engineering
Pittsburgh, Pennsylvania; USA

Explorations in Offshore DC Collection Systems

Brandon Grainger

Investigations in Offshore Generation

- ❑ The U.S. Department of Energy, through FOA-414, has found great interest in exploring the integration of *offshore* wind and has funded a team (including Pitt) to determine the optimal location for placing large wind turbines around the U.S. perimeter.
- ❑ The directions that many manufacturers are exploring with offshore technologies to harness and transmit electric power provides further encouragement that the direction towards offshore is viable.



U.S. Oil Drilling Opportunities
(2012 through 2017)

Planned location of Offshore Wind Turbines

Medium Voltage DC Application

- The off-shore oil drilling platform is an opportunity for a more innovative application while taking advantage of the offshore wind turbine power generation locally.
- Industrial facilities, like the oil platforms, experience three major types of power quality obstacles.
- Power quality is degraded due to harmonic currents produced during the *conversion from AC to DC for VFDs.*
- Mitigation techniques include active and passive filters and multi-pulse drives requiring additional space and increased platform weight.

Research & Development Needs for Microgrids

❑ Fundamental Requirements of Microgrids

(1) Capability of operating in islanding and/or grid connected modes with high stability

(2) Mode switching with minimum load disruption and shedding during transitions

(3) After a transition, stabilize in a certain amount of time

❑ Technical Challenges of Microgrids

(1) Operation modes and transitions that comply with IEEE1547

(2) Control architecture and communication

❑ Research Challenges of Microgrids

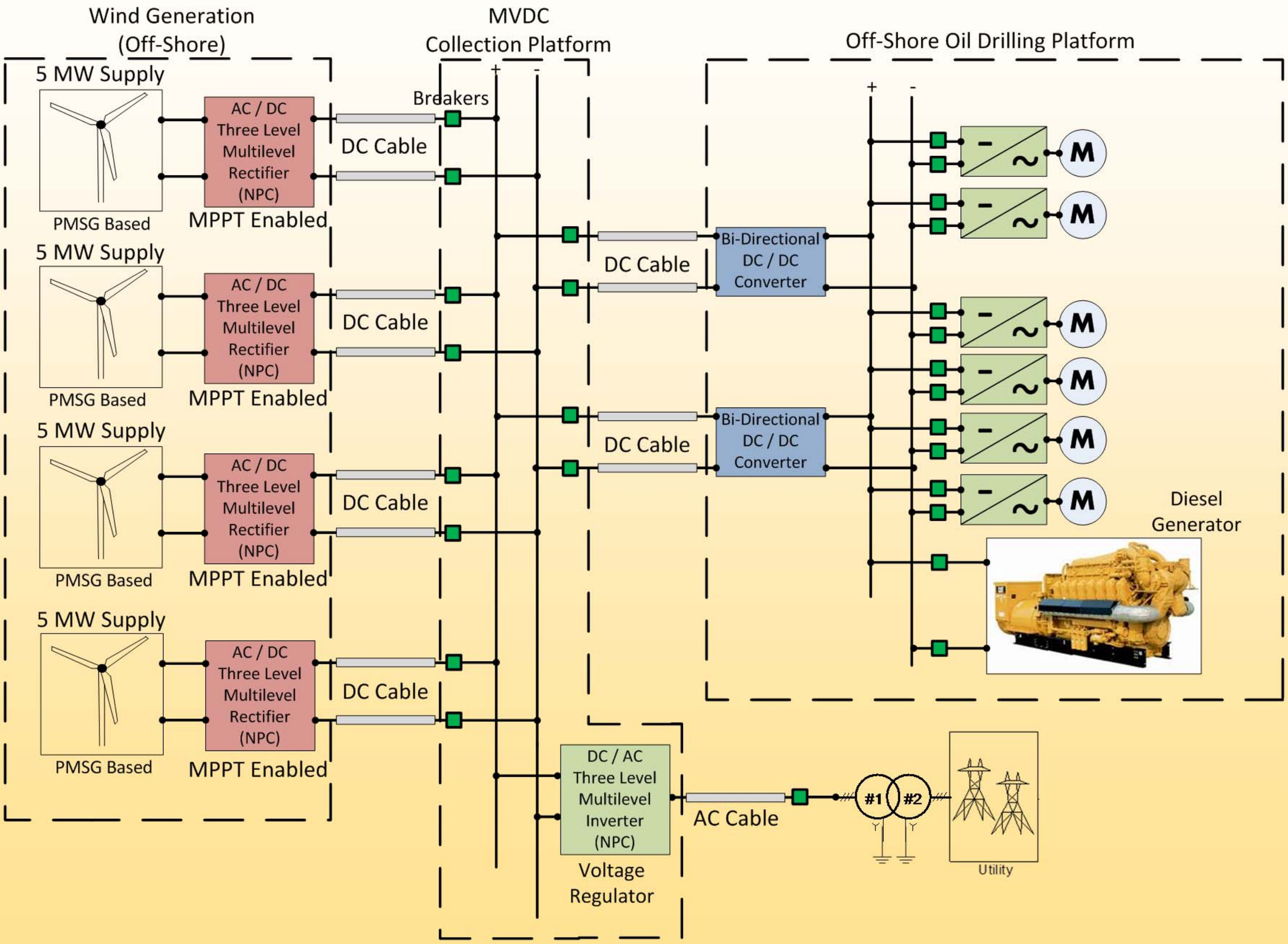
(1) Operational inverter improvements (harsh environment design, robust operation during fault conditions, improved overload, volume and weight reduction, etc).

(2) Integrated storage inverter & direct medium voltage inverter design

(3) <u>DC</u> microgrid subsystems.

(4) These components are extremely important but protection is also one of the most important challenges facing the deployment of microgrids.

Architecture Investigation



Design and Simulation of a DC Electric Vehicle Charging Station Interconnected with a MVDC Network

Adam Sparacino

Problem Statement

- Evaluate operation of common DC bus electric vehicle charging station (EVCS) employing level 2 DC fast chargers powered via MVDC grid.
- Investigate the operation, interaction, and system integration of power electronic conversion devices, battery energy storage systems and DC power systems.
    - EVCS is merely an application this could also represent a residential, commercial or industrial network with onsite energy storage and distributed generation.
- Benchmark applicability of bidirectional DC-DC converter as an interface between medium and low voltage networks within next generation DC power systems.
    - Unique implementation of bidirectional DC-DC converter employing both pre-charge and dc bus damping circuits.
- Determine ability of battery chargers (synchronous buck converter) to assist in mitigation of transient propagation in DC power systems.

Electric Vehicle Charging Station [1]

Level	Description	Power Level
Level 1 AC	Opportunity charger (any available outlet)	1.4 kW (12A) 1.9 kW (15A)
Level 2 AC	Primary dedicated charger	4 kW (17A) 19.2 kW (80A)
Level 2 DC	Commercial fast charger	60kW (150 A)

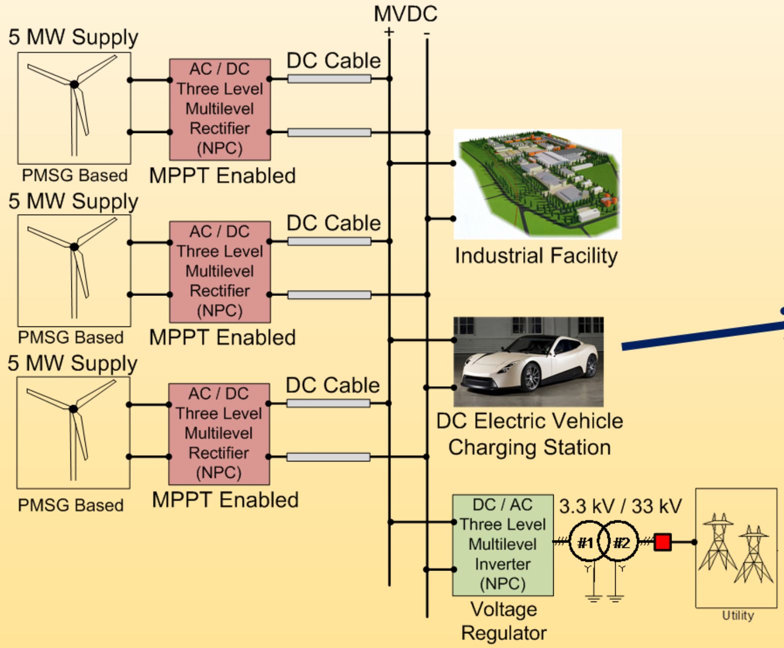
Charging Power Levels [2]

[1] "Eaton Research Facility Adds EV Charging Stations" - http://www.ccjdigital.com/eaton-research-facility-adds-ev-charging-stations/

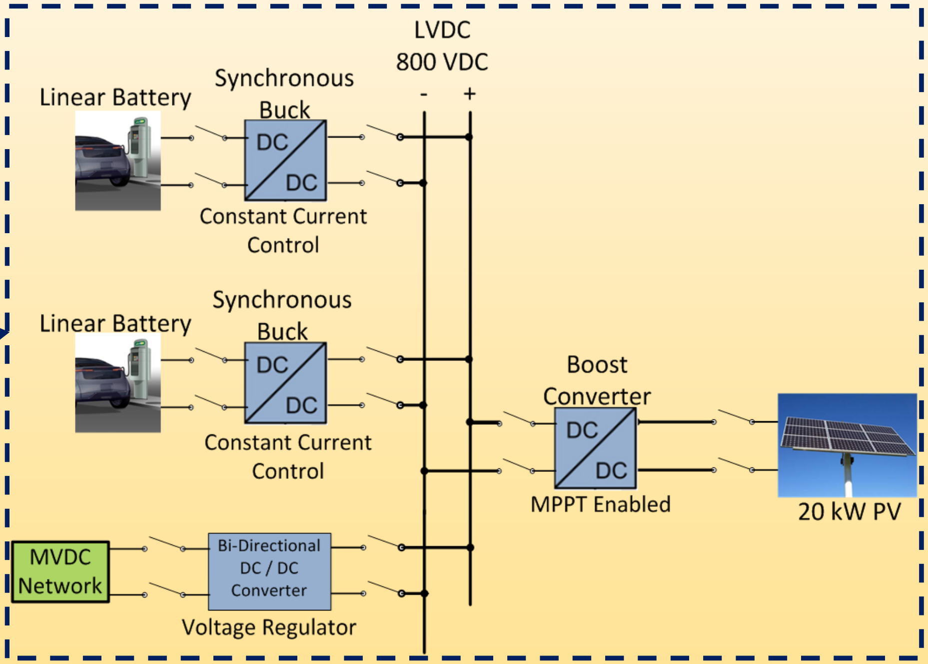
[2] Yilmaz et. al. – "Review of Benefits and Challenges of Vehicle-to-Grid Technology"

Modeled Systems

- ☐ Medium Voltage DC concept is ultimately a collection platform designed to help integrate renewables, serve emerging DC-based and constant-power loads, interconnect energy storage, and address future needs in the general area of electric power conversion.
- ☐ Certain applications require lower operating voltages and are unable to directly connect to the MVDC bus. EVCS is an example of such a system.
- ☐ Advanced power converters are necessary for interconnection of LVDC and MVDC systems.

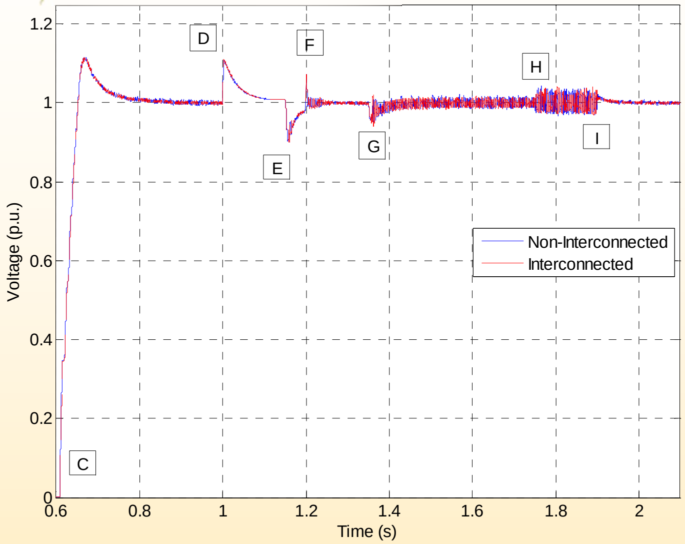


PSCAD MVDC Implementation

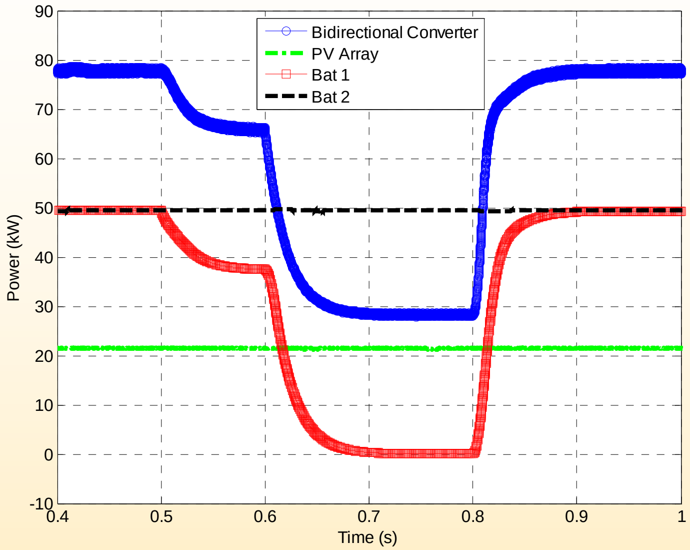


PSCAD Electric Vehicle Charging Station Implementation

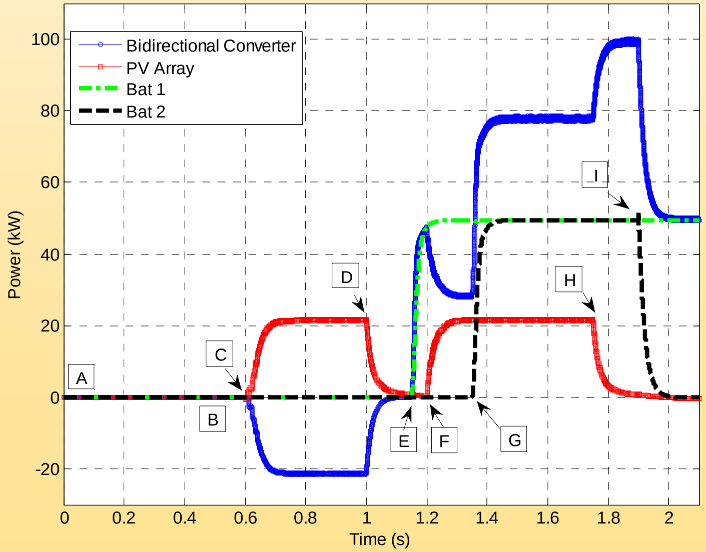
System Operation / Results



Regulated LVDC Bus Voltage



Power Flow During Battery Short Circuit



Component: Supplied and Absorbed Power

State	Process
(A) – 0.00 s	Wind turbines begin ‘warm-up’
(B) – 0.50 s	MVDC grid connected to EVCS
(C) – 0.61 s	PV array ON
(D) – 1.00 s	PV array OFF
(E) – 1.15 s	EV bat 1 begins charging
(F) – 1.20 s	PV array ON
(G) – 1.35 s	EV bat 2 begins charging
(H) – 1.75 s	PV array OFF
(I) – 1.90 s	EV battery 2 stops charging

Operating Regime

Conclusions

- Provided a literature survey on grid level energy storage systems and state of the art power converters for use within MVDC and EVSE architecture.
- Designed and tested the operation of a common DC bus level 2 DC electric vehicle charging station.
- The interaction of the interconnected EVCS and MVDC bus was examined.
    - The need of special circuits to mitigate problems caused by the use of non-ideal sources and loads.
- Applicability of the bi-directional DC-DC converter as a key component of next generation DC power systems.
- The ability of the synchronous buck converter to isolate faults in next generation DC power systems was explored.

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Instabilities in a Weak Grid Environment

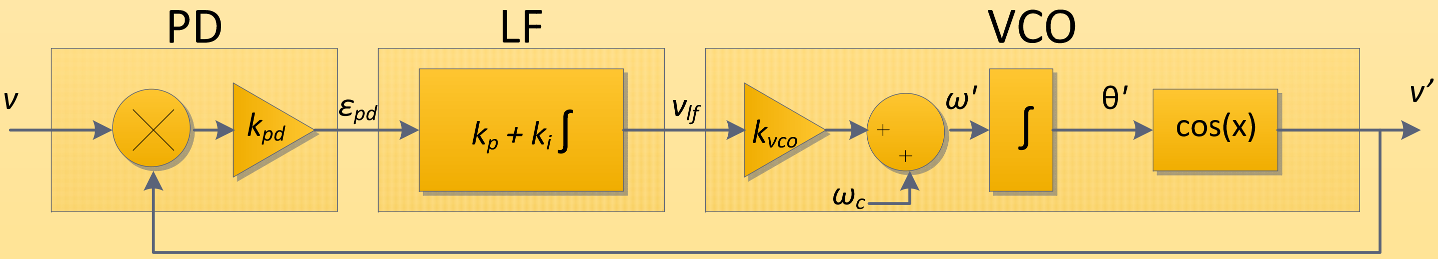
Matthew Korytowski

Weak Grid Environment

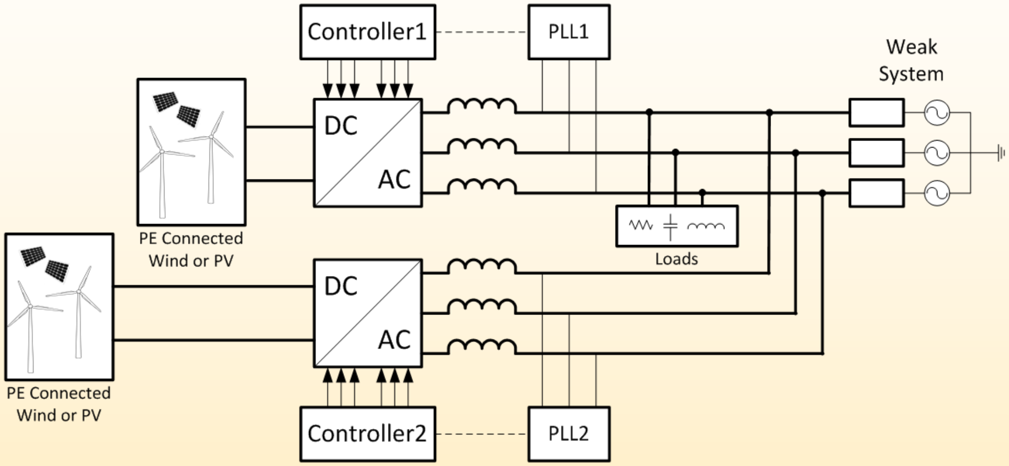
- ❑ Simple definition is a low ratio of X/R
  - Why is a weak grid important to explore?
- ❑ Power quality issues
  - Voltage Drop
  - Voltage Flicker
  - Frequency Deviations
  - Harmonic Distortion
- ❑ Renewable integration prone to these problems
  - Large amounts of resources located far from load centers and thus strong interconnection points

PLL Instability

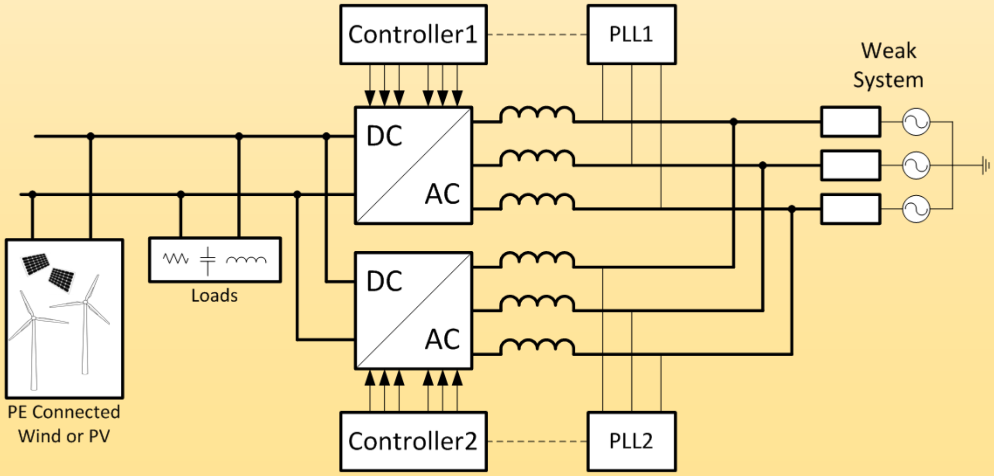
- Multiple inverters located near each other are necessary to connect renewable resources
  - PV converts from DC to AC
  - Type 4 Wind Turbines use an AC to DC to AC conversion
  - Each inverter requires a PLL
- Weak connections cause PLLs to become unstable and oscillate
- Solutions to this problem?
  - Tune parameters of each PLL control system
  - Eliminate need for PLLs at every connection using a DC system



AC and DC Scenarios



MVAC System



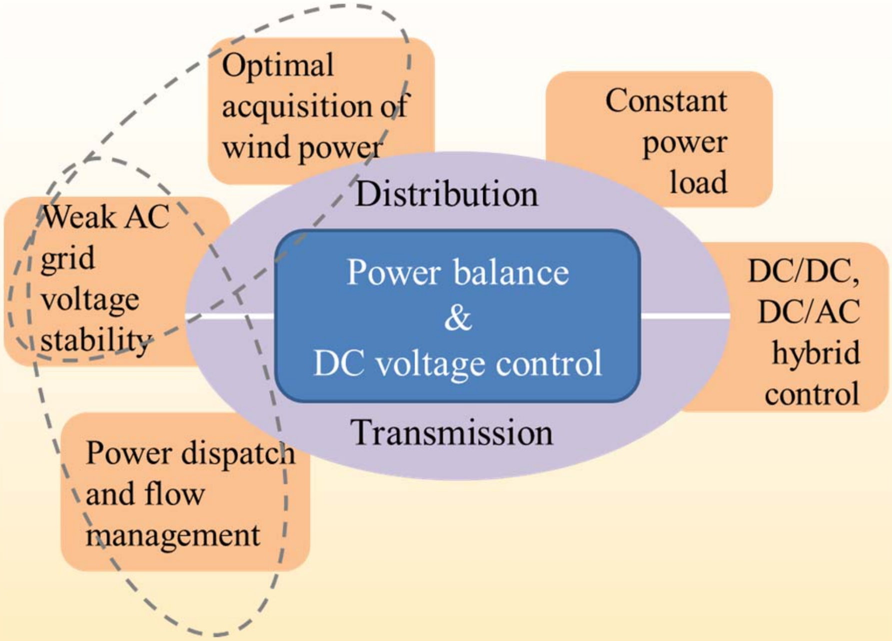
MVDC System

Towards Coordinated Control of Multi-terminal DC Network: Control and Communication Co-design

Shimeng Huang

Control Goals of VSC-MTDC Systems

- ❑ DC backbone
  - Input and output power balancing
  - DC voltage control
- ❑ AC side of individual converter
  - Application dependent
    - Weak AC grid stabilization
    - Optimal acquisition of renewable generation
    - Constant power load
    - Power dispatch requirement
    - Physical limit of converter
  - Correlation and conflicts
- ❑ Converter coordination required for realistic MTDC applications



Optimal acquisition of wind power

Constant power load

Weak AC grid voltage stability

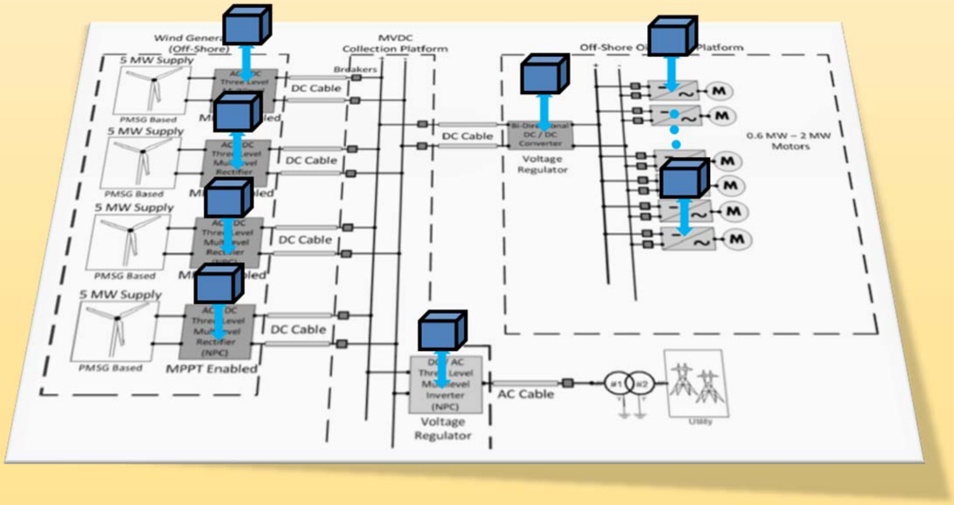
Distribution

Power balance & DC voltage control

DC/DC, DC/AC hybrid control

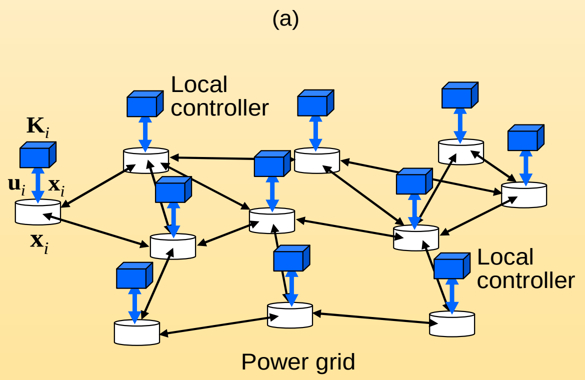
Transmission

Power dispatch and flow management

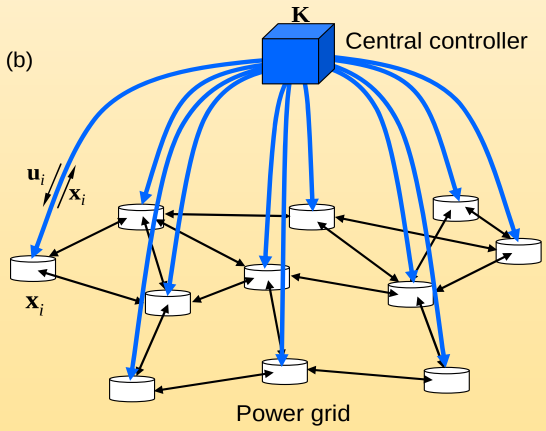


Existing Controller Structures

- Existing decentralized control methods (a) are focused at the local level.
  - Confliction between control goals are decoupled by certain assumptions
  - Lack global observation of other subsystems resulting in lower performance network-wide.
- Existing centralized control methods (b) can achieve global optimal performance.
  - Too complicated for large scale system.



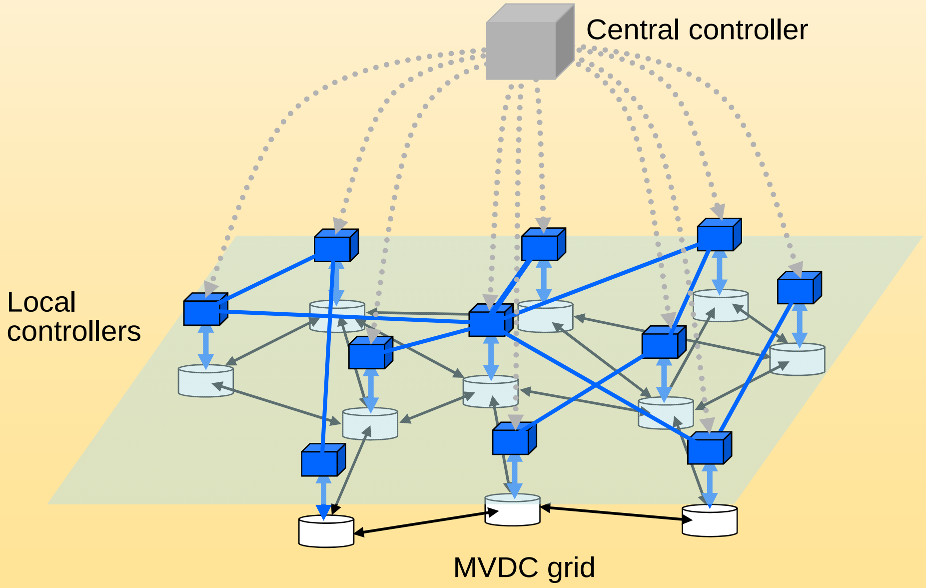
Decentralized, Non-Cooperative Control Architecture



Entirely Centralized Control Architecture

Control and Communication Co-Design

- ☐ The hierarchical control architecture has two layers (figure below).
  - Decentralized-control layer consists of distributed local controllers that are allowed to connect and cooperate with each other.
  - The second layer is a single central controller. This central controller does not control the local actions directly. Its function is to supervise and coordinates the operations of the local controllers in the first layer, and adaptively optimizes the control and communication topology in real time.



Summary

Out Now in IEEE P&E Magazine!

IEEE Power & Energy Magazine DC Issue

- Nov – Dec 2012 Issue
- Reed served as guest editor and contributed guest editorial piece
- Five articles make up the issue from the following organizations:
  - University of Pittsburgh (Reed, Grainger, Sparacino, Mao),
  - ABB Inc. (Lundberg, et. al.),
  - Emerge Alliance (Patterson),
  - EPRI - Electric Power Research Institute (Adapa),
  - Intel and Lawrence Berkley Nat'l Labs (Allee, Tschudi),
  - Siemens Energy and Clean-Line Energy (Majunder, Galli, et. al)